

Demand for US Treasuries After the 2008-09 Financial Crisis: Empirical Evidence and Potential Policy Implications*

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Abstract

Using data from US Treasury auctions, I construct a measure that proxies for the generally unobserved level of demand for government debt. The data span the period from January, 2000 to December, 2017 thus allowing me to identify changes in private investors' demand for US treasuries following the financial crisis of 2008. Two important findings stand out. First, the financial crisis generated a broad shift in investors' demand towards treasuries of shorter maturity. This shift is significant, highly persistent, and has likely contributed to short term yields hitting the zero lower bound. Second, the Treasury issued more debt during the Fed's first and third quantitative easing programs in what is likely to be an endogenous response to these unconventional policies. I discuss the implications of these findings for policymakers and researchers employing DSGE models.

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Keywords

Demand, Government Debt, Treasury, Federal Reserve, Conflict, Bid-to-Cover, QE, Interest Rates

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1 Introduction

Interest rates in the United States have been declining since the 1980s - the beginning of the Great Moderation. Some of this secular decline is a direct result of the decline in the volatility of output and inflation that has characterized the US economy ever since. On the other hand, some of decline can be traced to monetary policy.¹ Furthermore, a growing volume of work has identified safe asset shortages as a structural feature of the global economy for the past two decades. According to that literature, interest rates across developed countries have been declining since demand for safe assets has been outstripping their supply.² Part of this increased appetite for safe (and liquid) assets may be explained by an increase in investors' valuation of these securities. [Del Negro et al. \(2017\)](#) find that most of the reduction in interest rates in the United States (at least) since the late 1990s can be attributed to an increase in the premia investors have been willing to pay for the convenience (safety and liquidity) benefits of US treasuries.

The financial crisis of 2008-09 led to the destruction of a significant volume of safe private financial assets.³ Furthermore, the severity of the financial meltdown increased demand for high quality assets such as US treasuries. Combined, these two developments exacerbated the safe asset shortage. Coupled with an expansionary monetary policy, the financial meltdown in late 2008 brought along an extended period of record low interest rates. Short-term rates

¹[Kiley and Roberts \(2017\)](#) argue that nominal interest rates have been substantially below the averages of the last half century, because the Fed's inflation target has been below the inflation average.

²The main "producers" or suppliers of safe assets globally are developed countries. However, developing countries have been expanding their share of global output thus increasing their significance in global financial markets. Furthermore, safe and liquid assets such as debt from developed countries, are typically used to reduce the overall risk and volatility of financial portfolios. With financial markets among developing countries growing at a fast pace, the worldwide demand for safe assets has outstripped their supply thus contributing to a global shortage of safe assets. The excess demand has thus been putting downward pressure on interest rates. See [Caballero, Farhi and Gourinchas \(2008\)](#) and [Caballero and Krishnamurty \(2009\)](#) for additional information on this issue.

³Before the financial crisis, mortgage-backed securities and other private assets were overwhelmingly considered safe. The financial crisis led to a significant destruction in the overall amount of safe private assets in the US as a lot of these mortgages turned out to be "sub-prime". Further, the sovereign debt crisis destroyed a significant amount of public debt previously considered safe (notably, Spanish, Italian, and Greek debt) contributing to the global shortage of safe assets. See [Caballero, Farhi and Gourinchas \(2017\)](#) and [Gorton \(2017\)](#).

were constrained at their zero lower bound for seven years (between Dec. 2008 and Dec. 2015), while long-term rates, although already at historical lows, maintained a downward slide (Figure 1). Moreover, the large reductions in interest rates across the yield curve come on the back of a considerable expansion in the total amount of public debt held by private investors - an increase of more than \$5 trillion between 2008 and 2013.⁴ With conventional monetary policy exhausted, the Federal Reserve began to purchase large quantities of long-term debt from the secondary market (a policy known as quantitative easing (QE)) in an effort to reduce long-term interest rates. The Fed argued that if it were to reduce the outstanding amount of long-term debt held by private investors, this policy would bid up the price and therefore lower the yield on long-term treasuries.⁵ Although yields did drop, the Fed did not reduce the outstanding amount of long-term debt as shown in Figure 4. Thus, demand for US treasuries has likely also contributed to the reduction in yields.⁶

These developments highlight the potentially expanding influence that demand for US public debt (and safe assets in general) may exercise on interest rates in the United States (and the rest of the world). Low interest rates induced by rising demand for US public debt should thus be of significant concern for the Federal Reserve since low Treasury yields may interfere with the central bank's ability to respond to changing economic conditions. Yet, no research on this topic currently exists as demand for US government debt is not observed. My goal in this paper is thus to take the first step in filling this important gap in the literature. Specifically, I compile data from the auction sales of newly issued US government debt (i.e. the primary market) between January 2000 and December 2017. In every auction in my sample, I observe a maturity specific measure (called the bid-to-cover ratio) the Treasury typically uses to measure demand for the particular security sold at each auction. I show that this ratio is a good demand proxy for debt with maturity of five years

⁴In terms of real output, between these years privately held debt increased from 30% to 60% of real GDP. See Figure 3. That increase is unprecedented in modern US history. One would have to go as far back as World War II in order to observe an increase of similar scale.

⁵This mechanism is known as portfolio rebalancing and is the most popular theory that explains how QE affects yields.

⁶Noeth and Sengupta (2010) and Andolfatto and Spewak (2018) make the same argument.

or less.⁷ The financial crisis, which occurred about halfway through my sample, serves as a natural experiment to estimate changes in demand induced by the financial crisis shock. Moreover, the data also allows me to test for changes in the evolution of new debt issued by the Treasury throughout the duration of the Fed’s QE programs. I make two major findings that may have significant implications for monetary policy.

First, I find strong evidence for a large shift in private investors’ demand toward debt of shorter duration. This shift appears to be a direct consequence of the financial crisis and is highly persistent. It peaked around 2012, and only appears to have died down by the end of my sample period in Dec. 2017 - nine years after the financial crisis began. I offer a couple of potential reasons for this phenomenon. First, financial crises typically increase demand for liquid assets and shorter-duration Treasuries may be more liquid compared to longer-duration ones. Further, short-term Treasury yields are significantly less volatile than long-term yields. With short-term rates at zero and the Federal Reserve engaging in QE, two unprecedented events that may have raised economic uncertainty, investors may have increased their preference for Treasuries with stable (even if lower) returns. Ultimately, further research is necessary to pin down the exact reasons for this development as it may have important implications for policymakers.

Second, I find that the Treasury has issued more debt during the Fed’s QE1 and QE3 programs. Further, I argue that this result may be an endogenous response by the Treasury to an expectation that the Federal Reserve’s unconventional programs would reduce its long-term borrowing costs. Thus, the Treasury may have partially counteracted the effectiveness of these policies to reduce yields. These results highlight the conflicting objectives of the two institutions when short-term rates are constrained by zero - an issue first discussed by [Greenwood et al. \(2014\)](#).

⁷To the best of my knowledge, no paper to date has employed this data for macroeconomic or any non-auction specific purpose. The only paper that I know of that has used bid-to-cover, to some extent, is [Gorodnichenko and Walker \(2018\)](#). In their paper, the authors use the timing of QE announcements to estimate changes in futures prices of Treasury securities and thus evaluate the effectiveness of QE in reducing yields. In their analysis, they construct demand shocks which they show are highly correlated to the bid-to-cover ratio thus defending their claim that they represent demand.

