Finance and Economics Discussion Series
Divisions of Research & Statistics and Monetary Affairs
Federal Reserve Board, Washington, D.C.

Take it to the Limit: The Debt Ceiling and Treasury Yields

David Cashin, Erin Syron Ferris, Beth Klee, and Cailey Stevens

2017-052

Please cite this paper as:
Cashin, David, Erin Syron Ferris, Beth Klee, and Cailey Stevens (2017). "Take it to the Limit: The Debt Ceiling and Treasury Yields," Finance and Economics Discussion Series 2017-052. Washington: Board of Governors of the Federal Reserve System, https://doi.org/10.17016/FEDS.2017.052.

Take it to the Limit: The Debt Ceiling and Treasury Yields

David Cashin, Erin Syron Ferris, Beth Klee, and Cailey Stevens[1]

Federal Reserve Board of Governors

This Version: March 2017

Abstract

We use the 2011 and 2013 U.S. debt limit impasses to examine the extent to which investors react to a heightened possibility of financial contagion. To do so, we first model the response of yields on government debt to a potential debt limit "breach." We then demonstrate empirically that yields on *all* Treasuries rose by 4 to 8 basis points during both impasses, while excess yields on bills at risk of delayed principal payments were significantly larger in 2013. Perhaps counterintuitively, our model suggests market participants placed a lower probability on financial contagion resulting from a breach in 2013.

Key Words: Political Uncertainty; Debt Limit; Treasury Yields

JEL Codes: G12, G18, H63

---

[1] Cashin - e-mail: david.b.cashin@frb.gov, phone: 202-452-3991; Ferris – e-mail: erin.e.ferris@frb.gov, phone: 202-973-6160; Klee – e-mail: elizabeth.c.klee@frb.gov, phone: 202-721-4501; Stevens – e-mail: cailey.djule@gmail.com; Federal Reserve Board of Governors, 20th Street and Constitution Avenue NW, Washington, DC 20551. The views expressed here are strictly those of the authors. They do not necessarily represent the position of the Federal Reserve Board or the Federal Reserve System. We would like to thank Jeff Huther, Ugo Troiano, and seminar participants at the 2014 University of Michigan Tax Invitational, 2016 International Finance and Business Society conference, 107th Annual Conference on Taxation, 2015 International Institute of Public Finance Annual Congress, National Graduate Institute for Policy Studies (Japan), and Hitotsubashi University (Japan) for helpful comments and suggestions.

"A national debt, if it is not excessive, will be to us a national blessing."

Alexander Hamilton

1. Introduction

How do investors react to the possibility of financial contagion? This is a perennial question in financial economics.[2] That said, it is often difficult to identify clearly an impetus to a financial stress episode, and as such, is difficult to identify the effect of contagion. Other factors, including limited liquidity, multiple sources of financial stress, or counterparty credit risk can sometimes confound estimates.

While addressing all of these issues is difficult, the 2011 and 2013 U.S. debt limit impasses are illuminating case studies, as they represent a well-telegraphed event that had the potential to affect the most liquid and safest assets in the world. As shown in Figure 1, news reports focusing on the political impasse in Congress regarding the debt limit intensified in the summer of 2011 and the fall of 2013.[3] At the same time, the U.S. Treasury Secretary warned Congress multiple times that the Treasury's "debt limit," or the cap on the amount of borrowing by the U.S. Treasury, was expected to be breached imminently. If the cap is breached, then by law, the Treasury is unable to issue additional debt and therefore, the Treasury would be unable to make payments and U.S. Treasury debt would experience a technical default. The immediate result of a technical default would be that principal or interest payments on debt due right around the breach date could experience a delayed return to the investor. While there were many occasions on which this debt limit was raised without event, during the 2011 and 2013 episodes, there were a flurry of news reports suggesting that the debt limit may not be raised in a timely manner. In addition, top government officials warned of potential dire consequences to the global economy in the event of a debt limit "breach." Against this backdrop, yields on Treasury securities rose notably, and in particular, Treasury yields on securities that could be affected by delays in a principal payment increased even more.

[2] For recent examples, see Forbes and Rigobon (2001) and Longstaff (2010).

[3] Figure 1 displays the Debt Ceiling Index created by Scott Baker, Nicholas Bloom, and Steven J. Davis. The index is a measure of the fraction of articles appearing in major newspapers in the United States - the 1000+ newspapers covered by Access World News Newsbank Service - that use the phrase "debt ceiling". The monthly data are available at http://www.policyuncertainty.com/debt_ceiling.html. We are grateful to Scott Baker for providing us with a daily version of the index. A value of 0.01 represents a day in which one percent of all newspaper articles mention the term in question.

As such, this study estimates the effect of the 2011 and 2013 debt limit episodes on Treasury bill and coupon (hereafter, Treasury securities) yields. To do so, we first model the response of yields on government securities and an alternative private asset to a potential debt limit breach, whereby the potential debt limit breach is depicted as an increase in the probability of a technical default on principal and interest payments due on government securities soon after the breach. In the event of a debt limit breach, the probability of financial contagion, in which all assets experience default in the form of reduced principal payments, also rises. Several scenarios for which the increase in the probabilities of technical default and financial contagion vary are modeled, and their implications for yields on different types of government- and private-issued securities are explored.

Using data from the Treasury secondary market, we then estimate the effect of the 2011 and 2013 debt limit impasses on Treasury yields. Our methodological approach separates the average "wedge" over market rates that would persist in the absence of a debt limit episode on all Treasury securities outstanding from excess yields on individual securities that could be affected by a delayed principal or interest payment in the event of a debt limit breach. The former provides an estimate of the average increase in borrowing costs to the Treasury during and soon after a debt limit episode, while the latter indicates the discount that a relatively risk-averse investor is willing to accept to replace a Treasury security maturing (with interest payable) soon after a projected debt limit breach date with a security that matures (pays interest) outside that time frame. This approach of identifying the overall increase in yields versus the increase attributable to specific securities allows us to obtain a more nuanced understanding of the impact of debt limit episodes on Treasury yields than previous studies. Furthermore, the absolute and relative magnitudes of the wedge and excess yields enable us to determine the relative importance of the contagion effect during the recent debt limit impasses.

We find that yields across all maturities were 4 to 8 basis points (bps) higher than they otherwise would have been just prior to the projected breach dates during the 2011 and 2013 debt limit episodes, but fell precipitously upon resolution of the episode. As a result, Treasury borrowing costs during each episode were roughly $250 million higher than they otherwise would have been.

The fact that we observe an increase in Treasury yields across *all* maturities stands in contrast to previous studies, which find evidence of increased premiums only at the front end of the yield curve. While it may be the case that Treasury yields did not rise across the yield curve during debt limit impasses prior to 2011, we show that the reason other studies of the recent debt limit impasses (e.g. Nippani and Smith, 2014) do not find the same increase we do is because yields on constant maturity commercial paper (CP), the financial instrument used to control for variation in market rates unrelated to a debt limit impasse, were significantly affected by the 2011 and 2013 debt limit impasses. As such, CP is an inappropriate control variable. We instead control for variation in market rates unrelated to a debt limit impasse using the overnight index swap (OIS) rate, which is a geometric average of the expected daily effective federal funds rate over a specified period of time (e.g. 3 months). In theory, OIS and Treasury yields should exhibit a strong positive correlation via the expectations hypothesis, but because OIS is essentially risk free, it should be little affected by a debt limit impasse. We demonstrate that this is the case empirically, and as such, OIS is a more appropriate control for variation in market rates than CP.

Our second finding is that excess yields on individual bills maturing soon after the projected breach dates appeared earlier and were significantly higher during the 2013 episode, peaking at 46 bps in 2013, but only 21 bps in 2011. We find no evidence of elevated yields on coupons with interest payable soon after the projected breach dates in 2011 or 2013.[4]

Our study is special as it is a clean, "natural" experiment of contagion. That is, the bills most at risk of a delayed payment had one exogenous difference– the maturity date—from all other government debt. In other studies, particularly studying contagion across countries, there are a number of factors that may not be adequately controlled for or may be endogenous to the contagion that could influence the estimate of contagion. Because the date of issue is exogenous, predictable, and independent of every other characteristic of the affected and unaffected securities, and because we can properly control for variation in market rates unrelated to the debt limit episode, we can precisely identify whether the risk of delayed payments on certain bills had spillover effects elsewhere in the Treasury market. The fact that yields across all Treasury maturities rose as the projected breach dates neared implies that was indeed the case.

Our clean experiment, in the context of our model, also helps us to understand market participants' behavior over time. Specifically, the fact that we observe similar wedges during the

[4] Our model would suggest that the reason we observe no evidence of elevated yields on coupons is because the interest payments are small relative to the principal payments on bills due soon after the projected breach dates.

2011 and 2013 debt limit impasses but significantly larger excess yields in 2013 suggests, perhaps counterintuitively, that market participants placed a lower, albeit still positive, probability on financial contagion resulting from a debt limit breach in 2013 than in 2011. Why might we expect this to have been the case? It seems reasonable to believe that market participants learned from the 2011 debt limit impasse and its eventual resolution at the eleventh hour. Specifically, heavy debt limit news coverage during 2011 and the episode's eventual resolution just prior to its projected breach date taught market participants about the consequences and probability of a debt limit breach. In response, the primary focus of participants during the 2013 debt limit episode was selling off bills that matured soon after the projected breach date, with less concern regarding contagion. Corroborating this interpretation, Fidelity Investments, the nation's largest money market mutual fund manager, announced in early October 2013 that it had sold off all of its short-term bills in response to the debt limit impasse, an action it had not taken in 2011.

2. The Debt Limit and Treasury Security Yields[5]

The debt limit is an aggregate limit on nearly all federal debt outstanding. This includes debt held by the public in the form of bills, notes, and bonds, as well as debt held in intragovernmental accounts such as the Social Security trust fund, in which the Treasury is obligated to invest in nonmarketable Treasury securities. If the debt limit is reached, the Treasury Secretary can declare a Debt Issuance Suspension Period (DISP), which allows the Secretary to invoke "extraordinary measures" that temporarily extend the Treasury's borrowing capacity.[6] Once the extraordinary measures are exhausted (the "breach date"), the Treasury can only meet its obligations with incoming receipts and the cash on hand in the Treasury General Account (TGA) at the date of the debt limit breach. If payments due on a given day exceed incoming receipts and the TGA cash balance (the so-called X-date), then the Treasury may be forced to delay interest payments on Treasury securities as well as the principal due on maturing bills, notes, and bonds, triggering a technical default. For this reason, failure to increase the debt

[5] Most of the historical material in this section is drawn from Austin (2015) and Austin and Levit (2013).

[6] The use of extraordinary measures consists primarily of the temporary divestment of nonmarketable Government Account Series securities held in government accounts, which reduces nonmarketable debt, thereby allowing the government to issue marketable Treasury securities that finance the deficit while remaining below the debt limit. Once the debt limit is raised, the government accounts are restored, with most repaying any interest that would have accrued had the government account not been divested during the DISP.

limit has the potential to drive up yields on Treasury securities as the breach date nears, and likely even more so for the securities that mature soon after the breach date (Johnson, 1967).

Changes in the debt limit require the approval of Congress and the President. Since 1962, Congress has enacted 79 measures that have altered the debt limit, including 15 measures since 2001. Prior to 1995, legislation to increase, suspend, or revise the definition of the debt limit passed without much fanfare.[7] Since 1995, however, debate over legislation to increase the debt limit has become increasingly contentious, with Debt Issuance Suspension Periods (DISP) declared as a result. Previous literature has shown that political uncertainty (e.g. the elevated uncertainty resulting from a debt limit impasse) can cause a decrease in asset prices. For example, Pastor and Veronesi (2011) posit that political uncertainty can have a negative effect on asset prices because it is non-diversifiable, and non-diversifiable risk generally depresses asset prices by raising discount rates. A few recent studies have used the news-based measure of economic policy uncertainty (EPU) developed by Baker, Bloom, and Davis (2013) to show that some asset prices decline with additional uncertainty.[8] And indeed, researchers have shown evidence that debt limit episodes have affected the market for Treasury securities (Nippani et al., 2001; Ozgladi and Peek, 2013).

One common approach to analyze the impact of potential breaches of the debt limit on the market for Treasury securities is to examine changes in yield spreads between constant maturity commercial paper (CP) and Treasury bills. The underlying identification assumption is that yields on CP and Treasury bills generally track one another, but that CP yields should not be affected by a debt limit episode, while Treasury security yields may be affected. Nippani et al. (2001) document an increase in default risk premiums on Treasury securities during the 1995-1996 debt limit debate. To do so, the authors compare three- and six-month yield spreads between commercial paper and Treasury bills during the debt limit episode to spreads prior to the episode, controlling for other factors. The authors hypothesize that the yield spread during the 1995-1996 episode should be lower than it was prior to the chain of events that comprised the episode, and indeed, they find this to be the case, with the three-month yield spread falling more than the six-month yield spread (7 bps to 2 bps). The authors find no evidence that the debt limit episode had a sustained effect on Treasury bill rates following its resolution. Liu et al. (2009)

[7] Although there was some debate over the first debt limit increase in the 1950s. Refer to Garbade (2016).
[8] Examples include Brogaard and Detzel (2013) and Da, Engelberg, and Gao. (2013).

employ a similar strategy to determine whether the financial markets charged a default risk premium to U.S. Treasury securities during the four debt limit episodes between 2002 and 2006. The authors find a small significant effect on three-month yield spreads during the first two occurrences (1 and 2.4 bps, respectively), but no effect during the final two episodes. The authors posit that rational investors ignore political uncertainty when history suggests the controversies represent political posturing that will be settled before imposing real effects on the economy. The 2013 debt limit episode is examined by Nippani and Smith (2014), which uses the same empirical strategy as Nippani et al. (2001). The authors find a significant increase in the default risk premium on one-month Treasury bills as the projected breach date approached, but not on three-month Treasury bills. The authors interpret the results as indicating that the market expected the situation to be resolved quickly.

While the aforementioned studies find that Treasury security yields were only affected at the front end of the yield curve, one might question the validity of their underlying identification assumption. That is, it seems plausible that CP yields also respond to debt limit episodes, particularly through a contagion channel. Ozdagli and Peek (2013) outline several reasons why the term structure of the CP market might increase and steepen during a debt limit episode. For example, issuers could change the supply of securities before or after the projected debt limit breach date in order to avoid possible market complications at the time of the breach, as well as to insulate the securities from or take advantage of any possible rate effects arising from the debt limit episode. The authors then proceed to show that this was indeed the case during the 2013 debt limit episode.[9] As a result, the identification approach used in previous studies may lead to estimates of default risk premiums that are biased downwards, and increasingly so as one moves along the yield curve. It is also worth noting that Ozdagli and Peek (2013) document an increase in the level of the term structure of Treasury bill yields as the October 17 breach date neared, though the authors do not control for factors unrelated to the debt limit episode that could have affected rates across the Treasury bill yield curve.

In contrast to the aforementioned studies, Cole (2012) uses a difference in differences approach to examine the impact of the 2011 debt limit episode on Treasury security default risk

[9] Exhibits 5 and 8 in Nippani and Smith (2014) also show a sizeable increase in three- and six-month CP yields as the October 17, 2013 breach date neared.

premiums. Specifically, the author exploits an announcement on May 2, 2011 by the Treasury Secretary that reduced default risk for Treasury securities maturing between July 8 and August 2, 2011, but had no impact on default risk for Treasury securities maturing before July 8, 2011.[10] Cole finds that following the May 2, 2011 announcement, yields on Treasury securities maturing between July 8 and August 2, 2011 fell by a statistically significant one basis point relative to Treasury securities that matured just prior to July 8, 2011.

This study examines the impact of both the 2011 and 2013 debt limit episodes on Treasury security yields. Like Nippani et al. (2001), Liu et al. (2009), and Nippani and Smith (2014), we attempt to control for changes in market rates unrelated to the debt limit episode using a financial instrument that closely tracks Treasury security yields. Unlike the previous studies, we choose to use Overnight Index Swap rates (OIS) as the control, which we show to be less affected by debt limit episodes than CP. Furthermore, rather than focusing solely on constant maturity Treasury bills, we examine yields on all outstanding Treasury securities. As noted by Ozdagli and Peek (2013), this approach makes it possible to isolate the price effects of the debt limit on specific securities from the overall effects of the debt limit on the Treasury security market. This is because expectations for a technical default were focused on only a handful of CUSIPs (unique identifier for a Treasury security), and it was generally assumed that other securities would not be affected (hereafter, "unaffected" securities) in the sense that they were perceived to be at a much lower risk of technical default. Our approach thus allows us to separate any increase in the overall term structure of Treasury securities from excess yields on securities that mature or have interest payments due soon after the projected breach dates. The former allows us to estimate the impact of the recent debt limit episodes on the Treasury's borrowing costs, while the latter provides an estimate of the discount investors were willing to accept in order to replace Treasury securities that may have been perceived to be at risk of a delayed principal or interest payment. Before formalizing our model and empirical strategy, however, we provide additional background on the 2011 and 2013 debt limit episodes, as well as descriptive evidence of their impact on Treasury security yields.

[10] On May 2, 2011, Treasury Secretary Geithner announced that the Treasury projected it would have enough cash on hand to remain below the debt limit until August 2, 2011. A previous announcement by Secretary Geithner on April 4, 2011 projected that the Treasury would breach the debt limit no later than July 8, 2011.