These findings have several important policy implications. First, the observed shift toward treasuries of shorter duration, if coupled with expansionary monetary policy, may increase the likelihood that future downturns will be accompanied with very low or even zero short-term interest rates. Second, based on this finding and the maturity distribution of debt held by private investors, I argue that private demand has likely played a much more significant role relative to QE in reducing yields of medium duration (between one and five years). Similarly, I argue that the Fed is likely responsible for most of the drop in yields for treasuries of long duration (seven years or more). Third, these findings show that the objectives of the Treasury and the Federal Reserve may not necessarily align when the Fed decides to intervene - on a large scale - in the market for long-term government debt. Policy makers across the two institutions, at the very least, should be aware of this possibility, as it may become an issue under a hypothetical future large-scale intervention by the Fed in the market for long-term US treasuries. The findings in this paper also have important implications for DSGE models. In order to discuss these implications, I build a small stylized model in order to describe several new features and frictions that future DSGE models could incorporate in order to study some of the issues discussed in this paper.

Related Literature.—This paper builds on ideas from three different strands of literature. First, the paper is related to a growing list of research which provides evidence that investors are willing to pay a premium for the convenience benefits offered by US treasuries ([Krishnamurty and Vissing-Jorgensen \(2012\)](#), [Nagel \(2016\)](#) and [Del Negro et al. \(2017\)](#)). The results in my paper indicate that these convenience benefits may also be present within the market for US treasuries itself. Specifically, investors may be willing to pay a premium for holding shorter duration treasuries relative to holding longer duration debt. Second, this paper contributes to a small, but important literature which highlights the conflicting objectives of the Treasury and the Federal Reserve when the Fed engages in large-scale purchases of longer duration government debt ([Greenwood et al. \(2014\)](#)). Specifically, I show that the Treasury may have responded endogenously to the Fed’s QE programs, thus partially coun-

teracting the effectiveness of QE in lowering yields. Finally, this paper is broadly related to and borrows ideas from the growing literature on safe asset shortages and their role during the financial crisis ([Gorton \(2017\)](#), [Caballero, Farhi and Gourinchas \(2017\)](#), [Caballero and Krishnamurty \(2009\)](#) and [Caballero and Farhi \(2018\)](#) among others).

The rest of the paper is organized as follows. In section 2, I describe the institutional setting characterizing US Treasury auctions and provide more detail on the construction of the bid-to-cover measure. In section 3, I describe the data and provide some stylized evidence related to the market for Treasury debt, which I use to motivate the empirical framework. In section 4, I introduce the empirical framework and report all results. In section 5, I discuss the implications of my findings for policymakers and for researchers using DSGE models. Section 6 concludes.

2 Overview of US Treasury Auctions

The Treasury sells new debt securities through an auction process open to the public.⁸ Auctions are maturity specific and vary in frequency. Treasury bills with maturity of one, three, and six months are issued on a weekly basis. Securities with maturity greater than one year are issued at most once a month. The auction process begins with an announcement in which the Treasury discloses the amount of new debt it plans to sell, the auction date (typically a few days after the announcement) as well as any other pertinent information it deems important for bidders to know. After the announcement is made, bidders are allowed to place bids. The bidders themselves are classified into direct and indirect. Direct bidders are allowed to place bids directly with the Treasury or the Federal Reserve whereas indirect bidders must place bids through an intermediary. Indirect bidders are typically foreign buyers and certain types of institutional investors. The vast majority of newly issued securities are sold to a type of direct bidder referred to as a primary dealer.⁹ These dealers are typically

⁸Throughout the rest of the paper the terms government debt, debt securities, treasury debt, treasury securities or treasuries are used interchangeably to refer to US government debt

⁹[Fleming \(2007\)](#) estimates that around 70% of the newly auctioned securities are sold to primary dealers.

medium to large financial institutions and account for the bulk of all new purchases.¹⁰ The Treasury stops accepting bids at a prespecified time on the day of the auction. After the auction closes, the Treasury releases a report on its web page summarizing the results from that auction. One such release is displayed in Figure 5.

Two types of bids can be placed: competitive and non-competitive. A bidder who submits a non-competitive bid agrees to accept the yield determined through the competitive bidding process. Non-competitive bids are limited to around \$5 million per bidder and typically account for a tiny fraction of the total amount of bids placed. A competitive bidder submits a bid comprising of a desired yield and purchase amount. All bids are confidential and each bidder can place multiple bids. Treasury auctions are conducted under uniform or single-price auction rules. That is, after bidding closes, the Treasury arranges all bids in ascending order of their yield. The Treasury accepts all bids until it reaches its target sale amount. The yield associated with the last accepted bid (known as the shut-out yield and referred to as the high yield by the Treasury) is the return that each bidder whose bid was accepted will receive on their purchase amount.¹¹ To assess the demand for the security offered during each auction, the Treasury calculates what it refers to as the bid-to-cover ratio. This ratio is constructed by summing across the value of all bids placed across all types of bidders (excluding the Fed's SOMA account) and dividing it by the total value of the security sold at that auction. As such, it provides a rough estimate for the demand of a security during an auction and thus serves as a useful proxy for the maturity specific demand for government debt.¹²

¹⁰The number of primary dealers typically varies between 20 and 30 institutions. The current list of primary dealers can be found on the Federal Reserve Bank of New York's web page (<https://www.newyorkfed.org/markets/primarydealers>)

¹¹To give a specific example, assume the Treasury wants to sell \$100 worth of debt. Assume there are two bidders: A and B. Bidder A offers to accept a return of 2 percent and wants to buy \$60 worth of treasuries. Bidder B desires a return of 3 percent and wants to buy \$50 worth of treasuries. In this scenario, the shut-out yield is 3 percent, since that would be the highest accepted bid. In that case, bidder A who bid a lower amount gets his bid accepted in full. He gets 3 percent return on \$60. Bidder two, would get \$40 at 3 percent. Since, B offered more than what the Treasury wanted to sell, B gets to receive only the amount of her bid that covers the Treasury's planned sale amount.

¹²Note that in calculating this ratio, only the total amount tendered (offered) across individual bids matters. Thus, the bid-to-cover ratio is only a proxy for demand. To assess the true demand for the security

3 Data and Stylized Facts

3.1 Data

The Treasury announces the results of each auction it conducts on TreasuryDirect.gov. I use a web scraper to compile data on results announcements (as in Figure 5) for all auctions conducted by the Treasury between January, 2000 and December, 2017 for the following coupon-bearing securities: bills (with maturity of 1 month, 3 months, 6 months, and 1 year), notes (with maturity of 2 years, 3 years, 5 years, 7 years, and 10 years) and bonds (with maturity of 30 years).¹³ As in [Gorodnichenko and Walker \(2018\)](#), I exclude TIPS (Treasury Inflation Protected Securities) and CMBs (cash management bills) since they have different yield characteristics. Auctions for all securities (with the exception of t-bills with maturity of 6 months or less which are conducted weekly) are conducted at most once a month. Hence, the data are at a monthly frequency with weekly auctions averaged over each month. Table 1 provides detailed summary statistics for each individual maturity issued by the Treasury. The financial crisis reached its peak in September, 2008. Around the same time, the Treasury also increased significantly the amount of new debt it issues. For that reason, the statistics in Table 1 are divided in two periods with September, 2008 chosen as the cut-off point. All other data used in the paper are described in the appendix.

sold during each auction, one would also need to know the exact amount and desired return associated with each individual bid, which is not released by the Treasury.

¹³The Treasury provides information on the results for all auctions starting on July 27th, 1998. However, in November 1998, the Treasury switched to a uniform-price auction from the previously used multiple-price auction mechanism to determine yields for successful bidders. Under this auction mechanism each bidder would receive the yield that they bid. Hence, there was a distribution of awarded yields rather than a single yield. Hence, the bid-to-cover ratio cannot be directly compared between the two systems. Because, the bid-to-cover ratio may be biased in the period after the switch, I allow for the distinct possibility that bidders may have needed time to adjust to the new bidding system and learn how to optimally place bids. For that reason, I exclude all auction data from 1998 and 1999.

3.2 Stylized Facts

In this section, I summarize in a formal and detailed fashion the factual evidence discussed in the introduction since it motivates the empirical analysis in the paper.

Fact 1: *Treasury yields dropped significantly following the financial crisis.* Figure 1 shows that interest rates across the yield curve dropped by (at least) 100 basis points despite a large increase in the outstanding amount of debt held by private investors. Most of the literature that has quantified the impact of QE on treasury yields, ascribe only a fraction of these declines to the Fed’s unconventional policy intervention.¹⁴ As others have already pointed out, demand from private investors also likely played a significant role in reducing yields.¹⁵

Fact 2: *The real outstanding amount of government debt held by private investors increased significantly in the period after the financial crisis of 2008.*¹⁶ Figure 3 plots the real outstanding amount of public debt held by private investors as a share of real GDP. Between 2008 and 2012, privately held debt increased from roughly 30% of real output to 60%. Figure 3 also separates total outstanding debt securities into domestic and foreign private investors. This break down shows that foreign investors have been increasing their share of US Treasury holdings.

Fact 3: *Debt held by private investors also increased across all maturity classes.* Figure 6 (Top) plots the monthly outstanding amount of privately held debt by maturity class. The figure shows that debt held by private investors increased across all maturity classes, despite the Fed purchasing a significant amount of longer duration debt as illustrated in Figure 6 (Bottom). According to the portfolio-balance theory, the Fed’s QE works by reducing the

¹⁴Some of the more influential papers in this literature include: [Gagnon et al. \(2011\)](#), [Krishnamurty and Vissing-Jorgensen \(2011\)](#), [Bauer and Rudebusch \(2014\)](#), [Weale and Wieladek \(2016\)](#), and [Gorodnichenko and Walker \(2018\)](#). Although estimates vary significantly, none of these papers can attribute all of the large declines in yields to QE.

¹⁵See [Noeth and Sengupta \(2010\)](#) and [Andolfatto and Spewak \(2018\)](#).

¹⁶Debt held by private investors is defined as total outstanding public debt (minus) debt held by US government accounts (minus) debt held by The Federal Reserve.

outstanding market value of debt held by private investors.¹⁷ However, as Figure 6 shows, the Fed was not able to reducing the outstanding amount of debt held by private investors.¹⁸

Fact 4: *Demand for newly issued treasuries by private investors increased significantly following the financial crisis.* Figure 7 plots newly issued debt for short, medium, and long maturities (top) and the bid-to-cover ratio for the respective maturity categories (bottom). The observed increase in bid-to-cover point to a large increase in demand for newly issued treasuries. The observed increase in demand has likely maintained downward pressure on yields despite the large increase in debt held by private investors. Further, according to the figure, this increase appears to be more substantial for maturities of shorter duration.

4 Empirical Analysis and Results

4.1 Bid-to-Cover as a Proxy for Demand

Simple economic theory states that an increase in the demand for an asset bids up its price. Since prices and yields for treasury bonds are inversely related, it follows that if the bid-to-cover ratio were to proxy for demand, it must be negatively correlated with treasury yields. To what extent therefore is the bid-to-cover negatively correlated with interest rates? To provide an answer, I regress the maturity specific bid-to-cover on the auction determined bidder return (i.e. the high yield). Table 2 and Table 3 display the results. In general, there is a significant and negative relationship between the bid-to-cover and the equilibrium auction yield for short and medium term maturities. That relationship however breaks down

¹⁷A proponent of this theory was the chairman of the Fed at the time, Ben Bernanke. In a 2010 address he said: “I see the evidence as most favorable to the view that such purchases work primarily through the so-called portfolio balance channel, which holds that once short-term interest rates have reached zero, the Federal Reserve’s purchases of longer-term securities affect financial conditions by changing the quantity and mix of financial assets held by the public. Specifically, the Fed’s strategy relies on the presumption that different financial assets are not perfect substitutes in investor’s portfolios, so that changes in the net supply of an asset available to investors affect its yield and those of broadly similar assets”.

¹⁸A more accurate statement consistent with the data would be the following: The Fed reduced the growth rate in the outstanding amount of debt held by private investors.

for 7, 10, and 30 year issues.¹⁹ Bidding for long-term debt is likely more strategic in nature and the bid-to-cover measure cannot capture this auction specific strategic behavior. Thus, bid-to-cover is likely not a good demand proxy for these maturities.²⁰ For that reason, I restrict the remaining analysis to debt with maturity of five years or less.²¹

Further, the market for newly issued debt (or the primary market) is typically much smaller than the secondary market which involves trade of all outstanding treasury securities. Although bid-to-cover may proxy for demand across debt with maturity of five years or less in the primary market, it may not necessarily be a good measure for demand in the secondary market, and by extension, overall treasury demand. Note that the auction specific yield is a single rate determined during each auction. On the other hand, outstanding debt securities in the secondary market can be traded at any point of time during daily business hours and thus secondary yields are evolving on a daily basis. In order to determine how similar primary and secondary market yields are, Figure 8 plots the correlation between the high yield (auction determined equilibrium bidder return) and the secondary market yield for the main maturities of interest. According to the plot, these two rates are highly correlated and there do not appear to be any significant outliers. Therefore, I conclude that demand across the two markets is highly correlated and thus argue that any maturity specific behavior observed in the primary market is likely to apply to the whole market for US debt.²²

4.1.1 Bid-to-Cover and Interest Rate Changes: A Caveat

In my analysis, I cannot make any specific claim about the precise impact that the bid-to-cover may have had on interest rates. The bid-to-cover is only a proxy for the true unobserved

¹⁹These regressions are only meant to describe the correlation between bid-to-cover and the auction determined bidder return. This relationship is clearly endogenous and by no means can these tables be interpreted to imply any causality.

²⁰Even if that was not the case, however, the lack of auction data in the period before the financial crisis would render any empirical analysis meaningless.

²¹I also have to drop one and three year maturities from the analysis, due to lack data in the pre-crisis period.

²²Bidders in Treasury auctions have information about the secondary market price and thus place bids in the vicinity of current (secondary market) rates. In that sense, the high correlation between the two yields is to be expected.

level of demand for newly issued treasury debt. In order to make any claim about interest rates one would need information on the desired yield and purchase amount of each individual bid and the exact time each bid has been placed. This information, however, is confidential and is not released to the public. Hence, I cannot attribute any observed increase in the bid-to-cover to any reduction in interest rates.²³

4.2 Demand Across Individual Maturities: A Difference-in-Differences Approach

The observed increase in bid-to-cover in late 2008 is not surprising. Investors typically increase their demand for safe and liquid assets, such as US treasuries, as they navigate a market environment characterized by a significant increase in risk and uncertainty. Further, the nature of the financial meltdown in 2008 led to the destruction of a large amount of private financial assets previously considered safe. Yet, attributing this rise in bid-to-cover to a specific factor would be a challenging task.²⁴ Notice, however, that the observed increase in bid-to-cover displayed in Figure 7 is different across maturities. In particular, the increase in demand for shorter duration treasuries is greater than that of longer duration treasuries in the period after the financial crisis. On the other hand, there does not appear to be a large difference in the bid-to-cover ratio across maturities.²⁵ Thus, one could argue that the financial crisis shock may have generated a shift in investors' preference toward treasuries of

²³One can roughly quantify the effect on yields using Table 3, however by no means can these numbers be used to imply any causality.