In both May 2011 and 2013, Congress could not reach an agreement to increase the statutory debt limit, and consequently, the Treasury Secretary declared a DISP.[11] Throughout both episodes, the Treasury made several announcements in the form of letters to Congress, official statements, statements to the press, and Congressional testimony. By and large, these announcements informed Congress and the public of extensions to the DISP, and revisions to or affirmations of the projected debt limit breach date, which the Treasury ultimately declared to be August 2, 2011 and October 17, 2013. During the 2013 episode, the announcements also included projections of the Treasury's cash balance once extraordinary measures were exhausted. Table 1 lists the date, type, and summary of each announcement, as well as other important dates associated with the debt limit episodes, such as U.S. sovereign credit rating reviews and downgrades, which could have had an effect on Treasury yields.

As the projected breach dates neared and Congress failed to increase the debt limit, yields on Treasury bills increased (Figure 2), especially for bills maturing soon after the projected breach dates (Figure 3), which likely reflected concerns about possible delayed principal payments in the event of a debt limit breach.[12] Both episodes were officially resolved on their projected breach dates, and yields appear to have dropped back to more normal levels in response.[13]

Of course, there had been many debt limit "episodes" previously. A few mentioned by Secretary Lew include the Gramm-Rudman-Hollings budget compromises in 1985 and 1986; the Budget Enforcement Act in 1990, and the Balanced Budget Act in 1997. However, in 2013 the Secretary noted that the recent episodes were different. Specifically,

> In each of these three instances, the debate was driven by fiscal policy and how to achieve deficit reduction in a responsible, balanced manner. Neither political party thought that defaulting on our debt was a serious, credible option. In 1985, the need to raise the debt limit served as a deadline for budget negotiations. In 1990, Congress and the President worked together to avoid across-the-board cuts from the original Gramm-Rudman sequestration, which were universally viewed as the wrong way to reduce the

[11] The Treasury Secretaries during the 2011 and 2013 debt limit episodes were Timothy Geithner and Jack Lew, respectively.
[12] "…the fact that yields on Treasury bills that mature at the end of October are higher than bills that mature immediately before or after, might suggest nascent concerns about possible delays in payments on those bills." U.S. Department of the Treasury (October 2013), *The Potential Macroeconomic Effect of Debt Ceiling Brinkmanship.*
[13] In 2011, note that yields on 3-month constant maturity bills jumped again just a few days after the projected breach date. This increase coincided with the opening of business after the Standard & Poor's (S&P) downgrade of the U.S. long-term sovereign credit rating from 'AAA' to 'AA+'. However, we do not observe a similar yield increase for longer-term constant maturity Treasury securities, so it is not clear whether the yield increase was due to the S&P downgrade.

> deficit. In 1997, Congress added a debt limit increase at the end of negotiations, after the parties agreed on a deal to reduce the deficit responsibly and grow the economy. I participated personally in many of these negotiations, and I do not recall anyone ever seriously suggesting that the United States should fail to pay its bills.
>
> The summer of 2011 was different. Certain Members of Congress argued that default was an acceptable outcome if they were unable to achieve their legislative objectives. Rather than enter into a good-faith compromise on fiscal issues, these Members argued that the United States should voluntarily fail to pay its bills if their position was not accepted. Our economy paid a significant price for these irresponsible and protracted threats. The full faith and credit of the United States is not a bargaining chip. It is reckless and irresponsible to put our full faith and credit at risk.[14]

Reflecting this sentiment, in the lead-up to a potential debt limit debate in October 2015, Secretary Lew wrote the following:

> "For these reasons, I respectfully urge Congress to take action as soon as possible, raise the debt limit without delay, and remove an unnecessary threat to our economy. We have learned from the past that failing to act until the last minute can cause serious harm to business and consumer confidence, raise short-term borrowing costs for taxpayers, and negatively impact the credit rating of the United States. And there is no way to predict the irreparable damage that default would have on global financial markets and the American people."[15]

Secretary Lew's comments indicate a concern that a debt limit breach, or even the potential for one, could lead to financial contagion, with spillover effects elsewhere in the Treasury market and global financial markets more generally.[16] In this context, we use our methodology to evaluate the effect of the debt limit impasses in 2011 and 2013 on U.S. Treasury securities, as these episodes are generally viewed as similar in the sense that some members of Congress were perceived as believing that default was a viable option.

---

[14] https://www.treasury.gov/press-center/press-releases/Pages/jl2182.aspx

[15] https://www.treasury.gov/connect/blog/Pages/October-2015-Debt-Limit-Letter.aspx

[16] Following the literature on contagion in financial markets (e.g. Forbes and Rigobon, 2001; Longstaff, 2010), our concept of financial contagion is an episode in which there is temporary but significant increase in cross-market linkages after a shock occurs in one market. In our case, we think of the Treasury market as being comprised of two markets: a market for securities at the highest risk of delayed principal or interest payments in the event of a debt limit breach (e.g. a bill maturing two weeks after a projected debt limit breach) and a market for those Treasury securities that are at a significantly lower risk (e.g. longer-dated coupons).

3. Modeling the Effects of a Potential Debt Limit Breach on the Market for Treasury Securities

With this historical backdrop in mind, we now explore the effects of a possible debt limit breach on the market for Treasury securities. In particular, we are interested in the pricing implications of changes in default probabilities for both Treasury securities and alternative assets that may result from debt limit impasses such as those witnessed in 2011 and 2013.

Model

The model has two investors, three periods (labeled *0*, *1*, and *2*), and three assets. Each investor, i, is endowed with wealth, W_i, which is allocated between period *0* consumption, c_{0i}, and a portfolio composed of three (potentially) risky assets that pay out in periods *1* or *2*, for consumption in those periods.

As for the assets that can be held in the investors' portfolios, the first is a "near-dated" Treasury bill for which principal n_i is due in period *1*. The principal payment is subject to little to no risk of default when not in a debt limit episode, but is at a heightened risk of a "delayed" (i.e. "reduced" in the context of the model) principal payment in the event of a debt limit breach. The second asset is a longer-dated Treasury bond with principal l_i due in period *2*, and coupon payment cl_i due in period *1* (c is the coupon rate). Like n_i, the payment cl_i is normally subject to little to no risk of delay, but the risk increases during a debt limit episode. Furthermore, in the event of a debt limit breach accompanied by delayed principal and interest payments on Treasury securities in period *1*, the risk of default on the period 2 principal payment becomes non-zero. The third asset is a private asset with principal a_i due in period *1*. It can be thought of as an alternative to the near-dated government bill, and depending on the context, may or may not be a risky asset with the potential to default in period *1*. For example, OIS is generally perceived to be risk free, while CP carries default risk even outside of a debt limit episode. The rates of return on the bill, bond, and private asset are denoted by r_n, r_l, and r_a, respectively.

As suggested by Secretary Lew's October 2015 comments, we distinguish between two types of government debt defaults in the event of a debt limit breach. The first is a technical default that is resolved expeditiously. That is, period *1* principal and interest payments on government securities are delayed, but further defaults avoided. The second also features a technical default on period *1* government debt payments, but financial contagion induces defaults on the private asset and long-term government bond principal payments as well.

Altogether, there are five states of the world for investor i to consider when choosing a portfolio during a debt limit impasse:

1) The debt limit impasse is resolved prior to a debt limit breach. Neither government nor private debt defaults.
2) The debt limit impasse is resolved prior to a debt limit breach, but private debt defaults for an unrelated reason.
3) The debt limit is breached and there is a technical default on near-term government debt, but the breach is resolved expeditiously. Neither private debt nor the long-term government bond default.
4) The debt limit is breached and there is a technical default on near-term government debt, but the breach is resolved expeditiously. The long-term government bond does not default, while the private debt defaults for an unrelated reason.
5) The debt limit is breached and financial contagion ensues. All types of debt default.

To determine the probabilities of each state of the world, we must assign default probabilities. The probability of a debt limit breach with a technical default on near-term government debt is π_g. Conditional on the technical default occurring, the probability of financial contagion where all debt defaults is π_{gb}. For private debt, the probability of default is π_a, unless financial contagion occurs, in which case the probability is 1.

Payoffs differ according to the state of the world, s. If there is a debt limit breach accompanied by a technical default on period *1* government debt payments due, investors receive a fraction α of the principal due on the near-dated bill and coupon payment due on the longer-term bond. In the event that private debt defaults for reasons unrelated to the debt limit impasse, investors receive β of the principal due on private debt. Should financial contagion follow a technical default on government debt, investors receive $\alpha\varphi$ of the principal due on the near-dated bill and coupon payment due on the longer-term bond, φ of the principal due on the longer-term government bond, and θ on the principal due on the private debt, with $\theta \leq \beta$. Note that if α is less than 1, the recovery rate on the long-term bond is higher than on the bill, even in the case of financial contagion. We assume this structure in order to capture the feature that securities that are very near the breach date are likely at the greatest risk of a delayed payment.

In regards to the amount of debt outstanding, there exists an exogenously determined amount of each type of asset, which sets the market-clearing conditions. The states of the world, probabilities for the occurrence of each state, and consumption in each period for investor *i* in state *s* are detailed in the table below:

s	**Probability**	C_{0i}	C_{1is}	C_{2is}
1	$(1-\pi_g)(1-\pi_a)$	$W_i - \frac{n_i}{1+r_l} - \frac{l_i}{1+r_l} - \frac{a_i}{1+r_a}$	$n_i + cl_i + a_i$	l_i
2	$(1-\pi_g)\pi_a$	$W_i - \frac{n_i}{1+r_l} - \frac{l_i}{1+r_l} - \frac{a_i}{1+r_a}$	$n_i + cl_i + \beta a_i$	l_i
3	$\pi_g(1-\pi_{gb})(1-\pi_a)$	$W_i - \frac{n_i}{1+r_l} - \frac{l_i}{1+r_l} - \frac{a_i}{1+r_a}$	$\alpha n_i + \alpha cl_i + a_i$	l_i
4	$\pi_g(1-\pi_{gb})\pi_a$	$W_i - \frac{n_i}{1+r_l} - \frac{l_i}{1+r_l} - \frac{a_i}{1+r_a}$	$\alpha n_i + \alpha cl_i + \beta a_i$	l_i
5	$\pi_g\pi_{gb}$	$W_i - \frac{n_i}{1+r_l} - \frac{l_i}{1+r_l} - \frac{a_i}{1+r_a}$	$\alpha\varphi n_i + \alpha\varphi cl_i + \theta a_i$	φl_i

Each investor maximizes his expected utility, U_i, by choosing an allocation of the near-term bill, long-term bond, and private asset subject to the market-clearing conditions. The investors' utility over consumption exhibits constant relative risk aversion, and importantly, the investors have different coefficients of relative risk aversion, γ_i.[17] Formally, the investors' problem is given by:

$$U_i = \max_{n_i, l_i, a_i} \quad \mathrm{E}\left[\frac{C_{0i}^{1-\gamma_i}}{1-\gamma_i} + \delta_1 \frac{C_{1i}^{1-\gamma_i}}{1-\gamma_i} + \delta_1\delta_2 \frac{C_{2i}^{1-\gamma_i}}{1-\gamma_i}\right],$$

[17] For concreteness, one can think of the relatively risk-averse investor as money market mutual funds. For example, in early October 2013, Fidelity Investments, the nation's largest money market mutual fund manager, announced that it had sold all of its short-term U.S. government debt in response to the debt limit impasse. See http://citicommunitydevelopment.com/transactionservices/home/oli/files/fidelity_101013.pdf for more information.

with discount factors $\delta_1 > \delta_2$, since we expect the time that elapses between the coupon payment and the principal payment on the longer-term government bond (i.e. period *1* to *2*) exceeds the time that elapses between the debt limit impasse and the initial default (i.e. period *0* to *1*). We assume that from the investors' perspectives, the probabilities of default are taken as given, as are the primitives of the model: δ_1, δ_2, α, β, θ, φ, γ_1, and γ_2.[18]

The maximization problem leads to three first-order conditions for each investor, which are shown in the Appendix. These six equations, combined with the three market-clearing conditions, yield the model solution.

Before using the model to examine the pricing implications of a debt limit impasse on the market for Treasury securities, it is worth discussing two simplifying assumptions that we make. First, the model does not allow borrowing or lending between periods, only between investors. While this is likely not the case in reality, it does allow us to capture the sharp divergences in yields across securities. Specifically, borrowing and lending between periods allows investors to smooth consumption around the debt limit episode. In the absence of frictions and after adjusting for risk aversion, the ratio of the rates of return on the assets relative to their probabilities of default should equalize. However, the sharp movements in yields observed on some securities coupled with little observed movement in yields for others during the debt limit episodes suggest that frictions exist that prevent this type of smoothing. Second, we do not allow for endogenous issuance of government or private debt. While Ozdagli and Peek (2013) provide some evidence that issuance patterns for both government and private debt changed in the final weeks prior to the projected debt limit breaches (e.g. reduced issuance for debt maturing soon after the projected breach dates), the deviations in issuance were a relatively small percentage of the amounts outstanding that matured on a given date, and at least for government debt, were largely expected by investors. Consequently, the model abstracts from endogenous debt issuance.

Yield Implications of a Debt Limit Impasse for the Treasury Security Market

Our framework is sufficiently general that it can accommodate a variety of scenarios. For example, if c is zero, then we can use our model to compare the change in yields for bills

[18] See the Appendix for a list of model primitives under each modeling scenario.

that mature near the X-date and bills maturing later, with the l security viewed as the longer-term bill. On the other hand, if c is near the average coupon rate and δ_2 is less than δ_1, we can compare bills that mature near the X-date and coupons that have a coupon payment due near the X-date.[19] We can also compare the yields on Treasuries to those on private instruments that do and do not have default risk. For instance, we might think that OIS is risk free, so then we would expect π_a to be zero and θ to be one (or close to it). On the other hand, if we are comparing Treasury security yields to a private sector asset with default risk (for instance, CP), π_a would be greater than zero and θ and β could be significantly less than one.

Against this backdrop, by adjusting the π's, we can compare the change in yields for different types of securities.[20] First, consider an increase in π_g with $\pi_{gb} = 0$ and $c = 0$. Also suppose that the private asset is a risk-free asset.[21] It follows that an increase in π_g causes an increase in the near-term bill yield only, while the yields on both the private asset and the longer-term bill decline slightly as the more risk-averse investor moves away from the at-risk bill into the other two securities.[22]

Next, we allow π_{gb} to be positive. First, assume that the private asset is risk free. Then as π_{gb} increases, so too do the yields on the near- and long-term bills relative to the private asset. And so long as $\alpha < 1$, the yield on the near-term bill will increase by more than the long-term bill. Now suppose that the private asset carries default risk ($\pi_a = 0.2$). In this case, the yield changes depend upon the relative values of α, β, θ, and φ as well as the likelihood of being in the financial contagion state (which is $\pi_g * \pi_{gb}$). For instance, if $\pi_{gb} = 0.2$ and $\varphi = 0.9$, the

---

[19] For instance, if the bill is due in 3 months and the coupon's final payment is due in 9 months, as long as there is not hyperbolic discounting, δ_2 should be equal to δ_1. If the coupon's final payment is not due for several years, then it should be the case that $\delta_2 < \delta_1$.

[20] We also considered the possibility that the investors' coefficients of relative risk aversion changed as result of the debt limit impasses. In order to observe increasing yields on all government securities that are more pronounced for near-dated securities at a greater risk of technical default, we need two instruments: one that captures the overall increase in rates and one that captures the additional increase (i.e. excess yields) for at-risk securities. Empirically, both sets of yields rose gradually until the 2011 and 2013 episodes were resolved. In the model, we could have increased risk aversion (for either of the investors) rather than the probability of financial contagion and found a similar pattern to what we observe empirically so long as risk aversion increases gradually throughout the episode and the probability of technical default rises in a similar fashion. However, the gradual rise in risk aversion is difficult to justify. Moreover, in our data we are unable to separately identify a change in risk aversion versus a change in the probability of default. Future work using microdata on asset holdings could provide more insight into this matter.

[21] $\pi_a > 0$ leads to similar implications.

[22] See Appendix Figures for model implications.

relative magnitude of the yield changes for each asset depends upon θ. The changes are summarized in the table below.

$\boldsymbol{\theta}$	**Ordering of the change in yields for any increase in $\boldsymbol{\pi_g}$**
0.87-1	$\Delta r_n > \Delta r_l > 0 > \Delta r_a$
0.86-0.84	$\Delta r_n > \Delta r_l > \Delta r_a > 0$
0.80-0.83	$\Delta r_n > \Delta r_a > \Delta r_l > 0$
0.68-0.79	$\Delta r_a > \Delta r_n > \Delta r_l > 0$
0.67	$\Delta r_a > \Delta r_l > \Delta r_n > 0$
0.64-0.66	$\Delta r_a > \Delta r_l > 0 > \Delta r_n$
0-0.63	$\Delta r_a > 0 > \Delta r_l > \Delta r_n$

The key in this comparison is the relative recovery rate of the private asset in the financial contagion state of the world. Investors are primarily substituting between the at-risk bill and the private asset, since these two assets pay off during the same time period and we do not allow for borrowing or lending across periods. Unless we are in the financial contagion state, the riskiness of the private asset is not dependent on the probability of a technical default. However, because all assets lose value in the contagion state, the relative recovery rates for the at-risk bill and the private asset are the main driver of the relative change in yields across the assets.