²⁴To do so, one would have to account for all aggregate macroeconomic conditions that may affect demand for US debt. Further, since the financial crisis was a global event and foreign investors are a large buyer of US debt, one would also have to control for a whole array of foreign factors that may affect demand for treasuries from abroad. Thus, attempting to explain the increase in bid-to-cover opens the door to a whole array of potential endogeneity concerns.

²⁵Note that this does not imply that interest rates across different duration treasuries would be the same. It only means that demand across shorter and longer duration treasuries (as measured by bid-to-cover) is similar. However, when investors bid for a longer duration security, they would still bid a higher return (in line with the return from the secondary market) in order to be compensated for the extra risk (inflation risk, duration risk etc.).

shorter maturity.²⁶

To test this hypothesis, I divide my sample in two periods: a pre-crisis (January, 2000 - August 2008) and a crisis/post-crisis period (September, 2008 - December, 2017).²⁷ Then, I estimate a generalized OLS difference-in-difference (DID) regression and test whether the difference in bid-to-cover between shorter and longer maturities (first difference) is larger in the post-financial crisis period relative to the pre-crisis period (second difference). Specifically:

$$\begin{aligned} BC_{st} = \alpha + \theta \times (short-term_s) \times (post-crisis_t) + \lambda \times (short-term_s) \\ + \delta \times (post-crisis_t) + \beta \times X_{st} + yearFE_t + \epsilon_{st} \quad (1) \end{aligned}$$

where the dependent variable BC_{st} is the bid-to-cover ratio at time t for a grouping s between any two maturities i and j . I define the treatment maturity as the maturity with shorter duration in any grouping s . That is, for any $s = (i, j)$, I define the short-term (treated maturity) as $\min(i, j)$. Hence, in (1), $short-term_s$ is a dummy indicator equal to 1 for the treated maturity.²⁸ Similarly, $post-crisis_t$ is a dummy indicator that turns 1 after September, 2008. The coefficient on the interaction term in (1) is the DID estimator. Finally, X_{st} denotes yield on high quality corporate bonds which I use to control for the maturity specific opportunity cost of treasuries.

The specification in (1) will estimate the average difference between any two maturities i and j in the post-crisis period relative to the pre-crisis period. It will not, however, offer insight into when the shift in demand (if any) actually occurred and how persistent that

²⁶If the analysis is focused in explaining the difference across maturities, any endogeneity concerns shift toward maturity specific factors rather than aggregate macroeconomic conditions.

²⁷I choose September, 2008 as the cutoff point since September 15th, 2008 is widely cited as the date when the US averted a complete meltdown of the financial system. Financial stress and market risk were at their peak in that month.

²⁸For instance, estimating (1) for $s = (3 \text{ Months}, 6 \text{ Months})$ means that in this case the 6 Month maturity is defined as the long-term and the 3 Month maturity is the short-term. Hence, in (1) short-term is an indicator equal to 1 if maturity is 3 months

change may have been. For that reason, I conduct the following event study:

$$BC_{smy} = \alpha + \sum_{my=Jan.2000}^{Dec.2017} (\theta_{my} 1\{my = t\} \times short-term_s) + \beta \times X_{smy} + yearFE_y + \epsilon_{smy} \quad (2)$$

In (2), I have explicitly divided time t into a month m and a year y . The second term in (2) is the difference-in-difference estimator between any two maturities i and j for every month throughout the sample period except one. I omit August, 2008 and therefore all θ_{my} estimates are relative to that period.

4.2.1 Results

Table 4 reports results from estimating differences in bid-to-cover between short-term (maturity ≤ 1 year) and medium-term (2, 3, and 5 year) Treasuries using the regression specified in equation (1). The bid-to-cover ratio for these maturity classes is constructed by adding all bids and all asks (debt sold) across individual maturities in each maturity class.²⁹ The interaction term in column (1) is the difference-in-difference estimator and main variable of interest. This estimate is 0.889 and is highly significant. This means that in the post financial crisis period the bid-to-cover ratio for short-term debt is on average 0.889 higher compared to the bid-to-cover ratio for medium term debt relative to their difference in the period before the financial crisis. In order to understand the magnitude of this number, it is important to understand the behavior across these two groups in the two periods of interest. From Table 4, one could recover the pre and post-crisis bid-to-cover for short and medium duration debt. The bid-to-cover for medium duration debt in the pre-crisis period was 2.28, while in the post-crisis period it was 2.95. On the other hand, the bid-to-cover for short duration debt was 2.46 in the pre-crisis period and 4.02 in the post-crisis period.³⁰

²⁹The purpose of this aggregation across maturities is to generalize the results.

³⁰These numbers are derived from the coefficients in Table 4. Using the notation in equation (1), the bid-to-cover for medium-duration debt (the control group) in the pre-crisis period is given by the intercept α . In the post crisis period that estimate is: $\alpha + \delta$. For short duration-debt, the treated maturity, the pre-crisis estimate is given by: $\alpha + \lambda$. Finally, bid-to-cover for short-term debt in the post-crisis period (4.02) is defined as: $\alpha + \delta + \lambda + \theta$.

Stated otherwise, demand (as measured by the change in bid-to-cover) for medium-term debt increased by roughly 30% in the post-crisis period. On the other hand, demand for short-term debt increased by about 70%. These estimates indicate that the shift in demand toward shorter duration Treasuries was of significant magnitude.³¹ In column (2) of Table 4, I also include year fixed effects in order to control for any unobserved heterogeneity within years. Differences across maturities may be due to maturity specific differences in opportunity cost. To account for this possibility, in columns (3) and (4), I control for the yield on high quality corporate bonds (HQMCB). As one would expect, the relationship is negative, but insignificant.

In Table 5, I repeat this experiment for 3 month and 6 month t-bills. Perhaps not surprisingly, there is no significant difference in the bid-to-cover ratio in the post relative to pre-crisis period between these maturities. Investors are indifferent between holding three or six month treasuries as a difference in duration of three months is likely not large enough to reveal a change in preferences. In Table 6 I estimate the relative difference between 1 month and 3 month maturities. According to these results, demand for debt with duration of 1 month has grown at a slightly slower pace relative to demand for debt with duration of 3 months and these results are significant. This estimate is somewhat surprising as one would expect, at the very least, an insignificant difference in demand. I attribute this result to auction specific factors as bid-to-cover for 1 month maturity is highly volatile and characterized with huge spikes in demand. Further, the difference in return between debt with duration of 1 month, 3 months and 6 month maturity has hardly exceeded more than 5 basis points throughout the duration of the zero lower bound period. Thus, it is possible that this result may be due to auction specific factors. Did demand grow at a faster pace across the longer duration treasuries in my sample? To answer this question, in Table 7, I estimate the relative difference between 2-year and 5-year notes. The bid-to-cover ratio for 2 year notes is roughly 0.6 higher than the one for 5-year notes in the post-crisis period relative to

³¹Demand also increased across all individual maturities used in the analysis without exceptions.

the pre-crisis period. Therefore, the observed increase in demand for shorter duration assets is also present across longer maturities.

I generalize these findings by building a continuous measure of maturity employing the same empirical strategy as [Garicano and Steinwender \(2016\)](#).³² Specifically, I define each maturity as $\frac{1}{duration}$, where duration is defined in months. For instance, a 3 month maturity is therefore defined as $\frac{1}{3}$, a two year maturity as $\frac{1}{24}$ and so on. Therefore, a maturity with shorter duration is associated with a higher value. In my measure, I include maturities of 3 months, 6 months, 24 months and 60 months. Since there are multiple maturity categories, in this specification, I also control for maturity specific fixed effects. These findings are summarized in Table 8. The highly statistically significant coefficient on the interaction term and its magnitude indicate that demand for maturities of shorter duration has increased more than demand for longer duration maturities following the financial crisis. Once maturity fixed effects are included, this effect is slightly diminished, but remains highly statistically significant.