If the private sector asset is relatively safe in the financial contagion state of the world, then an increase in the probability of default mostly affects the at-risk bill. The yields on both government securities increase, but the increase for the shorter-term bill is significantly larger. The yield on the private asset does not change very much. Alternatively, if the private asset's recovery rate is well below that of the at-risk security, then the yield on the private asset will rise. Given a recovery rate on the private asset that is sufficiently low, the more risk-averse investor may actually purchase government debt, in turn driving yields on government securities down.

Before turning our focus to the response of coupons with interest payments due soon after the projected debt limit breach dates, our final comparative statics exercise for bills examines how changes in both π_g and π_{gb} affect the yields of at-risk and unaffected government securities. This exercise will assist our interpretation of yield differences between the 2011 and

2013 debt limit episodes, and is meant to highlight that while the period 0 likelihood of the financial contagion state is given by $\pi_g \cdot \pi_{gb}$, whether the variation in the likelihood of contagion is coming from π_g or π_{gb} matters for the relative differences between at-risk and unaffected government securities. First, suppose that π_{gb} is 0.1 and that π_g triples from 0.1 to 0.3 (Case 1).[23] Then the spread on the long-dated bill over the private asset increases by 16 basis points. We can achieve the same spread change for the long-dated bill given a larger probability for π_{gb} of 0.3 and a smaller increase in π_g from 0.1 to 0.21 (Case 2). However, under the first scenario, the spread on the at-risk bill over the private asset increases by 47 basis points, while in the second it only increases by 34 basis points.

At first glance, it may seem counterintuitive that the spread on the long-dated bill over the private asset rises by the same amount in Cases 1 and 2, given that the increase in the likelihood of contagion for Case 2 exceeds that for Case 1 and the private asset has a higher recovery rate than the long-dated bill in the event of contagion. However, recall that investors are primarily substituting between the at-risk bill and the private asset. Because π_g increases by a greater amount under Case 1, the private asset is relatively more attractive to hold in Case 1 than Case 2, and thus its return falls by a greater amount under Case 1. Consequently, even though the return on the long-dated bill increases by a greater amount under Case 2 than Case 1, the change in the spread on the long-dated bill over the private asset is the same in both cases.

Finally, we consider the yields on longer-term bonds with coupon payments due soon after the projected debt limit breach dates. Relative to the at-risk bills, the model suggests that the uptick in yields for these securities should be less pronounced. For instance, if π_g increases from 0.1 to 0.3, the yield on the at-risk bill increases by 32 basis points, but only 7 basis points for the at-risk coupon.[24] This result seems sensible given that the coupon payment is just a small fraction of the principal due on the longer-term bond.

All told, the model and comparative statics described here imply that yield spreads relative to a risk-free asset such as OIS should widen; the magnitude of that widening depends

---

[23] We assume that $\pi_a = 0$ and $\theta = 0.93$ in this exercise. If the private asset is not risk free, the corresponding increase in the long dated bill increases by 7 basis points. We can achieve that yield change if the probability is 0.4 with an increase in π_g from 0.1 to 0.18. The yields on the at-risk bills increase 35 basis points and 18 basis points respectively.

[24] In these scenarios, we assume that $\delta_1 = 0.95$, $\delta_2 = 0.94$ for the unaffected bill and $\delta_2 = 0.9$ for the coupons, $\theta = 0.88$, and the coupon is 5 percent.

importantly on the relative probabilities of default in different sectors. In what follows, we estimate the values of these spreads. Using those estimates, in the final section we characterize what these estimates imply for the perceived probability of default across assets.

4. Data and Methodology

We construct two data sets and estimate two regressions: one for Treasury bills (securities with an original maturity of less than one year) and one for Treasury coupons (Treasury notes, which have an original maturity of one to ten years, are used in this analysis).[25] Each data set contains information on Treasury bills or coupons outstanding from January 2011 to December 2013, with one observation per business day per outstanding CUSIP. Our primary data source is the Center for Research in Security Prices U.S. Treasury Database (CRSP). Each observation from CRSP contains the CUSIP, issue date, maturity date, annualized yield, and in the case of coupons, coupon rate. We augment our bill (coupon) data set with OIS rates, net bill and coupon issuance, outstanding bill supply, Federal Reserve purchases of Treasury securities, and the S&P 500 Index.

While we use nearly all Treasury issues to estimate our econometric model, we make a few key exclusions to ensure the robustness of our estimates. For the Treasury bill data set, we exclude Cash Management Bills (CMB). These are Treasury bills with non-standard maturities that are issued to meet temporary financing shortfalls, and often trade at slightly higher rates than regular bills. As such, including them in the analysis may distort the results.[26] After imposing the restriction, we are left with 25,076 observations on 286 CUSIPs for the Treasury bill regression analysis. For the Treasury coupon data set, we exclude coupons with less than 120 days to maturity, as yields on coupons of all tenors become increasingly volatile in the four months prior to maturity, making inference difficult.[27] After imposing these restrictions, we are left with 139,557 observations on 312 CUSIPs for the coupon regression analysis. We also drop all panels with less than five observations after our initial restrictions are imposed.

[25] We exclude all securities with original tenors greater than ten years as yields on these securities exhibit significantly more volatility than other tenors.
[26] In particular, in the lead-up to the 2013 debt limit episode, Treasury issued a cash management bill that cleared at a very low price relative to other bills issued in the surrounding weeks. Including this bill in the analysis would likely lead our estimates of the effect of the debt limit episode to be biased upward.
[27] Simple bond pricing formulas are consistent with sharp changes in yields for small changes in price. In addition, there can be unexplained swings in demand for these securities. As a result, we are unable to evaluate the effect of the most recent debt limit episodes on the yields of coupons that matured soon after the projected breach dates.

To conduct our analysis of Treasury security yields, we estimate the following empirical specification for both bills and coupons in first differences:

$$\Delta y_{c,t} = \alpha + \Delta \boldsymbol{X}'_{c,t}\boldsymbol{\beta} + \Delta \boldsymbol{Z}'_{t}\boldsymbol{\gamma} + \Delta \mathbf{1}(t \in D)\boldsymbol{\delta_t} + \Delta \mathbf{1}(t \in D, c \in B)\boldsymbol{\theta_{c,t}} + \epsilon_{c,t} \quad (1)$$

where $y_{c,t}$ is the annualized yield (in basis points) for CUSIP c on date t; $\boldsymbol{X_{c,t}}$ is a vector of variables that vary across time and CUSIPs; $\boldsymbol{Z_t}$ is a vector of variables that varies across time, but is constant across CUSIPs; $\mathbf{1}(t \in D)$ is an indicator that takes on a value of one if date t occurs during a debt limit episode, D, and zero otherwise; $\boldsymbol{\delta_t}$ is the corresponding vector of coefficients for the dates that comprise D; $\mathbf{1}(t \in D, c \in B)$ is an indicator that takes on a value of one if date t occurred during D and CUSIP c matured (paid interest) on or soon after a projected breach date, B, and zero otherwise; $\boldsymbol{\theta_{c,t}}$ is the corresponding vector of coefficients for the set of CUSIPs maturing (paying interest) on or after B during D; and $\epsilon_{c,t}$ is an error term.

We use first differences as many of the panels have non-stationary yields.[28] In addition, the yields on Treasury bills and OIS are cointegrated. However, in first differences, all panels have yields that are stationary. Another reason we use first differences is that there may be time-invariant characteristics of a Treasury security that affect its yield, such as whether the security matures at quarter end when firms are often in need of cash, and thus sells at a premium (i.e. lower yield) relative to other Treasury securities.[29] The vector $\boldsymbol{X_{c,t}}$ includes controls for time to maturity in our baseline bill and coupon specifications. The bills specification includes dummies for 0-4, 4-13, 13-26, and 26-52 weeks to maturity, respectively, as well as time to maturity polynomials of order two for 0-4, 4-13, 13-26, and 26-52 weeks to maturity. In effect, we are estimating a quadratic spline that allows for discontinuities at 4, 13, and 26 weeks. The coupons specification includes a quadratic term in time to maturity.[30]

In our baseline specifications, the vector $\boldsymbol{Z_t}$ includes the 3-month and 5-year OIS rates for the bill and coupon regressions, respectively.[31] The 3-month (5-year) OIS rate is the fixed amount a firm is willing to pay for receiving the federal funds rate, so it is a geometric average of

[28] 129 of 188 panels fail the Augmented Dickey-Fuller test at the 5% level.
[29] See Garbade (1996) for further information.
[30]Other research including Collin-Dufrense et al (2001) use quadratic functions of Treasury yields in their specifications to mimic a traditional quadratic spline specification. See https://rfs.oxfordjournals.org/content/15/1/243.full.pdf+html.
[31] We chose the 3-month and 5-year OIS rates because the weighted average maturities of bills and coupons outstanding in our samples are closer to these values than other available OIS rates.

the expected federal funds rate over the next three months (five years). Inclusion of the rate in our empirical specification is particularly important because it acts as a control for aggregate factors affecting Treasury security yields not related to a debt limit episode. Several authors (e.g. Sarno and Thornton, 2003) have argued that the federal funds rate and Treasury security yields track each other because they are linked by the expectations hypothesis. That is, the classic model for a Treasury security's yield suggests that the yield should be equal to the market's expectation for future short-term interest rates over the term plus a term or risk premium, for holding a longer-term instrument.[32] Thus, the OIS rate should proxy for the expectation for short-term interest rates. It follows that during a debt limit episode, any change in the spread between the two instruments should be due to changes in the risk premium on Treasuries.

These hypotheses are generally consistent with the data. Treasury yields closely track the OIS rate outside the debt limit episodes, with a correlation coefficient of 0.81. Furthermore, a regression of the constant maturity 3-month Treasury bill yield on the 3-month OIS rate obtains a coefficient close to one.[33] However, during the two debt limit episodes, as shown in Figure 4, movement in the OIS rate was relatively muted, while the constant maturity Treasury bill yield rose sharply as the projected breach dates neared and fell precipitously upon their resolution.[34] Consequently, we believe the OIS rate is a valid control for aggregate factors affecting Treasury yields unrelated to the debt limit episodes.

Reflecting back to the model described in the previous section, because OIS should be risk free, it may be a reasonable proxy for the private risk-free asset described above. In addition, the model also suggests that in order to isolate the effect of the debt limit episode on yields, it is necessary to have an asset that is essentially risk-free and does not respond to the debt limit impasse. In contrast, note that Figure 4 also contains the 3-month CP yield. During both episodes, the CP rate rose by nearly as much or more than the constant maturity Treasury yield, which reinforces the findings of Ozdagli and Peek (2013) and casts doubt on its validity as a control. The model would also suggest that since CP is not a risk-free asset, its rate might increase during a debt limit episode.

[32] Of course, these term or risk premiums can be negative, and the federal funds rate can contain its own risk premium.

[33] Results are similar when comparing constant maturity Treasury coupon yields to the 5-year OIS rate.

[34] The OIS rate rose as the August 2, 2011 breach date neared and fell upon resolution, indicating it may have been affected to some extent by the debt limit episode. As a result, we treat our estimate of the average wedge in 2011 as an estimate of the lower bound.

The δ_t's and $\theta_{c,t}$'s are our primary coefficients of interest. The CUSIP- and date-specific coefficients, $\theta_{c,t}$, are included for individual CUSIPs that mature or have interest payable in the weeks just prior to and following the projected breach dates in 2011 and 2013. Specifically, we include the $\theta_{c,t}$ coefficients for bills maturing between July 28 and September 8 for the 2011 debt limit episode, and between October 10 and November 21 for the 2013 episode. $\theta_{c,t}$ coefficients are included for coupons with interest payable between July 15 and September 15 during the 2011 debt limit episode, and September 30 to November 30 during the 2013 episode. We interpret each of the $\theta_{c,t}$ coefficients as the excess yield associated with a CUSIP as the projected breach date nears. It follows that the $\theta_{c,t}$'s provide a measure of the discount that investors were willing to accept to replace Treasury securities that were perceived to be at risk of a delayed principal or interest payment in the event of a debt limit breach with a security that matures or pays interest outside that time frame.

The date fixed effects, δ_t, are included for each business day from July 14, 2011 to August 12, 2011 and September 25, 2013 to October 25, 2013. We interpret these coefficients as the average wedge over expected market rates on date t resulting from the debt limit episode net of any excess yields for Treasury securities at risk of a delayed principal or interest payment. The δ_t's thus reflect the average premium that the Treasury must offer in order to issue a Treasury security on date t.[35]

Standard errors are robust and allow for correlations of unknown form. To test the robustness of our baseline estimates, additional controls were employed. In addition to time to maturity, $\boldsymbol{X}_{c,t}$ includes dummies for "on the run" (i.e. the most recently issued security for a particular tenor) securities and bill reopenings.[36] For $\boldsymbol{Z}_t$, we augment the OIS rate with supply factors that may affect Treasury security yields, such as net bill and coupon issuance, outstanding

---

[35] This assertion assumes that the Treasury security being issued matures on a date not perceived to be at risk of a delayed principal payment.

[36] The market for Treasury securities that are "on the run" tend to be characterized by higher liquidity, and as a result, may sell at a premium to "off the run" securities. Each 4-week bill is a reopening of a previously issued 13-week, 26-week, or 52-week bill (i.e. same CUSIP). Each 13-week bill is a reopening of a previously issued 26-week or 52-week bill. Each 26-week bill may or may not be a reopening of a previously issued 52-week bill. On the one hand, reopened bills may be more liquid than bills of similar maturities, and thus command a premium. On the other hand, reopenings increase the supply of an outstanding CUSIP, which should increase its yield. Fleming (2001) finds that the supply effect dominates the liquidity effect, and thus we would expect to see that the bill reopening dummies included in the days prior to and following a reopening have a positive coefficient. More current estimates suggest this effect is pronounced at the 4-week tenor, although less so for longer-term bills.

bill supply, and Federal Reserve purchases of Treasury securities, as well as economic indicators that influence Treasury security yields like the S&P 500 index. Finally, we experimented with shorter time periods for the δ_t's and $\theta_{c,t}$'s around the projected breach dates. Reassuringly, none of the additional controls or alternative time periods fundamentally change our baseline estimates for our coefficients of interest.

More generally, the specification in (1) allows us to decompose the rate on a Treasury security into three components: a liquidity premium, a risk premium, and the expected future short rate. First, securities that are more likely to experience a delayed principal or interest payment will command a lower price or higher rate than those that will not. We interpret this as lower liquidity in the security and attribute this factor to a liquidity premium, which is evidenced by the $\boldsymbol{\theta_{c,t}}$ coefficients. Second, the average wedge over expected market rates is reflected in the risk premium, or the amount for which investors need to be compensated in order to hold the security, represented by the $\boldsymbol{\delta_t}$ coefficients. Finally, we use the comparable-maturity OIS rate to stand in for the expected market rates; specifically, the OIS is equal to the expected future short rate. Importantly, this expected future short rate is derived from a swap agreement, and as a result, there should be little liquidity risk (because principal is not exchanged) and little credit risk (because the underlying contract, federal funds trades, are viewed as relatively safe), providing a clean read on market expectations. The γ coefficient provides an estimate of this effect on all Treasury securities.

Of note, in order to identify the estimated parameters and attribute these premiums to them, we must assume that other factors affecting yields are constant over the estimation period. For example, this assumption implies that the term premium and inflation risk premium for a particular CUSIP does not vary over the estimation period, and consequently, our specification in equation (1) that uses first differenced yields eliminates these factors from consideration. Because our samples are relatively short, this seems like a reasonable assumption. However, if these factors did change over the sample, it is likely that both the term premium and the inflation risk premium declined, given contemporaneous quantitative easing purchases by the Federal Reserve as well as continued low readings on inflation expectations. As a result, our estimated parameters for the effects of liquidity and risk are likely a lower bound.

5. Results

Treasury Bills

First, we test whether rates on both near-term bills and longer-term bills rose as the projected breach dates in 2011 and 2013 neared. Then we test whether rates on near-term bills (or at-risk bills) rose more than longer-term bills that were at a lower risk of delayed principal payments. We begin by examining the effect on all bills outstanding for both the 2011 and 2013 episode. Figure 5 provides point estimates and 95 percent confidence intervals for the δ_t's from the bills regression. What is striking from the figure is how similar the paths and magnitudes of the average wedge are as the breach dates neared during the 2011 and 2013 debt limit episodes, though the wedge in 2013 did not appear until a bit closer to the projected breach date. Furthermore, the average wedge reached a maximum of approximately 7 to 8 bps just prior to each projected breach date, with the average wedge falling back to normal levels upon resolution. Given the average wedge estimates and observed bill issuance patterns leading up to the projected breach dates in 2011 and 2013, our results imply that the Treasury's borrowing costs were $260 and $230 million greater than they otherwise would have been. Finally, note that a few days following resolution of the 2011 debt limit episode, yields across the bill curve temporarily spiked. This result may be partially attributable to the downgrade of the U.S. long-term sovereign credit rating by Standard & Poor's (S & P) on August 5, 2011. However, we do not observe a corresponding uptick in yields on longer-term coupons, so it is not clear whether the spike is a result of the downgrade.