Note that these results are average estimates across two explicitly defined time periods. Therefore, they do not provide information on the exact time period this effect began or how persistent it has been. To account for this, I estimate (2) across the same maturity groups as in (1) and plot the coefficients in Tables 9, 10, 11, and 12. In each table, a dot plots the estimated coefficient for month m in year y while the area represents the 95% confidence interval associated with each estimate. Each coefficient is the estimated difference in bid-to-cover between the relevant maturities relative to their difference in August, 2008 (the omitted and therefore reference period). The solid line indicates the post-crisis period cut-off of September, 2008. The increase in demand for treasuries of shorter duration does appear to have occurred around late 2008. Moreover, this effect is persistent and has peaked around 2012, before starting to decline. Table 12 reports results from the continuous measure and

³²They study the cost of credit shocks by comparing reductions between long-term and short-term investments. As in my estimation, they employ a DID strategy that estimates relative changes between short and long investment before and after the financial crisis.

thus generalizes all other results in a single specification (at the expense of higher standard errors). The strong demand for shorter duration treasuries has peaked around 2012 and appears to have completely died down by the end of the sample period.

In general, these results indicate that the financial crisis generated a broad shift in demand toward treasuries of shorter duration. Further, this effect is very pronounced and highly persistent. Although, government debt is typically considered risk-free and highly liquid, there may be differences in safety and liquidity (real or perceived) across individual maturities. If shorter duration debt is typically easier (and thus faster) to sell on the secondary market, then it would be more liquid than longer duration debt. Similarly, investors may not perceive a 3-month t-bill as equally safe as a 5 year t-note. Thus, part of this shift in demand toward shorter duration treasuries may be explained to a rise in the premia investors are willing to pay these convenience benefits of shorter duration treasuries. If that were the case, these results would support the existence of a convenience premia as described by [Krishnamurty and Vissing-Jorgensen \(2012\)](#) within the market for US treasuries. Further, longer duration treasuries pay higher returns since they are exposed to higher inflation risk. If investors expected that QE may increase inflation in the medium term, they would prefer to hold shorter duration treasuries since inflation would reduce the real return on treasuries of longer duration.³³ Moreover, due to overall duration risk, yields on longer duration treasuries are typically much more volatile. With short-term rates at zero and central banks across the developed world engaging in various forms of unconventional monetary policies, the global economy was in uncharted territory. With future expectations clouded by uncertainty, investors may have been willing to trade off higher expected returns for lower return volatility.³⁴ Although I provided some potential reasons for this shift toward treasuries of shorter duration, future research would need to address the precise factors for

³³At the time, QE was widely thought that it may generate a lot of inflation since the Fed was essentially flooding banks with reserves. These fears did not materialize, however, since commercial banks froze their extension of credit despite the large increase in the volume of their excess reserves.

³⁴US Treasuries are commonly used to decrease the overall volatility and increase the overall safety of financial portfolios. That may also explain why demand for shorter duration treasuries has been higher.

this phenomenon since it may have broad implications for monetary policy.

4.3 Newly Issued Debt During the Fed’s QE Programs

As [Greenwood and Hanson \(2015\)](#) argue, optimal management of the maturity of government debt involves a trade-off. On one hand, the fiscal authority would like to tilt its issuance towards short-term debt in order to minimize its financing costs. On the other hand, short-term financing exposes the government to rollover risk. Hence, as its debt burden grows, the fiscal authority would choose to optimally extend the maturity of its outstanding obligations in order to reduce rollover risk. According to [Figure 9](#), the Treasury has indeed been increasing the duration of its debt. The average maturity of the government’s outstanding obligations has been increasing since the beginning of the financial crisis despite the Fed’s QE programs implemented between 2009 and 2014.

By issuing more debt of longer duration, the Treasury reduced its rollover risk, but was forced to incur higher interest expenses on servicing its outstanding obligations. However, if the Treasury expected that the Fed, through its QE policies, would reduce long-term interest rates (the Fed’s explicitly stated purpose for conducting these programs), the Treasury may have decided to issue more debt of medium and long duration (over and above what it may have already planned to issue prior to the QE announcements) throughout the duration of each of the Fed’s QE programs.

To test this hypothesis, I estimate:

$$\ln(D_t^j) = \alpha + \sum_{L=1}^4 (\gamma_L \times X_{t-L}) + \beta_1 \times QE1_t + \beta_2 \times QE2_t + \beta_3 \times QE3_t + yearFE_t + \epsilon_t \quad (3)$$

where $\ln(D_t^j)$ is the logged (inflation adjusted) newly issued debt D at time t for maturity j . QE1, QE2, and QE3 are dummy indicators equal to 1 throughout the duration of each QE program and 0 otherwise (see [Figure 2](#) for exact dates of each program). I also include year fixed effects to remove any unobserved heterogeneity within years. Further, since the

Treasury expanded the maturity of its outstanding obligations as its overall debt burden grew (Figure 9), I also control for the outstanding debt-to-GDP ratio denoted by X_t in (3). If the overall debt-to-GDP ratio is high, the Treasury may issue longer duration debt in future auctions to reduce rollover risk. For that reason, I control for up to 4 lags of the outstanding debt-to-GDP ratio.³⁵ Finally, as Figure 7 indicates, the Treasury significantly expanded its issuance of new debt around the peak of the financial crisis in late 2008. That expansion appears to have continued until the end of 2017. Hence, I drop all pre-crisis data and thus estimate (3) on the sub-sample of September, 2008 - December 2017.

4.3.1 Results

Did the Treasury issue more debt during each of the Fed’s QE programs in anticipation of lower borrowing costs? Table 13 provides an answer to this question. In Table 12, I pool individual maturities into short term (maturity of 1 year or less) , medium-term (2, 3 and 5 year) and long-term (7, 10 and 30 year) duration. Each coefficient estimates the relative change (in percent) in the average monthly issuance of debt during each QE program relative to periods with no Fed intervention. I focus my discussion on the columns where year fixed effects are included as this is a more robust specification. According to these results, the Treasury issued (on average) 14% more debt of medium maturity during QE1 and 7% more during QE3. In terms of amount, these numbers roughly translate to about \$16 billion and \$6 billion, respectively. Hence, throughout the duration of QE1 and QE3, the Treasury issued roughly \$192 billion and \$132 billion more medium duration treasuries respectively relative to its average issuance of medium duration debt in the post crisis period.³⁶ During QE1, the Fed purchased about \$300 billion in government debt, thus the Treasury may have (possibly endogenously) counteracted part of the expected effect on yields from QE. On the other hand, issuance of long duration assets during each QE program does not appear to

³⁵I have also experimented with various other lag structures as a further robustness check. These results are not sensitive to the lag structure.

³⁶QE1 lasted 12 months while QE3 lasted 22 months.

differ significantly from its post period average. This result is to be expected. The Treasury is fully aware that the Fed’s intervention in the market for long-term government debt is a medium-term policy. Thus, the Treasury would not necessarily issue long-term debt only due to an expectation that the costs associated with servicing that debt may be lower in the beginning, but not necessarily be affected throughout the remaining term-to-maturity of each long-term security. In addition, short-term debt appears to be lower on average across each QE program, but insignificant. This result is anticipated, as QE is unlikely to have any effect on short-term interest rates already constrained by zero. Further, past values of the debt-to-GDP ratio do not seem to affect these estimates in any meaningful way and all four lags are insignificant.³⁷ In Table 14 and Table 15, I break down newly issued debt into individual maturities. These results mostly confirm the findings from Table 12. Most of the increase in newly issued debt during QE1 and QE3 has been concentrated in lower duration maturities.³⁸

5 Implications

5.1 For Monetary and Fiscal Policy

The results in this paper highlight some important developments that may have broad implications for the conduct of future monetary and fiscal policy. First, according to my findings the sharp increase in demand for treasury maturities of shorter duration appears to be a direct result of the financial crisis. If this “flight” toward shorter-duration treasuries is a recurring theme in future financial panics, once coupled with expansionary monetary policy, it may increase the likelihood that future downturns would be accompanied by very low or even zero short-term rates. Thus, the Fed’s ability to respond to future busts with conven-

³⁷As a further robustness check, I have experimented with various other lag structures, but these results are not affected.

³⁸These results are nevertheless reduced form estimates and it is possible that there may have been other factors that have contributed to the increase in debt (apart from QE), which these regression estimates do not capture. Thus, these estimates might be upwardly biased.

tional measures might be diminished, a possibility which should be of significant concern for the Federal Reserve.³⁹

Second, as illustrated in Figure 4 (bottom), the Fed purchased roughly one trillion dollars in treasuries with duration between one and five years. This amount represents about half of the Fed’s total treasury holdings. Yet, the outstanding amount of debt held by private investors across these maturities expanded by two and a half trillion dollars. It is highly unlikely, therefore, that the Fed has been solely responsible for the reduction in yields across Treasuries of medium duration.⁴⁰ Demand from private investors must have played a significant role in reducing these yields. On the other hand, the fact that bid-to-cover on maturities of 7, 10, and 30 year bonds does not reflect changes in those yields is a signal that demand for these maturities is likely to be smaller than demand for shorter-duration Treasuries.⁴¹ It is much more likely that the Fed has been responsible for a large fraction of the reduction in those yields. This poses the question of whether the Fed made the optimal choice on the distribution of the maturities it purchased. If the private market had the ability to absorb greater supply of medium duration Treasuries, the Fed may have focused more of its purchases toward Treasuries of longer duration possibly improving the overall effectiveness of QE.

Third, the objectives of the Treasury and the Federal Reserve do not necessarily align when the Fed intervenes in the market for long-term government debt. In normal times, the Fed controls short-term rates, while the Treasury determines the market value and maturity of the new debt securities it sells. However, in an environment where the Fed attempts to reduce long-term yields by engaging in QE, the objectives of the two institutions “con-

³⁹In further support of this argument, note that in Figure 10, the Fed has been reducing its holdings of t-bills from 2008 until 2015. In addition, between 2013 and 2015 it held zero debt with maturity less than one year. The Fed was likely aware that demand for t-bills was very strong. Thus, in order to prevent additional downward pressure on the yields for t-bills it likely decided to reduce its demand for them. Note that demand for t-bills was already waning by the time the Fed decided to lift interest rates from zero.

⁴⁰This argument explicitly assumes that the portfolio-balance theory is the main transmission channel of QE. There are other channels through which QE is thought to affect yields and they may have also played a role in reducing yields.

⁴¹The bid-to-cover for these maturities isn’t even correlated with yields.

flict” with each other. If the Treasury anticipates that QE may reduce longer duration yields, it may adjust the amount and maturity of debt it issues thus simultaneously reducing rollover risk and the costs associated with servicing debt of longer-duration. According to my reduced-form estimates, the Treasury may have issued more debt of medium duration during QE1 and QE3 thus partially counteracting the effectiveness of these Fed programs.⁴²

Finally, the period after the financial crisis showed that treasury yields in the United States appear to have become much less responsive to changes in the government’s overall debt burden. Further, despite an extended period of recovery and unemployment at a 50 year low, the US government has no plans for any budget consolidation in the medium term. On the contrary, deficits are projected to grow in the next five years and the debt-to-GDP ratio will continue to increase. To what extent, therefore, could the current behavior of the government be attributed to a growing lack of concern for any major ramifications associated with its growing debt burden? That is an important question that future research would have to address as a large debt burden could become a significant liability in the long-term.

5.2 For DSGE Models⁴³

The issues highlighted in this paper also have important implications for research on the convenience premia of Treasury bonds, unconventional monetary policies, fiscal policy, and the determination of long-term interest rates. In order to clearly illustrate these implications, in the appendix, I build a small stylized model with several distinguishing features motivated by the results presented in the paper. In particular, the model consists of private investors who derive utility from holding short and long-term government bonds, a fiscal authority

⁴²In a situation, where the government is facing a budget deficit, the Treasury has no choice but to issue more debt. That is inevitable and something that the Fed is likely very much aware of when it decides on the scale of its purchases of longer-duration debt. However, the Fed may not necessarily take into account the possibility that the Treasury may react endogenously to its programs and thus issue more debt than the Fed may have anticipated. That is what I mean when I say that "the Treasury may have partially counteracted the effectiveness of these program".

⁴³This section is standalone in the sense that the issues discussed here are not important for the overall message of the paper, but are useful for researchers from a modelling perspective. In order to clearly understand the issues discussed in this section, interested readers should first read through the stylized model described in the appendix.

that issues short and long-term debt, and a central bank that implements quantitative easing (through the purchase of long-term government debt from private investors). The complete model is described in the appendix. Here, I only present the pricing conditions for short-term (eq.4) and long-term debt (eq.5) implied by the model:

$$\hat{R}_t^s = E_t \hat{\pi}_{t+1} + \theta_1 \left(-\hat{\alpha}_t^s + \hat{b}_t^s \right) \quad (4)$$

$$\hat{R}_t^l = E_t \hat{\pi}_{t+1} + \frac{\rho}{R^l} E_t \hat{R}_{t+1}^l + \theta_2 (R^l - \rho) \left(-\hat{\alpha}_t^l + \left(\frac{b^g}{b^h} \hat{b}_t^{g,mv} - \frac{b^c}{b^h} \hat{b}_t^{c,mv} \right) \right) \quad (5)$$

where a variable $\hat{x}_t$ denotes a deviation of that variable from its steady state value x . In (5), $\hat{b}^{g,mv}$ and $\hat{b}^{c,mv}$ respectively denote the market value of long-term debt issued by the government and held by the Federal Reserve.⁴⁴ Thus, the last two terms in (5) together describe the equilibrium amount of long-term debt held by private investors. Similarly, in (4) $\hat{b}^s$ is the equilibrium amount of short-term debt held by private investors. Further, α_t^s and α_t^l are time varying preference parameters one can interpret as shifts in demand for government debt. $E_t \hat{\pi}_{t+1}$ is agents' expectations of inflation next period, while ρ in (5) is the average maturity of the portfolio of long-term debt. Finally, θ_1 and θ_2 govern the magnitude of the deviation of $b^{j,mv}$ and α^j from their steady state. A complete derivation of the above equations is also provided in the appendix.

According to the market segmentation and preferred habitat theories of interest rate determination, assets of different maturities are imperfect substitutes (albeit for slightly different reasons) and thus the expectations theory of the term structure of interest rates does not hold.⁴⁵ Note that the assumption that private investors value short and long-term

⁴⁴Technically, the steady state debt values b^g, b^h and b^l are also in market value terms and should be indexed with mv. However, I suppress the mv index in equation (5) to avoid unnecessarily cluttering the expression.