Next, we consider the yields on at-risk bills. We would expect the effect on at-risk bill rates to be statistically significantly larger than those on unaffected bills. As shown in Figures 6.A and 6.B, we find that yields on at-risk securities in 2011 and 2013 rose prior to the expected breach date and fell upon resolution of the debt limit impasses. However, while the increase in rates across the bill yield curve was similar in 2011 and 2013, the same cannot be said for excess yields on maturing Treasury bills that may have been at risk of a delayed principal payment in the event of a debt limit breach. The most conspicuous feature of this figure is that excess yields appeared earlier and were significantly higher as the projected breach date neared in 2013. The Treasury bills maturing on August 11, 2011 and October 31, 2013 provide a nice example of this phenomenon. Each of these bills was the second bill to mature after the projected breach date and exhibited the largest excess yields for the 2011 and 2013 episodes, respectively. However, the excess yield on the bill maturing on October 31, 2013 was significantly higher throughout the two week period leading up to the projected breach date, and its peak (46 bps) was more than twice the value of its 2011 counterpart (19 bps). We observe a similar pattern for other corresponding bills (e.g. the bills payable on August 18, 2011 and November 7, 2013).

Another notable feature of Figure 6 is the monotonic decline in excess yields that we observe for each successive bill maturing after the August 11, 2011 and October 31, 2013 bills. This observation suggests that in the event of a debt limit breach, market participants placed the highest probability on a delayed payment for those securities maturing a couple weeks after the official breach date. In addition, the monotonic decline in excess yields suggests that market participants only expected a short-lived delay in payment on selected securities, rather than a more general default on Treasury debt. For each episode, excess yields were close to zero for bills maturing three weeks after the bill with the highest excess yield, which suggests that market participants believed that in the event of a delayed principal payment, a resolution would be reached within a few weeks. Finally, it is worth noting that the spike in excess yields observed on October 9, 2013 (eight days prior to the projected breach date) coincided with the issuance of a 5-day CMB whose high rate (30 bps) exceeded market expectations.

Interpreting the bill results in the context of the model

In both episodes, we find that bill yields increased, especially for the at-risk securities. The rise in at-risk security yields suggests that the probability of a technical default, π_g, increased throughout each episode until their resolutions. This result is expected and is consistent with the previous research discussed in Section 2. However, we also find that yields on bills that experienced little to no risk of technical default increased.[37] In the model, this result can be achieved either through an increase in the probability of the financial contagion state, $\pi_g \cdot \pi_{gb}$, or through a gradual rise in risk aversion on behalf of either of the agents. In Section 3, we modeled such an increase in the probability of the contagion state as an increase in π_g holding

[37] Longstaff (2010) highlights three major channels by which contagion effects can be propagated through different financial markets: the correlated information, liquidity, and risk premium channels. Our finding of a significant and positive average wedge on “unaffected” Treasury securities is most consistent with contagion effects propagated via the risk premium channel. The correlated information channel requires contemporaneous yield changes for the at-risk and unaffected Treasury securities, but in 2013 excess yields on at-risk securities appeared well before the wedge on unaffected securities. The liquidity channel requires a decrease in overall liquidity, but we observe no significant change in liquidity for the unaffected Treasury securities during the debt limit impasses.

π_{gb} constant at a value greater than zero. Doing so induces relative yield changes in the model similar to what we observe empirically for at-risk and unaffected Treasury bills. On the other hand, if risk aversion were to rise, it would have to be tied positively to the likelihood of a technical default. This connection might be harder to justify, or would have to appeal to behavioral or other motives in order to do so.

As mentioned above, we find that across the two episodes, although the increase in yields was similar for unaffected Treasury bills (i.e. across the yield curve), yield changes for at-risk bills were significantly larger in 2013 than 2011. As shown in our exercise in Section 3, this outcome would obtain if π_g increased by more in 2013 than 2011, but the likelihood of π_{gb} was lower.[38] What might explain this relative change in default probabilities? We believe the most plausible explanation for this behavior across episodes is that the 2011 debt limit episode provided a learning experience for Treasury bill market participants. Heavy news coverage throughout the 2011 episode (as seen in Figure 1) and its eventual resolution at the eleventh hour may have altered the probabilities that market participants applied to technical default and financial contagion. In regards to technical default, participants recognized that bills maturing soon after the projected breach date were indeed at the greatest risk of a delayed principal payment. In fact, a 2015 report by the Government Accountability Office notes that Treasury market participants' contingency plans were "more fully developed and implemented by the fall 2013 [debt limit] impasse", and included avoiding Treasury securities maturing around the dates that Treasury projected its extraordinary measures would be exhausted. Furthermore, the eleventh hour resolution in 2011 may have indicated to market participants that even if there were a debt limit breach, in all likelihood it would be resolved quickly. In other words, the 2011 episode taught participants that the likelihood of a catastrophic event following a technical default was lower than previously perceived.

In addition to the learning hypothesis, the results could be interpreted as suggesting that the private asset, OIS, possessed more interest rate risk in the summer of 2011 than the fall of 2013. Recall our model shows that the extent to which bill rates increase depends in large part on the riskiness of the bill relative to the riskiness of the private asset. In general, financial market uncertainty was higher during the summer of 2011 than in the fall of 2013, possibly in

---

[38] Furthermore, we find evidence that 3-month CP-OIS yield spreads rose more in 2011 than 2013, which is also consistent with π_g increasing by more in 2013 than 2011, combined with a lower likelihood of π_{gb}.

part because of ongoing concerns regarding European sovereign debt as well as the discussion of a potential U.S. debt downgrade. As such, there may have been more uncertainty surrounding the future path of monetary policy in 2011 than in 2013, and consequently more interest rate risk for OIS. Indeed, using options on federal funds futures, the width of the 90 percent confidence interval of the federal funds rate 12 months hence was around 47 basis points on average in 2011, but only 36 basis points in 2013. Of course, both of these estimates are likely truncated by the zero lower bound, and as such, the differences in uncertainty surrounding those two periods may be understated.

Treasury Coupons

We also examine longer-term coupon securities. Figure 7 provides point estimates and 95 percent confidence intervals for the δ_t's from the coupons regression. Note that like the estimates of δ_t from the bills regression, the paths of the average wedges were similar in 2011 and 2013 prior to the projected breach date. In each case, yields began to rise approximately two weeks prior to the projected breach date and peaked around 4 to 5 bps. Following resolution of the debt limit episodes, yields on coupons fell. The model would suggest that coupons should react somewhat like unaffected bills in the Section 3 exercises, especially if they did not have a coupon payment due around the time of the projected debt limit breaches.

Excess yield estimates for CUSIPs with interest payable around the projected breach dates are presented in Figure 8. In general, the estimates are less stark than those presented in the bill regressions, which the model suggests is to be expected.

To summarize, we find that the average wedges over expected market rates were similar in magnitude and duration in 2011 and 2013, while excess yields on bills maturing soon after the projected breach dates appeared earlier and were significantly larger in 2013. We attribute these results to learning by market participants during the 2011 episode. In addition, when viewed through the lens of our model, the increase in aggregate uncertainty in 2011 and therefore the implicit heightened probability of default on private assets may have dampened the relative reaction of the at-risk securities to all other securities available to investors.

6. Conclusion

This study provides evidence that failure to increase the debt limit when it is reached significantly impacts Treasury security yields not only at the very front end of the yield curve, but across the yield curve. This contagion effect - by which yields on longer-term Treasury securities not perceived to be at risk of delayed principal or interest payments are nevertheless affected - leads to higher borrowing costs to the Treasury as the projected breach date nears. In addition, given that with each passing episode, market participants appear to be reacting earlier and more strongly for bills maturing soon after a projected debt limit breach, what we refer to as excess yields in this study could in fact reflect significantly higher borrowing costs to the Treasury at the front end of the yield curve.[39] That said, it is difficult to separate the learning argument that we posit from general changes in overall market conditions, and so our interpretation of the results should be treated with caution. More research using microdata on individual firms' holdings of assets during these periods may help shed light on some of these behavioral issues.

[39] Specifically, if we observe 'excess yields' on bills with greater than four weeks to maturity, this excess yield should also be present for a newly issued 4-week Treasury bill.

References

Austin, D. Andrew (2015). "The Debt Limit: History and Recent Increases", *Congressional Research Service Report for Congress*, RL31967.

Austin, D. Andrew and Mindy R. Levit (2013). "The Debt Limit: History and Recent Increases", *Congressional Research Service Report for Congress*, RL31967.

Baker, Scott R., Nicholas Bloom, and Steven J. Davis (2013). "Measuring Economic Policy Uncertainty", *Working Paper.*

Brogaard, Jonathan and Andrew Detzel (2013). "The Asset Pricing Implications of Government Economic Policy Uncertainty", *Working Paper*.

Cole, Adam J. (2012). "Measuring Default Risk in U.S. Treasuries: Evidence from the 2011 Debt Limit Impasse", *mimeo*.

Collin-Dufresne, Pierre, Robert S. Goldstein, and J. Spencer Martin (2001). "The Determinants of Credit Spread Changes," *Journal of Finance,* vol. 56, no. 6, p. 2177-2207.

Da, Zhi, Joseph Engelberg, and Pengjie Gao (2013). "The Sum of All FEARS: Investor Sentiment and Asset Prices", *Working Paper*.

Fleming, Michael (2001). "Are Larger Treasury Issues More Liquid? Evidence from Bill Reopenings", *Journal of Money, Credit, and Banking*, vol. 34, no. 3, pp. 707-735.

Forbes, Kristin and Roberto Rigobon (2001). "Measuring Contagion: Conceptual and Empirical Issues," Chapter in *International Financial Contagion*. Edited by Stijn Claassens and Kristin Forbes (Eds.), Kluwer Academic Publishers.

Garbade, Kenneth D. (1996). *Fixed Income Analytics*, MIT Press.

Garbade, Kenneth D. (2016). "The First Debt Limit Crisis," Federal Reserve Bank of New York Staff Report no. 783, June.

Johnson, Ramon E. (1967). "Term Structures of Corporate Bond Yields as a Function of Risk of Default", *The Journal of Finance*, vol. 22, no. 2, pp.313-345.

Longstaff, Francis A. (2010). "The subprime credit crisis and contagion in financial markets," *Journal of Financial Economics*, vol. 97, pp. 436-450.

Liu, Pu, Yingying Shao, and Timothy J. Yeager (2009). "Did the repeated debt ceiling controversies embed default risk in U.S. Treasury securities?", *Journal of Banking & Finance*, vol. 33, pp. 1464-1471.

Nippani, Srinivas, Pu Liu, and Craig T. Schulman (2001). "Are Treasury Securities Free of Default?", *The Journal of Financial and Quantitative Analysis*, vol. 36, No. 2, pp. 251-265.

Nippani, Srinivas and Stanley D. Smith (2014). "The Impact of the October 2013 Government Shutdown on U.S. Treasury Default Risk", *The Journal of Fixed Income*, Fall 2014, pp. 79-91.

Ozdagli, Ali and Joe Peek (2013). "Cliff Notes: The Effects of the 2013 Debt-Ceiling Crisis", *Public Policy Briefs*, Federal Reserve Bank of Boston, No. 13-9.

Pastor, Lubos and Pietro Veronesi (2013). "Political Uncertainty and Risk Premia", *Journal of Financial Economics*, vol. 110, pp. 520-545.

Sarno, Lucio and Daniel L. Thornton (2003). "The dynamic relationship between the federal funds rate and the Treasury bill rate: An empirical investigation", *Journal of Banking & Finance*, vol. 27, pp. 1079-1110.

United States Government Accountability Office (2015). "Debt Limit: Market Response to Recent Impasses Underscores Need to Consider Alternative Approaches", *GAO Highlights*, GAO-15-476.

Table 1. Debt Limit Announcements from the Treasury and Other Important Events

Episode	Date	Type*	Summary
2011	May 2, 2011	Letter to Congress (T)	Announcement of Debt Issuance Suspension Period (DISP) lasting through August 2, 2011
	Jun 1, 2011	Statement (T)	August 2nd breach date projection reaffirmed
	Jul 13, 2011	Statement	Moody's places U.S. sovereign credit rating of 'Aaa' on review for possible downgrade
	Jul 14, 2011	Statement	Standard & Poor's places its 'AAA' long-term and 'A-1+' short-term credit rating on the U.S. on Credit Watch negative
	Jul 15, 2011	Statement (T)	August 2nd breach date projection reaffirmed
	Aug 2, 2011	Legislation	Budget Control Act of 2011 is passed, which immediately increases debt limit by $400 bn; two additional increases of $500 bn and $1.2-1.5 trn subject to a Congressional motion of disapproval
	Aug 5, 2011	Statement	Standard & Poor's lowers long-term sovereign credit rating on U.S. to 'AA+' from 'AAA'
2013	May 17, 2013	Letter to Congress (T)	Announcement of DISP lasting through August 2, 2013
	Aug 2, 2013	Letter to Congress (T)	Extension of DISP to October 11, 2013
	Aug 26, 2013	Letter to Congress (T)	Extraordinary measures projected to be exhausted by mid-October 2013
	Sep 25, 2013	Letter to Congress (T)	Extraordinary measures projected to be exhausted no later than October 17, 2013
	Oct 1, 2013	Letter to Congress (T)	Final extraordinary measures being used; reaffirmed exhaustion of extraordarinary measures no later than October 17, 2013; cash balance of $30 bn on hand; government shutdown begins
	Oct 15, 2013	Statement	Fitch places U.S. sovereign credit rating of 'AAA' on negative watch

Oct 16, 2013	Legislation	Continuing Appropriations Act, 2014 is passed, which suspends the debt limit until February 7, 2014

*(T) indicates that the announcement came from the Treasury Department.
Source: "Debt Limit," U.S. Department of the Treasury, http://www.treasury.gov/initiatives/pages/debtlimit.aspx; Brandimarte, Walter and Daniel Bases (June 13, 2011). "Moody's puts U.S. ratings on review for downgrade," Reuters, www.reuters.com/article/2011/07/13/us-usa-ratings-moodys-idUSTRE76C6PT20110713; "Research Update: United States of America Long-Term Rating Lowered to 'AA+' on Political Risks and Rising Debt Burden; Outlook Negative (August 5, 2011). Standard & Poor's, http://img.en25.com/Web/StandardandPoors/UnitedStatesofAmericaLongTermRatingLoweredToAA.pdf; Budget Control Act of 2011 (August 2, 2011). Government Printing Office, http://www.gpo.gov/fdsys/pkg/PLAW-112publ25/html/PLAW-112publ25.htm; H.R. 2775 – Continuing Appropriations Act, 2014 (October 17, 2013), Congress.gov, http://beta.congress.gov/bill/113th-congress/house-bill/2775

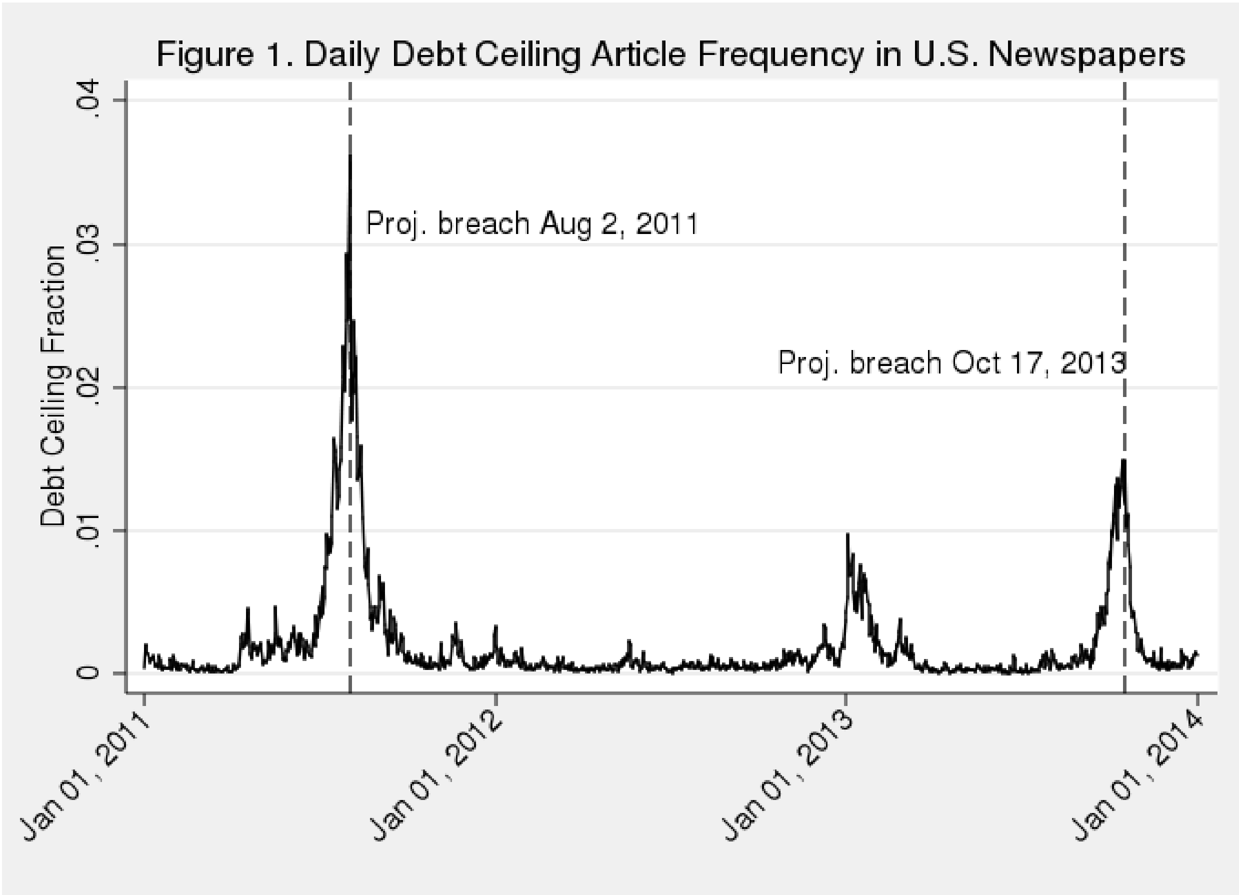
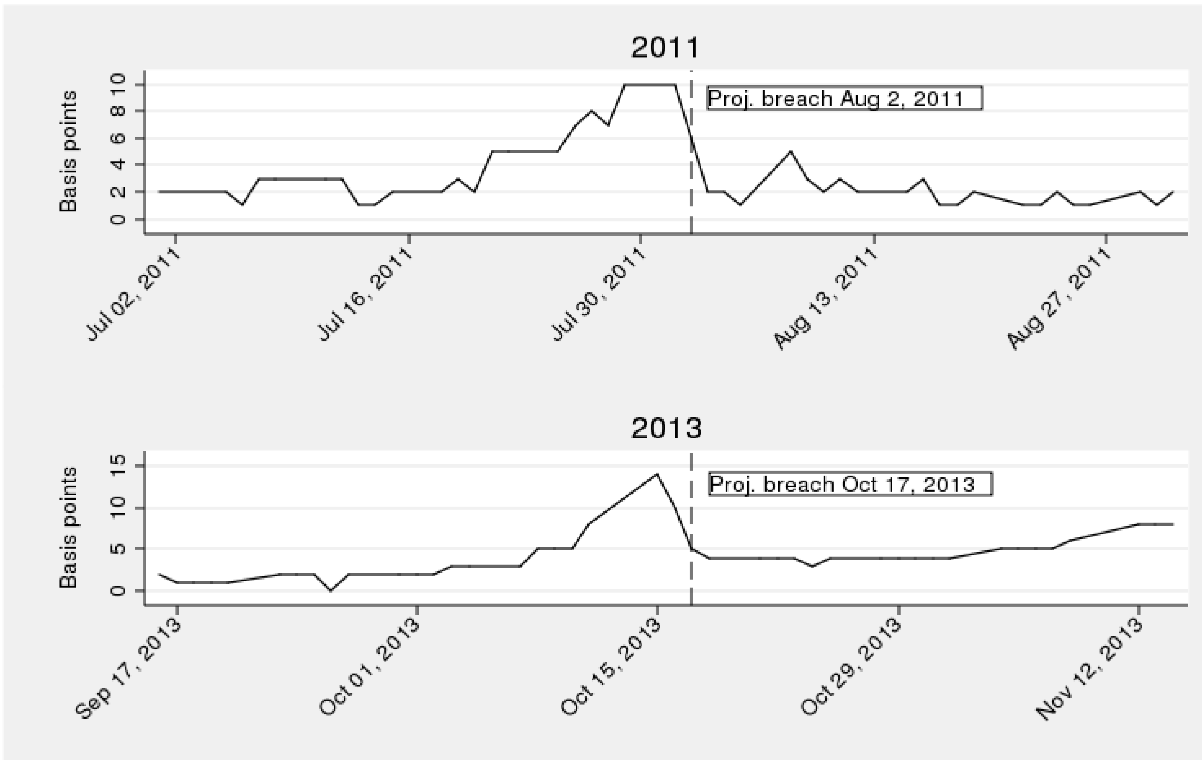


Figure 1 displays the Debt Ceiling Index created by Scott Baker, Nicholas Bloom, and Steven J. Davis. The index is a measure of the fraction of articles appearing in major newspapers in the United States - the 1000+ newspapers covered by Access World News Newsbank Service - that use the phrase "debt ceiling". The monthly data are available at http://www.policyuncertainty.com/debt_ceiling.html. We are grateful to Scott Baker for providing us with a daily version of the index. A value of 0.01 represents a day in which one percent of all newspaper articles mention the term in question.

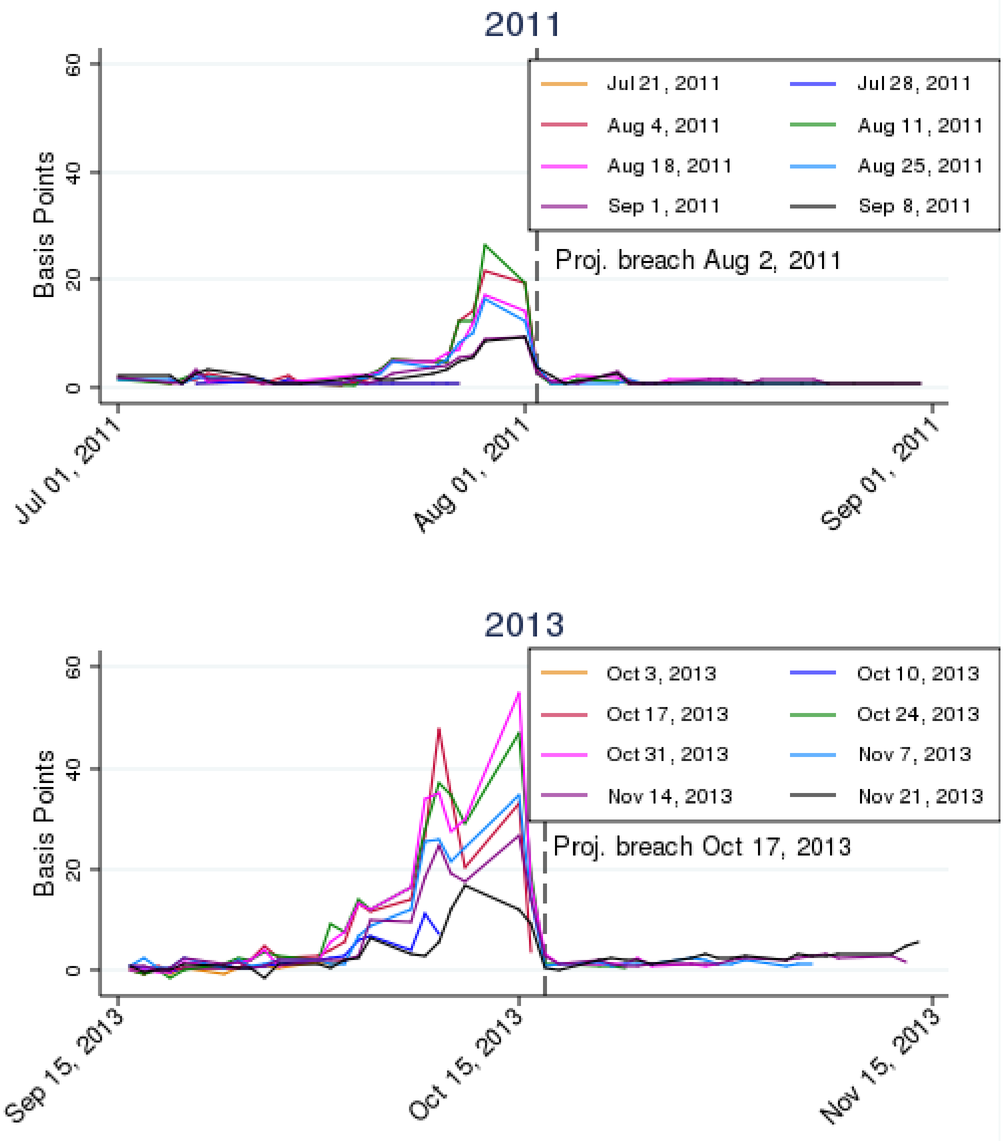
Figure 2. Market yield on U.S. Treasury securities at 3-month constant maturity



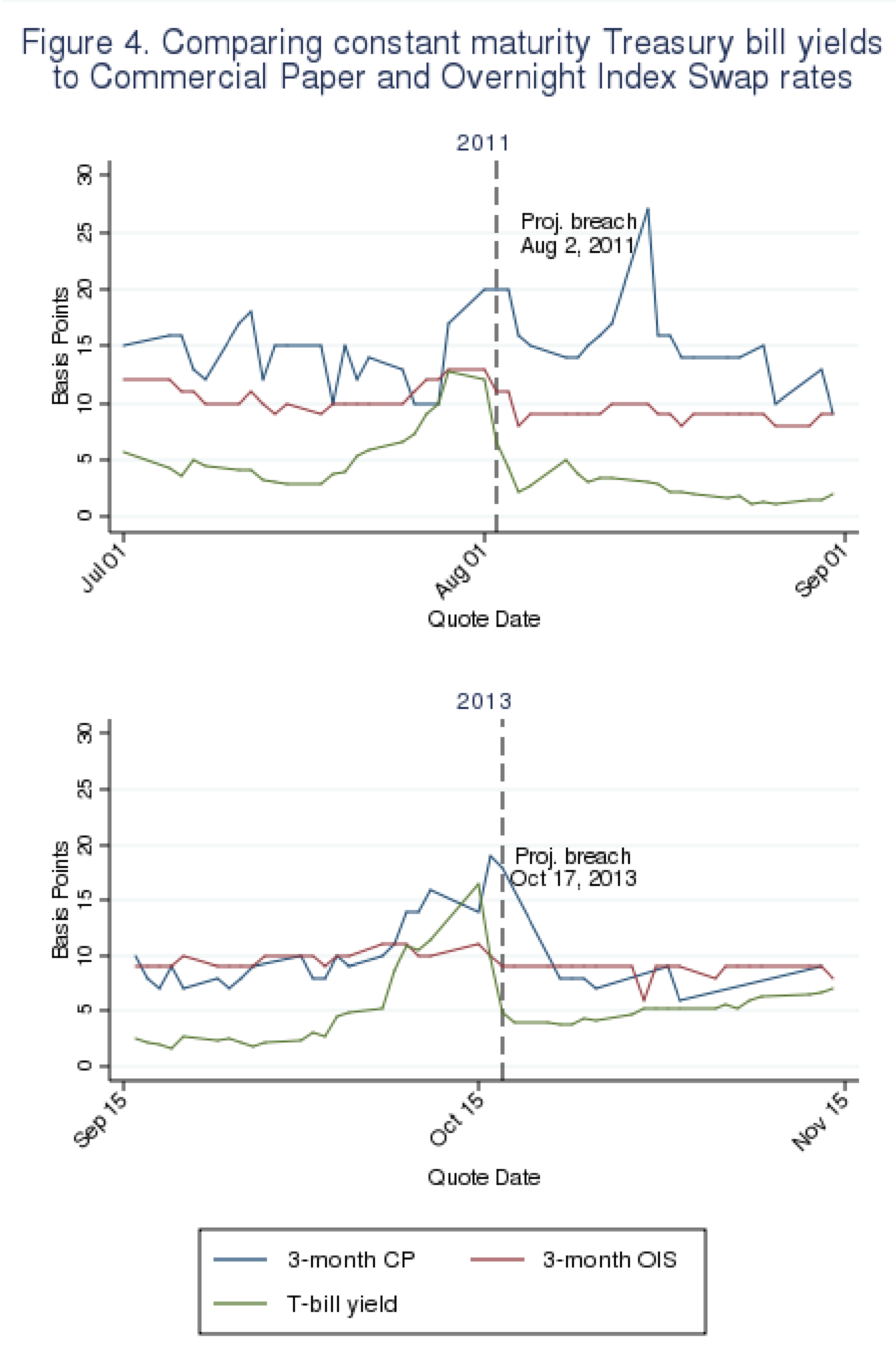
Source: Federal Reserve Board (2014), Statistical Release H.15, "Selected Interest Rates (Daily)" (March 13).

Figure 3. Individual Treasury Bill Yields

By Maturity Date



Source: Center for Research in Securities Pricing (CRSP). *CRSP/U.S. Treasury Database*, Wharton Research Data Services (WRDS), wrds-web.wharton.upenn.edu/wrds/about/databaselist.cfm.



Source: Federal Reserve Board, Statistical Release H.15 (2014), "Selected Interest Rates (Daily)" (March 13); and Center for Research in Securities Pricing (CRSP). *CRSP/U.S. Treasury Database*, Wharton Research Data Services (WRDS), wrds-web.wharton.upenn.edu/wrds/about/databaselist.cfm.

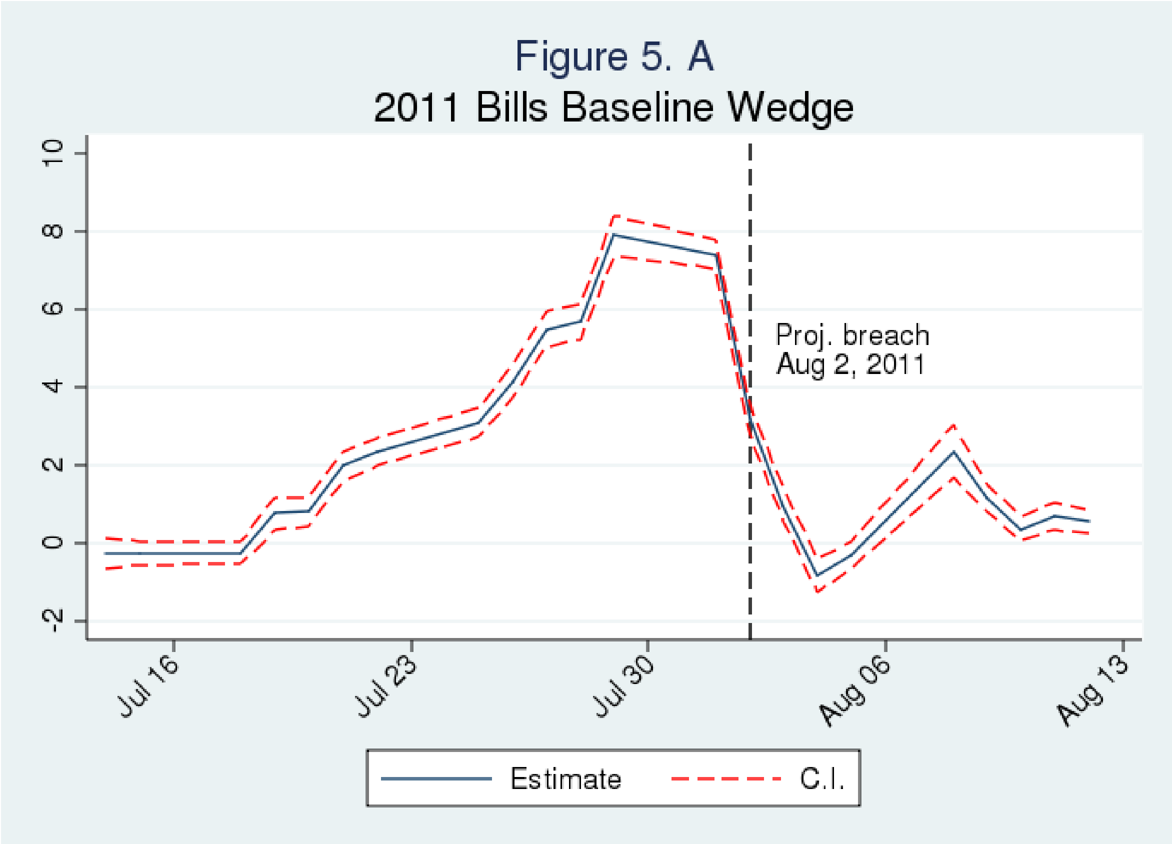


Figure 5. A
2011 Bills Baseline Wedge
10
8
6
4
2
0
-2
Proj. breach
Aug 2, 2011
Jul 16
Jul 23
Jul 30
Aug 06
Aug 13
Estimate
C.I.