⁴⁵According to the market segmentation theory, there are unique investor clienteles for bonds of specific maturities. Thus, bonds of individual maturities should be treated as separate markets. Some of the papers that build on this theory are: [Tobin \(1969\)](#), [Andres, Lopez-Salido and Nelson \(2004\)](#), and [Chen, Curdia and Ferrero \(2012\)](#). According to the preferred habitat theory, investors have a unique preference for bonds of different maturities and would only be willing to buy outside of their preferred maturity habitat if they were

bonds differently implies that investors in the model consider the two assets imperfectly substitutable. According to my findings, there is strong evidence to back this assumption. Following the financial crisis, investors appear to express a stronger preference for treasuries of shorter duration. Thus, within the context of the model one can interpret this finding as a shock to the relative preference of $\hat{\alpha}_t^s > 0$.⁴⁶ Moreover, one could interpret this shock as a temporary, but relatively persistent shift in investors' preferred maturity habitat.

The Fed's QE programs have been widely credited with reducing long-term yields, although the real effect from these reductions is still subject to debate. Yet, QE's overall impact on long-term yields may be more nuanced than previously thought. The term $\frac{b^g}{b^h} \hat{b}_t^g - \frac{b^c}{b^h} \hat{b}_t^c$ in (5) describes the equilibrium amount of long-term debt held by private investors. How much long-term debt private investors hold depends on how much debt the government has issued ($\hat{b}_t^g$) and how much of that debt, the central bank has taken off the market ($\hat{b}_t^c$). If total holdings of long-term debt held by private investors increase, other things equal, the model predicts that interest rates would have to increase. Investors would be willing to absorb a greater supply of longer duration debt if they were compensated with a higher return. However, if the Fed were to reduce the outstanding amount of debt held by investors, it would reduce longer yields since the overall supply of debt (which investors value) would decrease. This mechanism is known as portfolio re-balancing and is arguably the most popular theory describing the transmission mechanism of QE.⁴⁷ As evidenced by Figure 4, the outstanding amount of debt held by private investors increased since the Treasury's newly issued debt significantly outpaced the Fed's purchases of treasuries in the secondary market. Thus, according to (5), yields should have increased. As already acknowledged, however, yields dropped (Figure 1) since demand for treasuries exceeded supply. In (5), yields can

compensated with a higher return. Some notable papers in this literature include: [Modigliani and Sutch \(1966\)](#), [Vayanos and Villa \(2009\)](#), and [Greenwood and Vayanos \(2014\)](#)

⁴⁶Alternatively, one could interpret these findings as a simultaneous shock (or shift) to both $\hat{\alpha}_t^s$ and $\hat{\alpha}_t^l$ such that $\hat{\alpha}_t^s > \hat{\alpha}_t^l$

⁴⁷As mentioned previously, the chairman of the Fed was also a proponent of this theory. However, there are also other theories describing various signaling effects on yields induced by QE. Their persistence or overall significance is hard to quantify however.

drop only if investors' overall desire or preference to hold government debt (represented by $\hat{\alpha}_t^l$) exceeds the rise in their supply. Thus, (5) further illustrates the importance of modeling asset pricing frictions when studying the determination of long-term interest rates or monetary/fiscal policies (conventional or otherwise).

Further, models typically only distinguish between short-term debt (one period) and long-term debt (typically modeled as a portfolio of long-term assets). I have made a similar assumption in this model as well. Yet, distinguishing only between short and long-term debt may not be sufficient. As already acknowledged, debt of medium duration (between one and five years) held by private investors increased significantly (despite the Fed taking roughly one trillion dollars of these securities off the market) while yields across these medium duration treasuries dropped significantly. Thus, demand for debt of medium duration may have been much stronger than demand for debt of long duration. Further, the Treasury may have issued more debt of medium duration during QE, in what may be an endogenous response to the Fed's QE programs. Thus, future work may have to explicitly distinguish between debt of medium duration and debt of long-duration, since demand and supply across these two maturity classes may differ significantly.

6 Conclusion

A growing volume of work has argued that interest rates in the United States have been declining due to a shortage of safe assets. The financial crisis of 2008-09 exacerbated this shortage and brought along an extended period of record low interest rates despite a considerable increase in the amount of US public debt held by private investors. This development highlights the growing need to understand the behavior of demand for safe assets such as US treasuries. Yet, demand for US treasuries is unobserved and researchers have been forced to make residual claims about demand based on the overall supply of US government debt and the behavior of yields.

Using US Treasury auction data, however, I recover data on the bid-to-cover ratio, commonly used to measure demand for the particular security sold during an auction. Using maturity specific data on bid-to-cover, I estimate changes in demand across individual maturities in response to the financial crisis of 2008-09. I find that demand for shorter-duration Treasuries is significantly larger compared to longer-duration Treasuries in the period after the financial crisis. This "shift" toward Treasuries of shorter duration may have contributed to short-term yields hitting the zero lower bound. Although I offer several potential explanations for this shift, further research is necessary to pin down the exact reasons behind this development. Further, based on these findings, I argue that this shift toward treasuries of shorter duration likely contributed to an increase in private demand for debt of medium duration thus casting doubt on the overall performance of QE in reducing yields across this maturity class.

I also find that the Treasury issued more debt of medium duration in response to QE1 and QE3. I argue that this outcome is the result of an endogenous response by the Treasury in an effort to reduce its debt servicing costs while simultaneously reducing rollover risk. This decision, therefore, counteracted some of the effectiveness of QE. Thus, this result highlights the conflicting objectives of these two branches of the government when the Fed's goal is to reduce long-term yields.

In addition to policy, these results also have broad implications for macroeconomic research on monetary and fiscal policy, asset pricing, the determination of long-term interest rates and more. Existing DSGE models typically do not incorporate asset pricing frictions across bonds of different maturities. According to my results, however, investors appear to value short and long-term bonds differently. Similarly, models typically do not separate the government into a central bank and a fiscal authority. Yet, based on my findings, the relationship between the two institutions may be more complex than previously thought. In analyzing unconventional policies, future research may have to explicitly separate these two branches of the government. In the appendix, I described a small stylized model which

incorporates these frictions. Developing a proper general equilibrium framework, however, is a task I intend to undertake in the future.