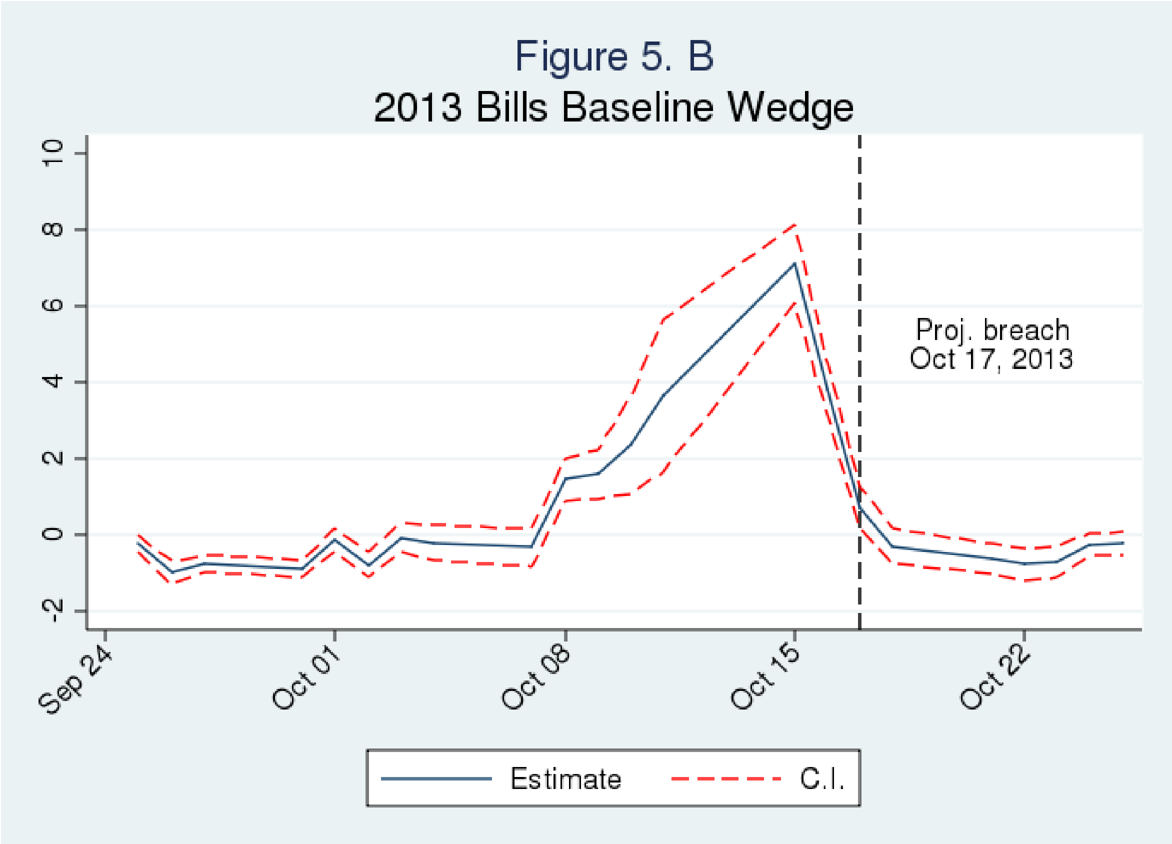
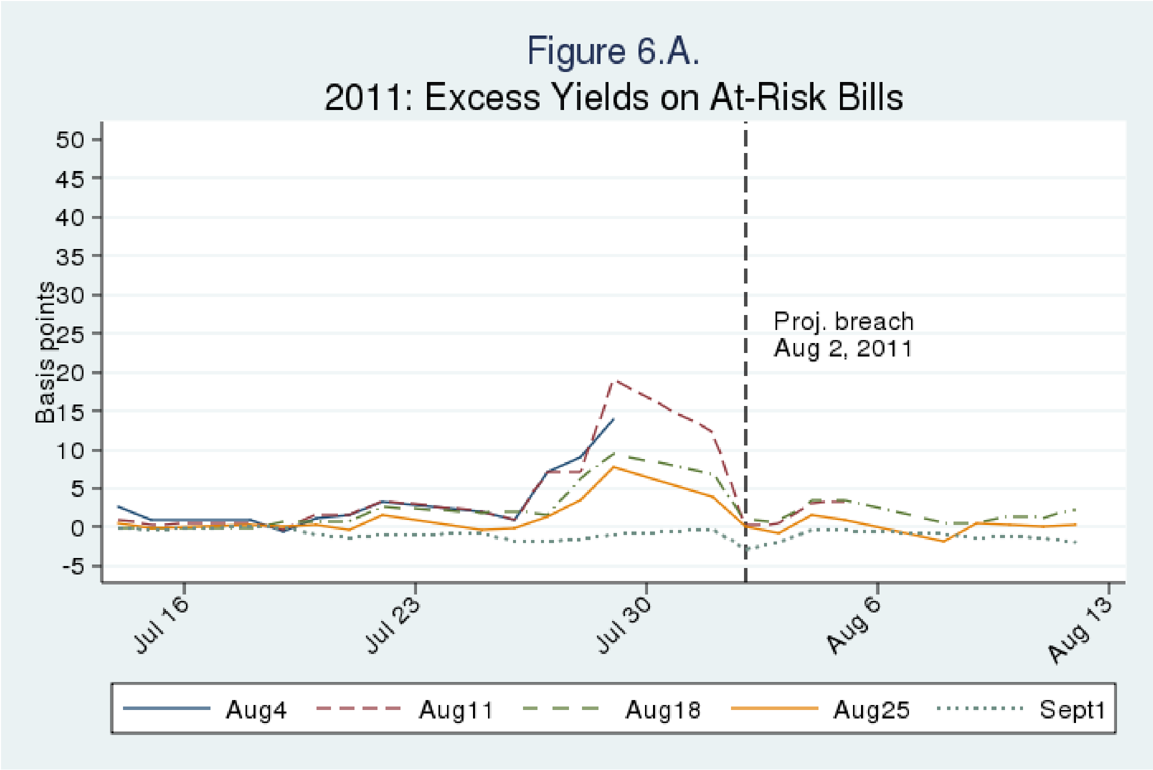
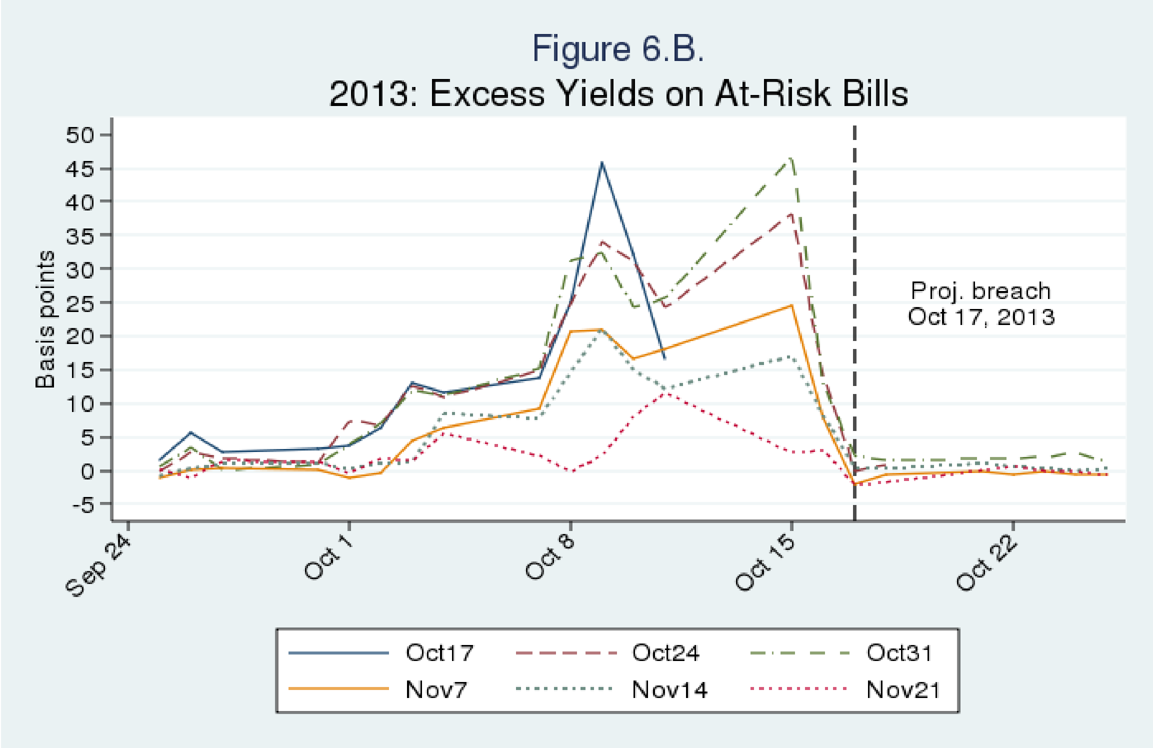


Figure 5. B
2013 Bills Baseline Wedge
10
8
6
4
2
0
-2
Proj. breach
Oct 17, 2013
Sep 24
Oct 01
Oct 08
Oct 15
Oct 22
Estimate
C.I.



Note: Coefficients for August 4, August 11, August 18, and August 25 are statistically significant.



Note: Coefficients for October 17, October 24, October 31, November 7, November 14, and November 21 are statistically significant.

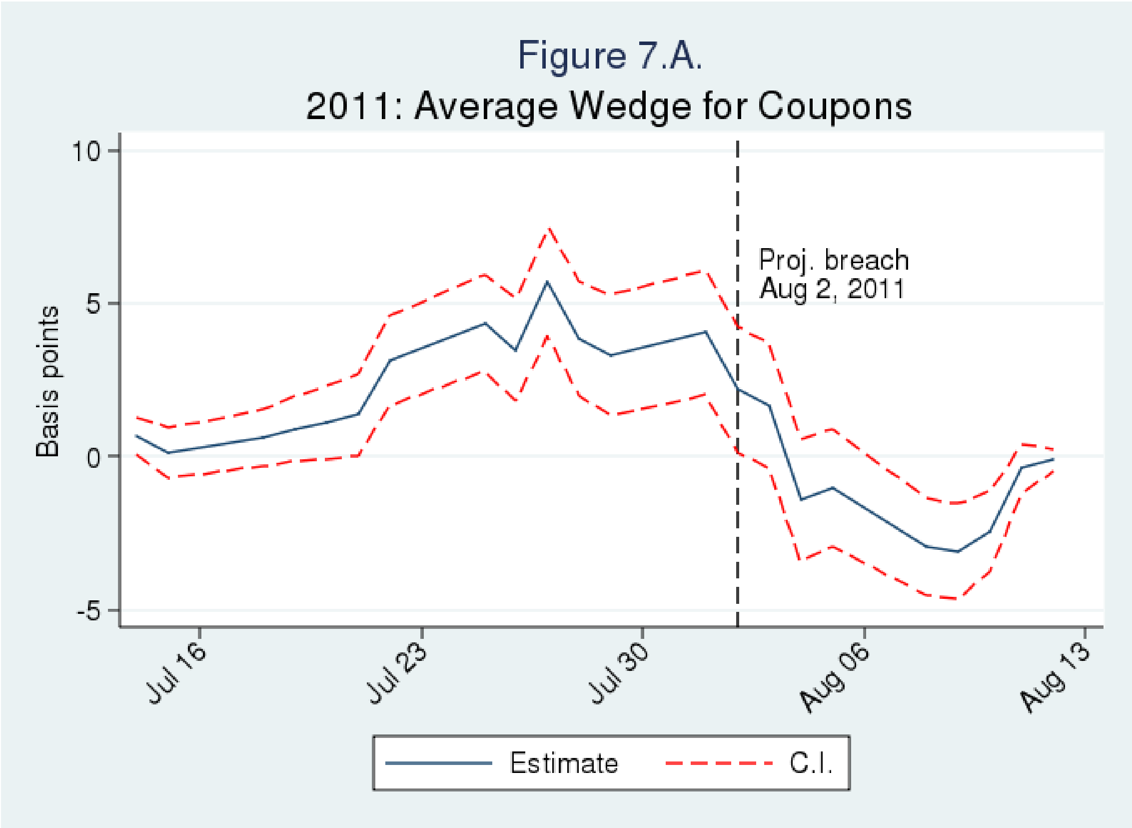


Figure 7.A.
2011: Average Wedge for Coupons
Basis points
10
5
0
-5
Proj. breach
Aug 2, 2011
Jul 16
Jul 23
Jul 30
Aug 06
Aug 13
Estimate
C.I.

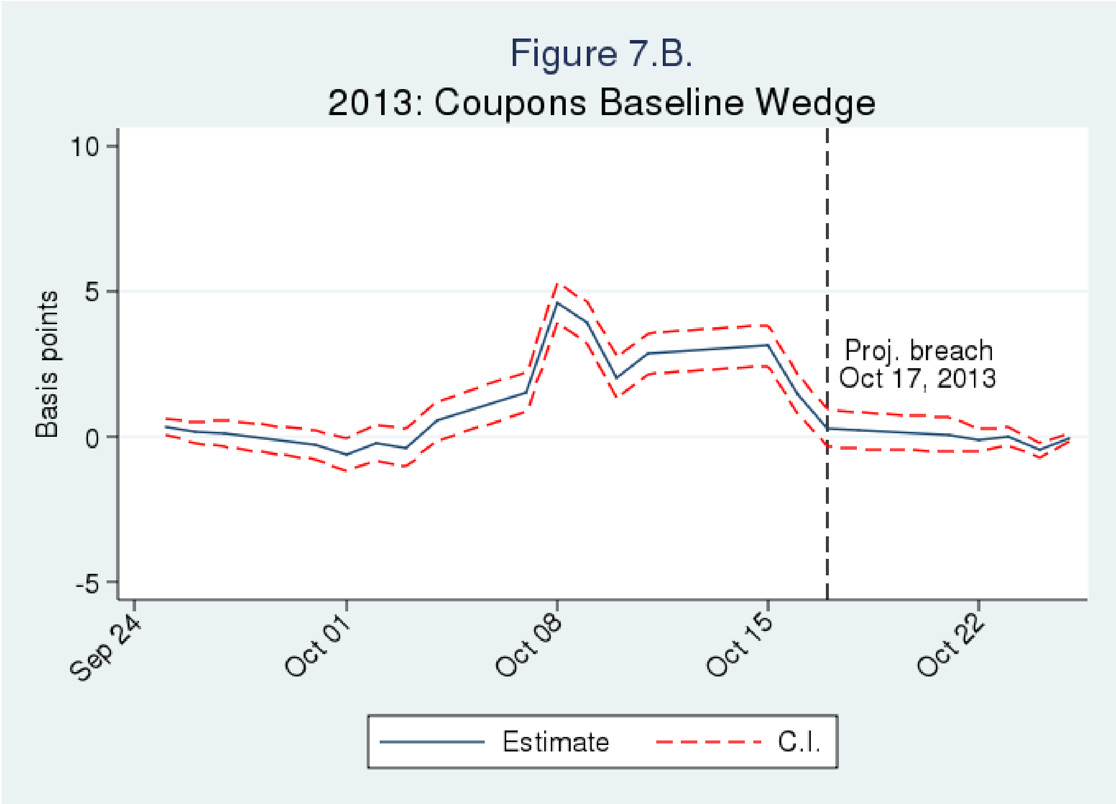
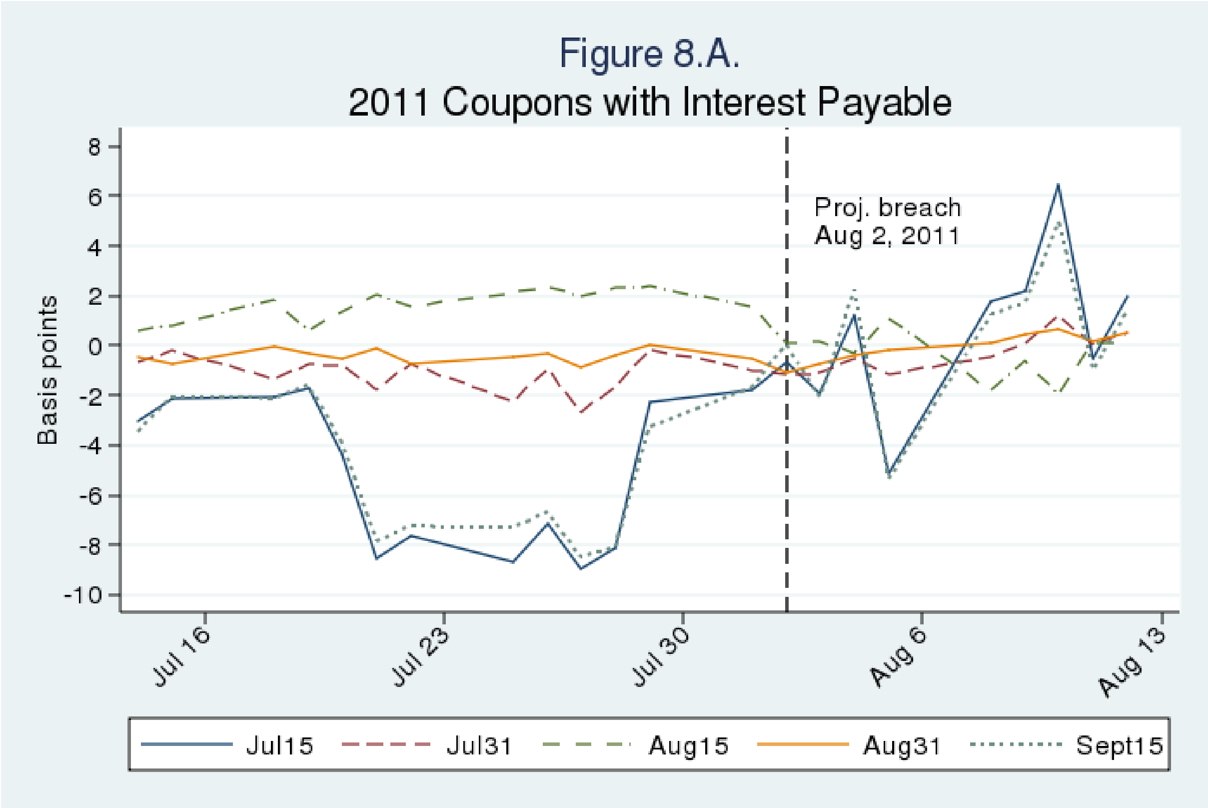
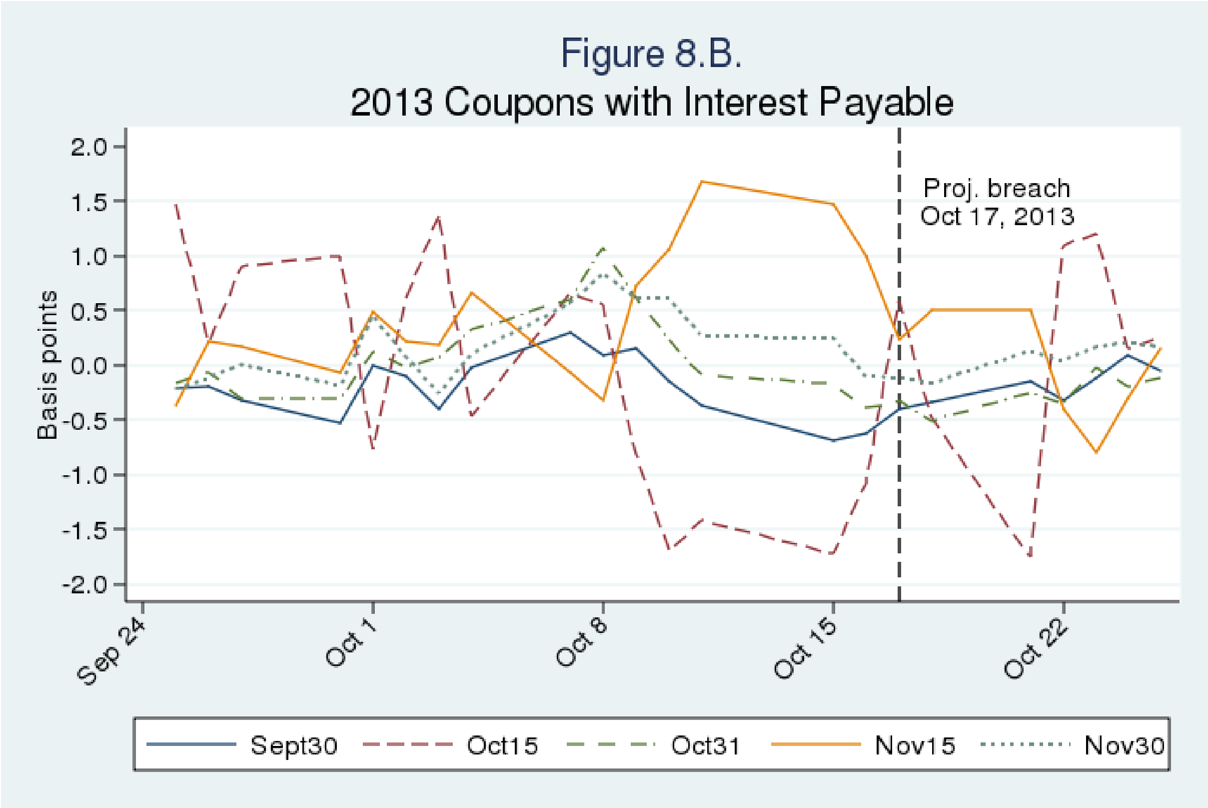


Figure 7.B.
2013: Coupons Baseline Wedge
Basis points
10
5
0
-5
Proj. breach
Oct 17, 2013
Sep 24
Oct 01
Oct 08
Oct 15
Oct 22
Estimate
C.I.



Note: None of the coefficients are statistically significant immediately before the debt limit episode.



Note: None of the coefficients are statistically significant immediately before the debt limit episode.

Table 2.A

	(1) Baseline	(2) Add'l Controls	(3) Longer Window
2011 Bills Panel			
July 18	-0.244	-0.145	-1.963
	(0.293)	(0.304)	(0.518)
July 19	0.792	0.800	-0.857
	(0.337)	(0.357)	(0.534)
July 20	0.813	0.823	-0.760
	(0.357)	(0.376)	(0.540)
July 21	1.943	1.918	0.446
	(0.378)	(0.396)	(0.547)
July 22	2.276	2.245	0.850
	(0.396)	(0.409)	(0.553)
July 25	3.131	3.128	1.773
	(0.415)	(0.425)	(0.560)
July 26	4.205	4.217	2.911
	(0.437)	(0.448)	(0.567)
July 27	5.573	5.684	4.341
	(0.456)	(0.469)	(0.575)
July 28	5.735	5.934	4.573
	(0.475)	(0.492)	(0.582)
July 29	7.968	8.192	6.867
	(0.488)	(0.543)	(0.590)
August 1	7.589	7.833	6.552
	(0.492)	(0.599)	(0.594)
August 2	3.232	3.683	2.274
	(0.490)	(0.639)	(0.594)
August 3	0.989	1.413	0.0986
	(0.469)	(0.698)	(0.588)
August 4	-1.012	-0.260	-1.813
	(0.435)	(0.751)	(0.577)
Constant	-0.0720	-0.0751	-0.0732
	(0.00636)	(0.00636)	(0.00635)
Observations	24,478	24,347	24,478
R-squared	0.375	0.386	0.388

Note: Standard errors are robust. Full regression results include coefficients from July 14 to August 12.

Figure 2.B

	(1) Baseline	(2) Add'l Controls	(3) Longer Window
2013 Bills Panel			
October 1	-0.164	-0.0364	-1.141
	(0.340)	(0.340)	(0.472)
October 2	-0.884	-0.740	-1.854
	(0.395)	(0.395)	(0.507)
October 3	-0.146	0.0840	-1.117
	(0.456)	(0.457)	(0.546)
October 4	-0.296	-0.107	-1.264
	(0.506)	(0.507)	(0.577)
October 7	-0.253	-0.00874	-1.225
	(0.560)	(0.560)	(0.611)
October 8	1.506	1.839	0.537
	(0.617)	(0.618)	(0.652)
October 9	1.620	1.955	0.653
	(0.663)	(0.664)	(0.683)
October 10	2.274	2.403	1.318
	(0.695)	(0.695)	(0.721)
October 11	3.556	3.650	2.602
	(0.701)	(0.701)	(0.735)
October 15	7.232	7.524	6.271
	(0.580)	(0.581)	(0.718)
October 16	3.872	4.079	2.919
	(0.518)	(0.519)	(0.690)
October 17	0.664	0.773	-0.281
	(0.456)	(0.456)	(0.660)
October 18	-0.371	-0.299	-1.313
	(0.404)	(0.404)	(0.634)
October 21	-0.586	-0.509	-1.532
	(0.357)	(0.357)	(0.608)
Constant	-0.0720	-0.0751	-0.0732
	(0.00636)	(0.00636)	(0.00635)
Observations	24,478	24,347	24,478
R-squared	0.375	0.386	0.388

Note: Standard errors are robust. Full regression results include coefficients from September 25 to October 25.

Table 3.A

	(1) Baseline	(2) Add'l Controls	(3) Longer Window
2011 Coupon Panel			
July 18	0.607	2.157	0.418
	(0.468)	(0.459)	(0.896)
July 19	0.905	2.708	0.985
	(0.541)	(0.523)	(0.924)
July 20	1.118	3.168	1.463
	(0.608)	(0.580)	(0.950)
July 21	1.361	3.501	1.963
	(0.687)	(0.660)	(0.985)
July 22	3.138	5.677	4.019
	(0.750)	(0.723)	(1.014)
July 25	4.351	7.349	5.514
	(0.804)	(0.766)	(1.038)
July 26	3.491	6.816	4.928
	(0.856)	(0.806)	(1.061)
July 27	5.710	9.617	7.413
	(0.907)	(0.835)	(1.081)
July 28	3.847	8.082	5.822
	(0.961)	(0.869)	(1.104)
July 29	3.320	8.135	5.587
	(1.005)	(1.069)	(1.155)
August 1	4.048	9.153	6.602
	(1.037)	(1.103)	(1.170)
August 2	2.182	7.756	5.018
	(1.043)	(1.194)	(1.186)
August 3	1.676	7.716	4.773
	(1.046)	(1.247)	(1.192)
August 4	-1.422	5.373	1.964
	(1.023)	(1.314)	(1.191)
Constant	0.250	0.249	0.260
	(0.0131)	(0.0138)	(0.0132)
Observations	139,403	133,518	139,403
R-squared	0.579	0.581	0.583

Note: Standard errors are robust. Full regression results include coefficients from July 14 to August 12.

Table 3.B

	(1) Baseline	(2) Add'l Controls	(3) Longer Window
2013 Coupon Panel			
October 1	-0.621	-0.483	-0.0461
	(0.286)	(0.288)	(0.665)
October 2	-0.195	-0.0527	0.407
	(0.320)	(0.321)	(0.667)
October 3	-0.373	-0.0846	0.250
	(0.331)	(0.333)	(0.662)
October 4	0.542	0.720	1.178
	(0.344)	(0.346)	(0.657)
October 7	1.539	1.854	2.208
	(0.351)	(0.354)	(0.652)
October 8	4.602	5.087	5.292
	(0.356)	(0.361)	(0.646)
October 9	3.929	4.424	4.637
	(0.360)	(0.365)	(0.641)
October 10	2.026	2.226	2.750
	(0.361)	(0.363)	(0.635)
October 11	2.853	2.895	3.597
	(0.359)	(0.360)	(0.629)
October 15	3.135	3.337	3.915
	(0.355)	(0.359)	(0.623)
October 16	1.453	1.696	2.258
	(0.346)	(0.349)	(0.617)
October 17	0.305	0.531	1.136
	(0.325)	(0.326)	(0.609)
October 18	0.201	0.253	1.051
	(0.318)	(0.318)	(0.604)
October 21	0.0844	0.171	0.964
	(0.300)	(0.300)	(0.596)
Constant	0.250	0.249	0.260
	(0.0131)	(0.0138)	(0.0132)
Observations	139,403	133,518	139,403
R-squared	0.579	0.581	0.583

Note: Standard errors are robust. Full regression results include coefficients from September 25 to October 25.

Appendix: Model First-Order Conditions

$$
\begin{aligned}
n_i:\ \ 0 = &-\frac{C_{0i}^{-\gamma_i}}{1+r_n} \\
&+ \delta_1\left[\left(1-\pi_g\right)(1-\pi_a)C_{1i1}^{-\gamma_i} + \left(1-\pi_g\right)\pi_a C_{1i2}^{-\gamma_i} + \pi_g(1-\pi_{gb})(1-\pi_a)\alpha C_{1i3}^{-\gamma_i}\right. \\
&\left. + \pi_g(1-\pi_{gb})\pi_a \alpha C_{1i4}^{-\gamma_i} + \pi_g \pi_{gb} \alpha \varphi C_{1i5}^{-\gamma_i}\right]
\end{aligned}
$$

$$
\begin{aligned}
l_i:\ \ 0 = &-\frac{C_{0i}^{-\gamma_i}}{1+r_l} + \delta_1\delta_2\left[\left(1-\pi_g\pi_{gb}\right)C_{2i1}^{-\gamma_i} + \pi_g\pi_{gb}\varphi C_{2i5}^{-\gamma_i}\right] \\
&+ \delta_1 c\left[\left(1-\pi_g\right)(1-\pi_a)C_{1i1}^{-\gamma_i} + \left(1-\pi_g\right)\pi_a C_{1i2}^{-\gamma_i} + \pi_g(1-\pi_{gb})(1-\pi_a)\alpha C_{1i3}^{-\gamma_i}\right. \\
&\left. + \pi_g(1-\pi_{gb})\pi_a \alpha C_{1i4}^{-\gamma_i} + \pi_g \pi_{gb} \alpha \varphi C_{1i5}^{-\gamma_i}\right]
\end{aligned}
$$

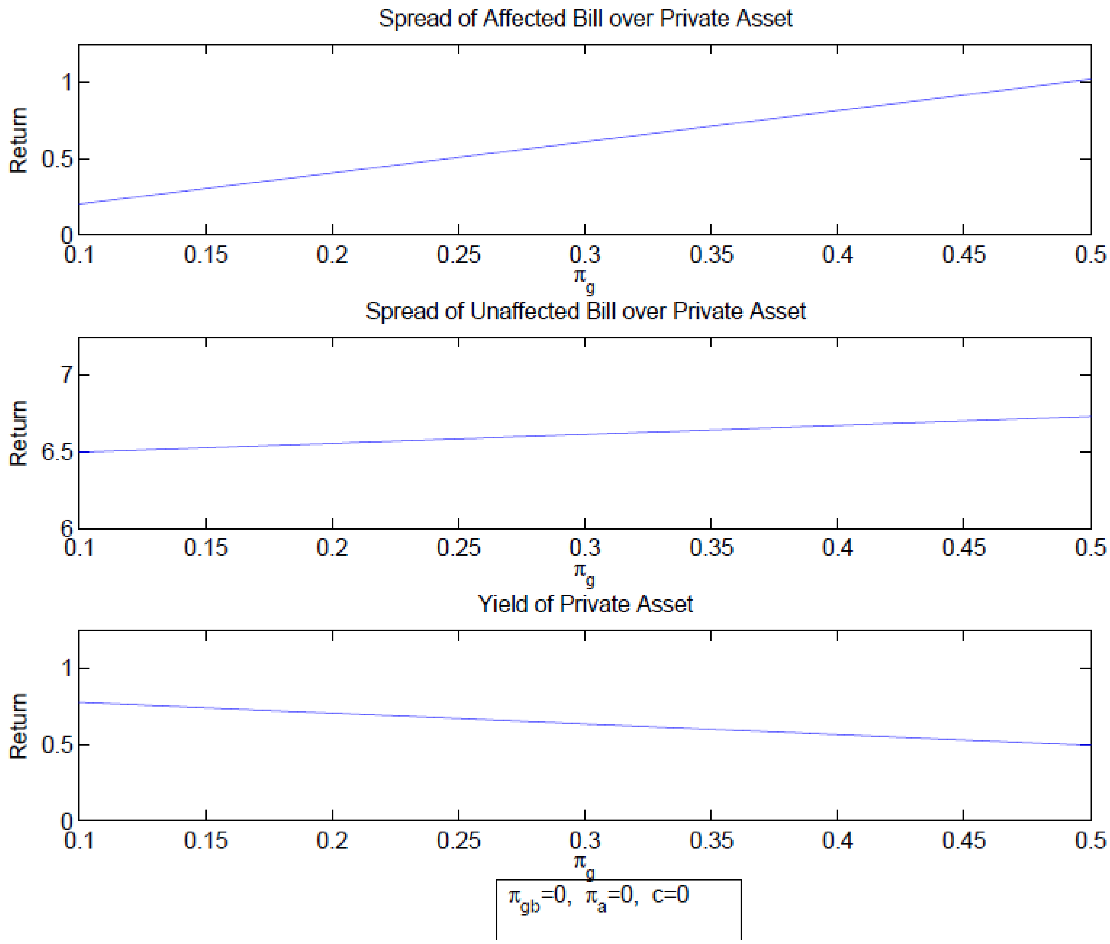
$$
\begin{aligned}
a_i:\ \ 0 = &-\frac{C_{0i}^{-\gamma_i}}{1+r_a} \\
&+ \delta_1\left[\left(1-\pi_g\right)(1-\pi_a)C_{1i1}^{-\gamma_i} + \left(1-\pi_g\right)\pi_a \beta C_{1i2}^{-\gamma_i} + \pi_g(1-\pi_{gb})(1-\pi_a)C_{1i3}^{-\gamma_i}\right. \\
&\left. + \pi_g(1-\pi_{gb})\pi_a \beta C_{1i4}^{-\gamma_i} + \pi_g \pi_{gb} \theta C_{1i5}^{-\gamma_i}\right]
\end{aligned}
$$

Appendix: Model Primitives

	Model Scenario						
Parameter	1	2	3	4	5	6	7
π_a	0	0.2	0	0	0.2	0	0
π_{gb}	0	0	0.2	0.2	0.2	0.2	varies
c	0	0	0	0	0	0.05	0
θ	1	0.88	1	0.88	0.88	0.88	0.88
δ_1	0.95	0.95	0.95	0.95	0.95	0.95	0.95
δ_2	0.94	0.94	0.94	0.94	0.94	0.9	0.94
α	0.98	0.98	0.98	0.98	0.98	0.98	0.98
β	0.9	0.9	0.9	0.9	0.9	0.9	0.9
φ	0.9	0.9	0.9	0.9	0.9	0.9	0.9
γ_1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
γ_2	0.7	0.7	0.7	0.7	0.7	0.7	0.7

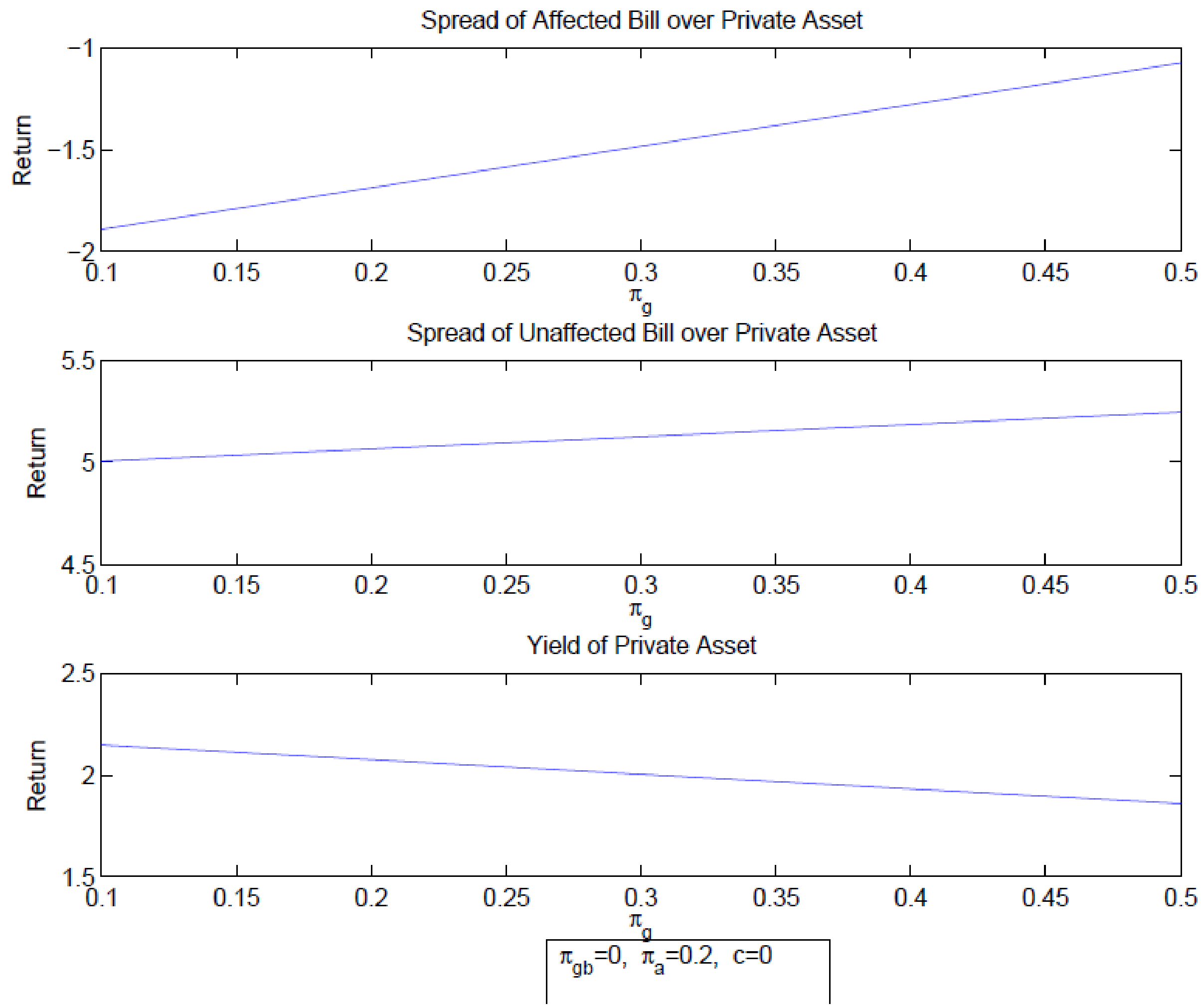
Appendix Figure 1

Model Scenario 1



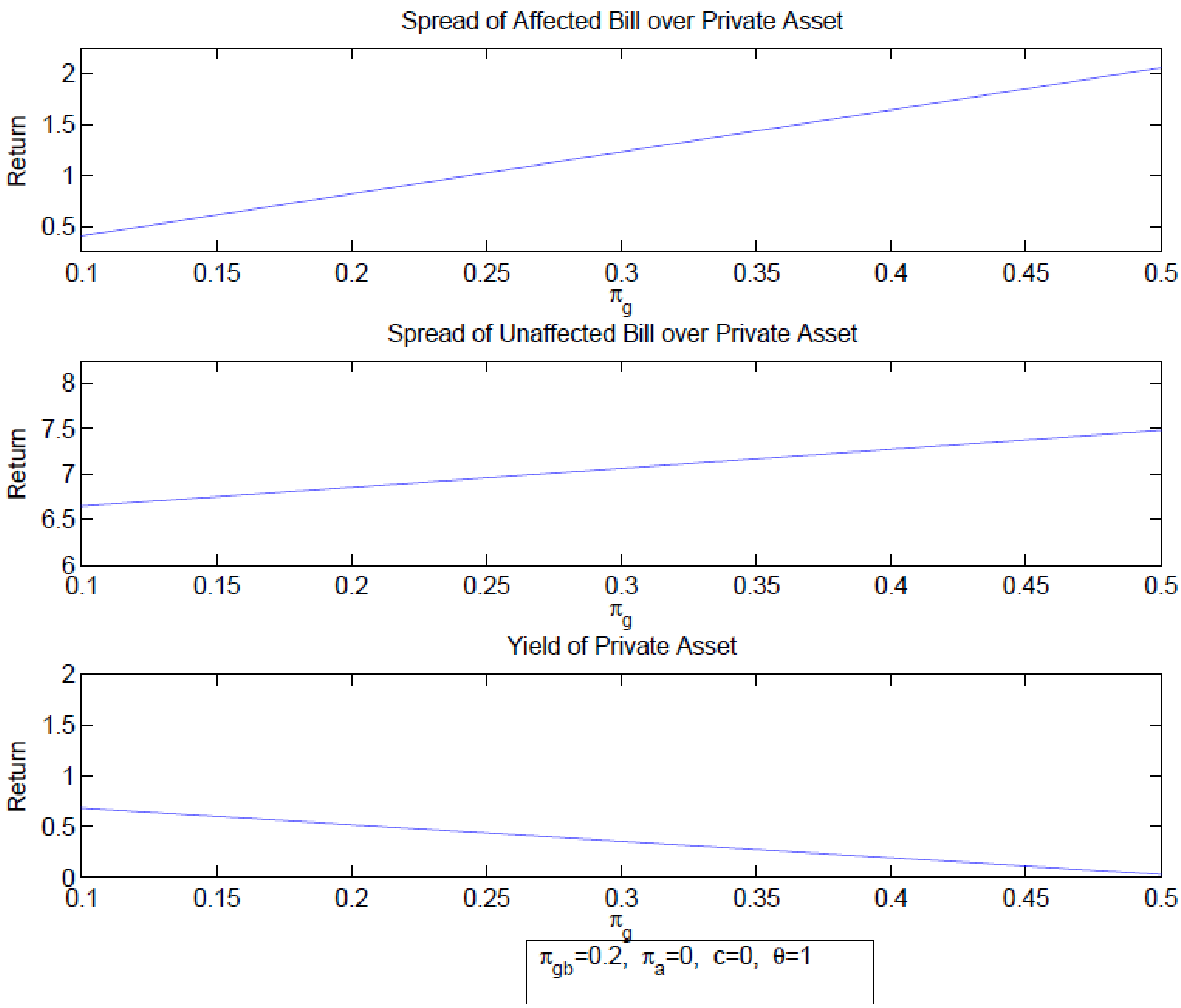
Appendix Figure 2

Model Scenario 2



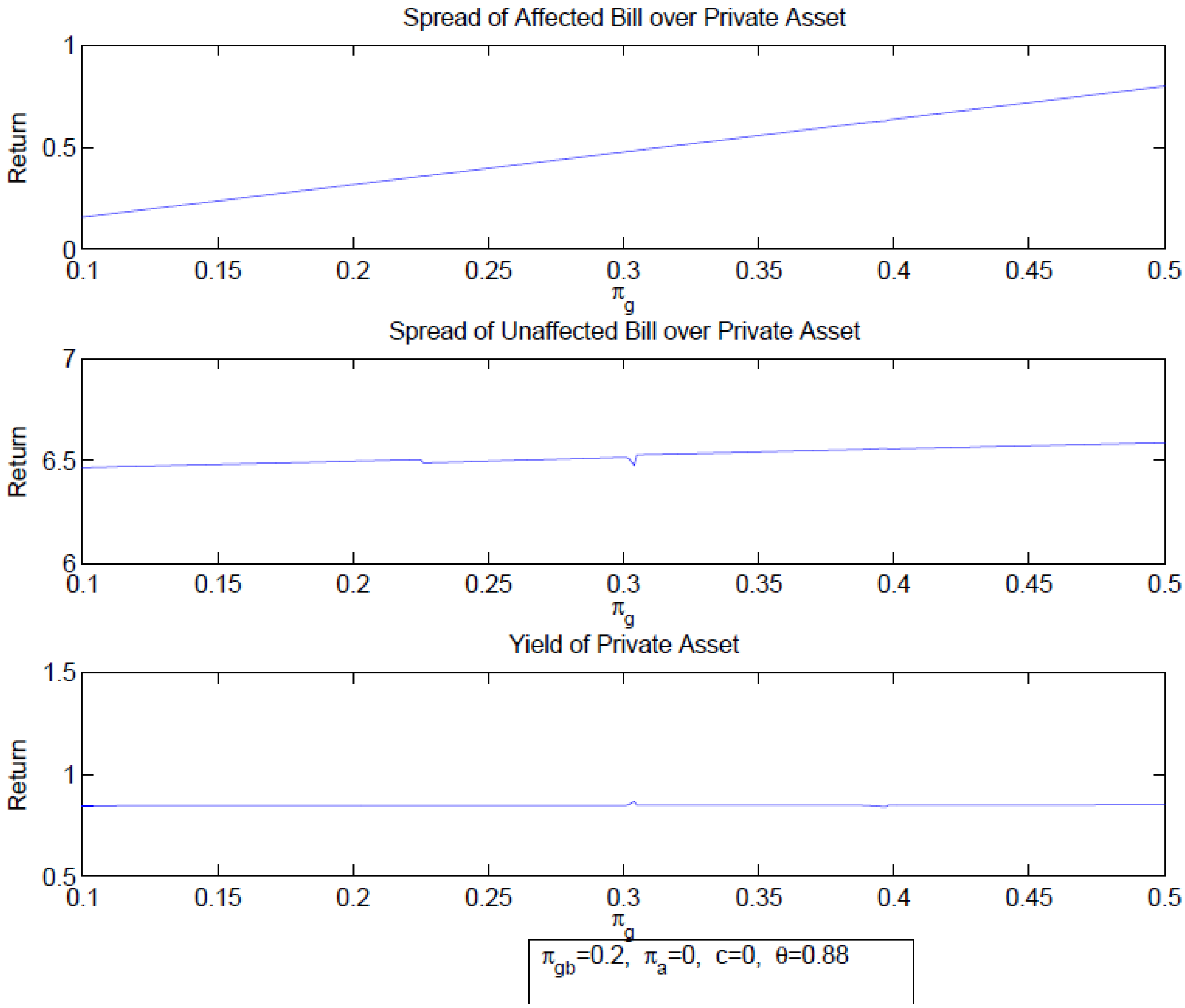
Appendix Figure 3

Model Scenario 3



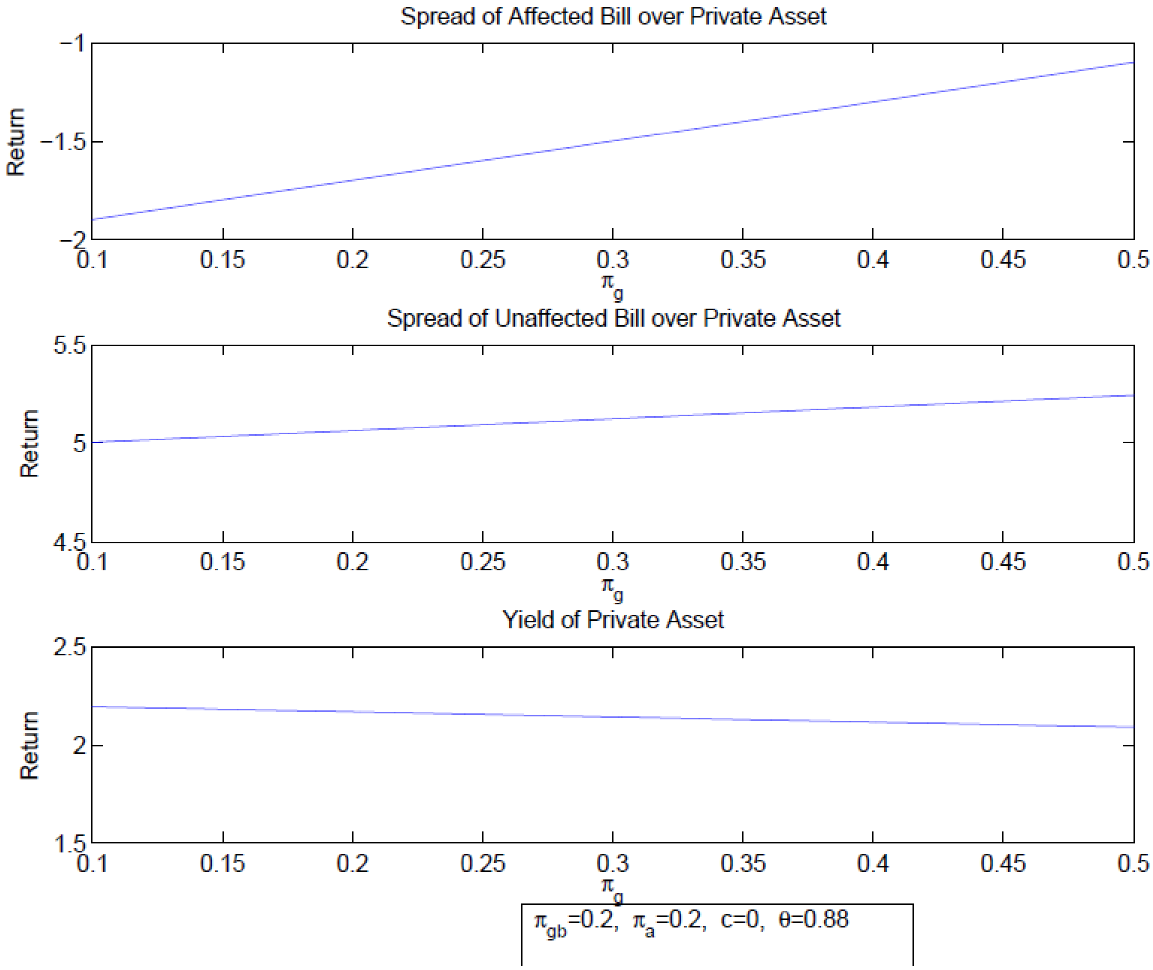
Appendix Figure 4

Model Scenario 4



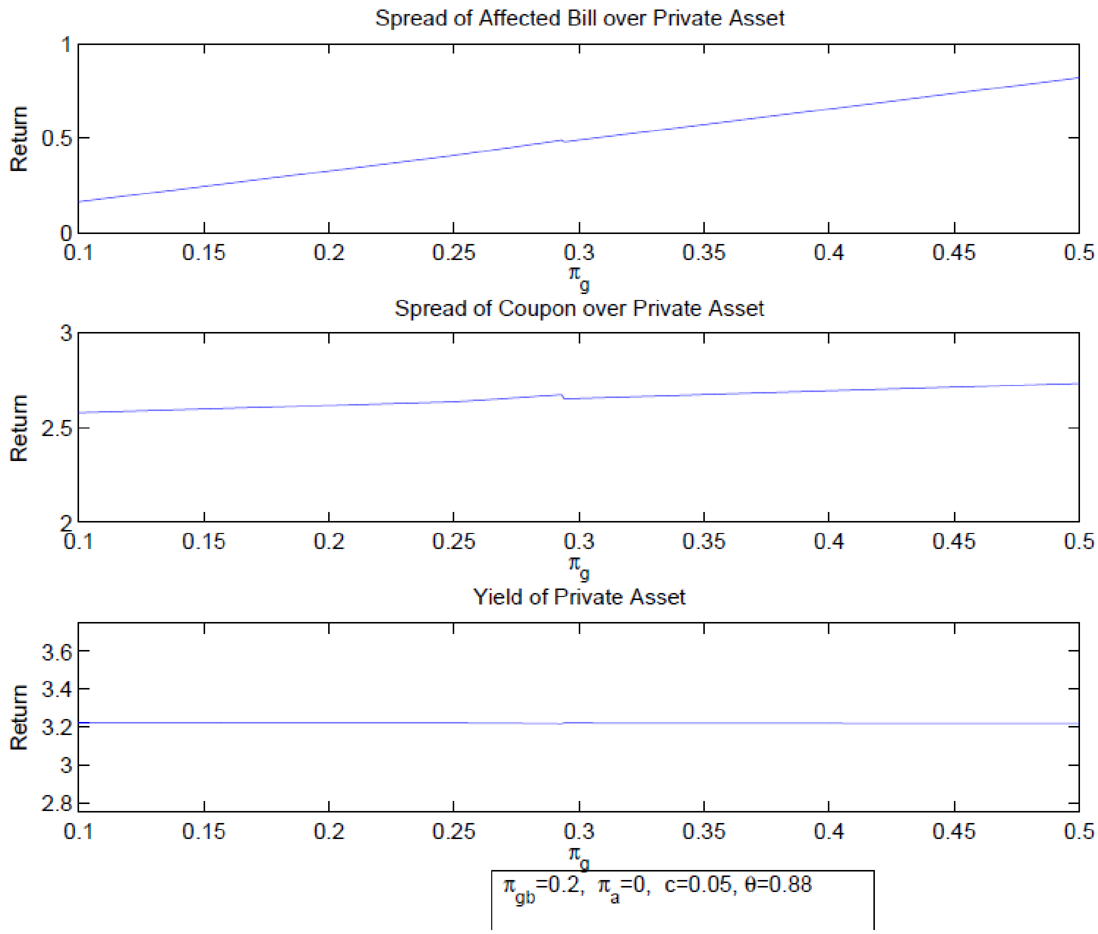
Appendix Figure 5

Model Scenario 5



Appendix Figure 6

Model Scenario 6



Appendix Figure 7

Model Scenario 7