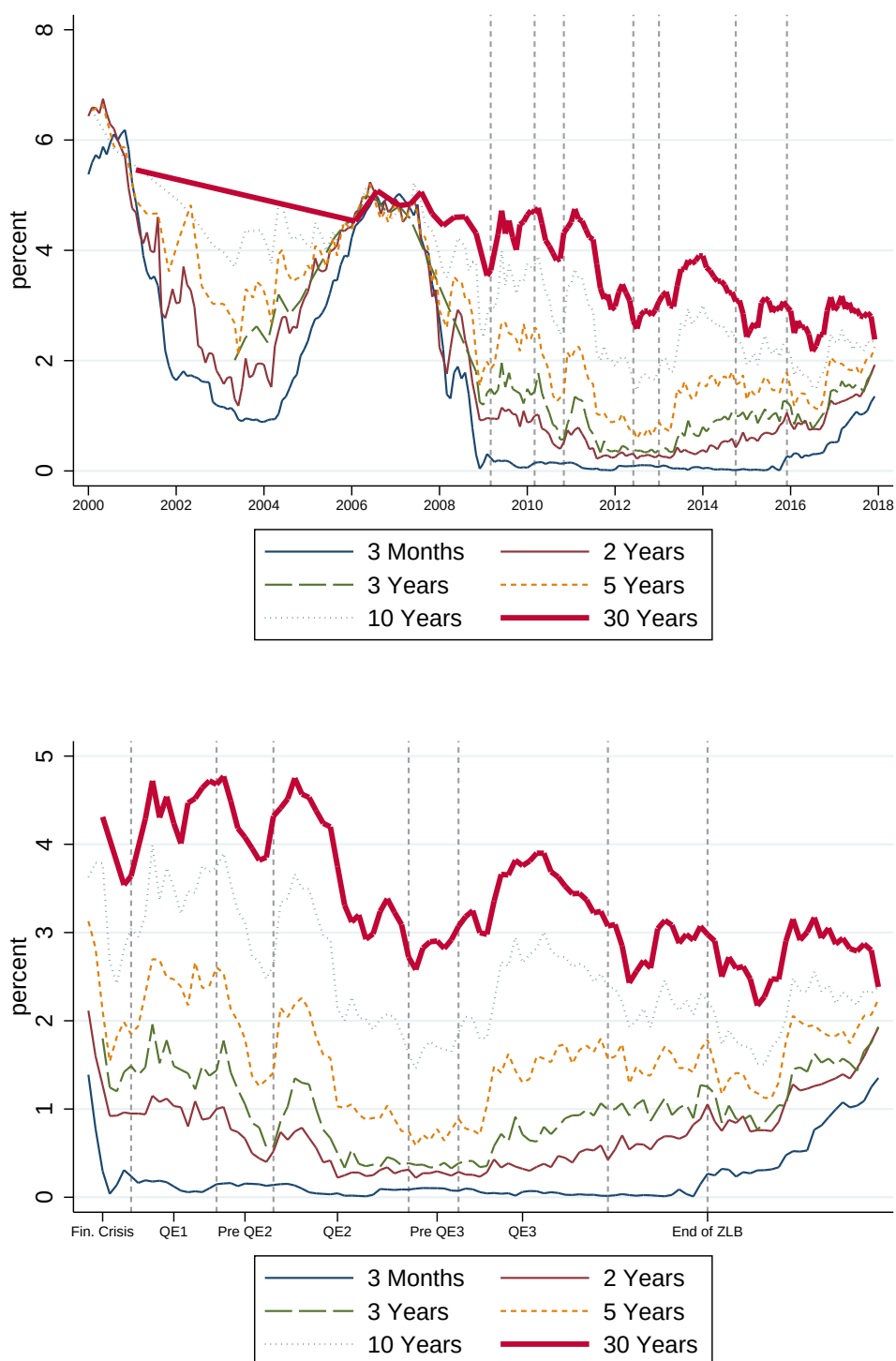
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Figure 1: Interest Rate Yields on Newly Issued Treasury Debt by Maturity: Jan.2000- Dec.2017(Top) and Sep.2008-Dec.2017(Bottom)



NOTES: The Dashed lines on the figures correspond to the dates in Figure 2. The first dashed line in the top figure refers to Sep. 2008 and is the cutoff used to plot the bottom Figure. The US Treasury did not issue 30 year bonds between 2001 and 2006. The straight line on the Top plot is simply connecting missing observations.

Figure 2: Timeline of Events

Timeline

Jan. 2000 - Aug. 2008	Pre-Crisis Period
Sep. 2008 - Feb. 2009	Financial Crisis - Pre-QE1 Period
Mar. 2009	QE1 Initiated: The Fed Announces the Purchase of Up to \$300 Billion of Long-Term Government Bonds
Mar. 2010	QE1 Terminated:
Apr. 2010 - Sep. 2010	Pre-QE2 Period
Nov. 2010	QE2 Initiated: The Fed Announces That It Intends to Purchase \$600 Billion in Long-Term Treasury Securities by the End of the Second Quarter of 2011 (a pace of \$75 Billion a Month).
Jun. 2012	QE2 Terminated: Under the Program, the Fed Purchased \$827 Billion in Treasury Securities
Jul. 2012 - Dec. 2012	Pre-QE3 Period: The Fed's Operation Twist is Still in Progress, but is Terminated in Dec. 2012
Jan. 2013	QE3 Initiated: The Fed Begins to Purchase More Long-Term Treasuries at a Pace of \$45 Billion a Month
Oct. 2014	QE3 Terminated. By the End of QE3 the Fed's Balance Sheet Held More Than 2 Trillion of Treasuries
Nov. 2014 - Dec. 2015	Post QE3 - ZLB End
Jan. 2016 - Dec. 2017	Post ZLB - End of Sample

Figure 3: Outstanding Amount of Debt Held by Private Investors (Adjusted for Inflation) as a Share of Real GDP

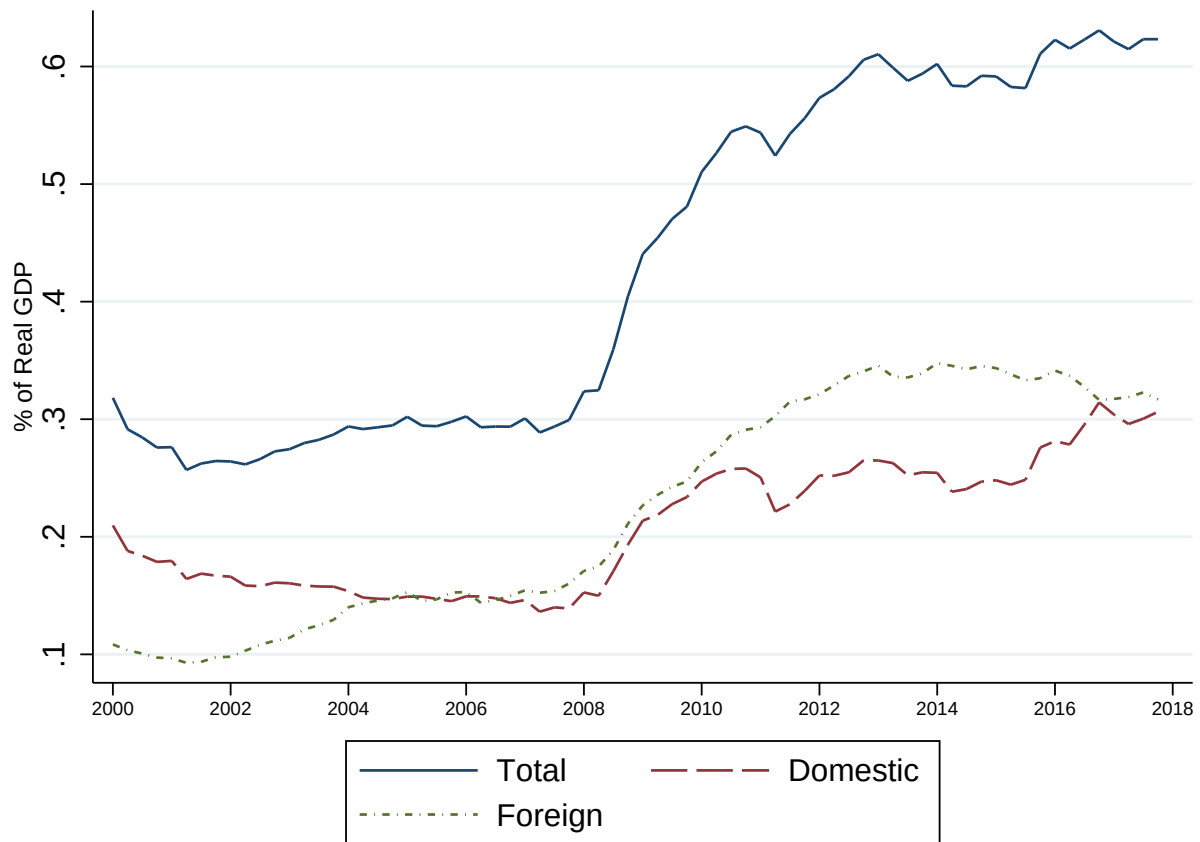
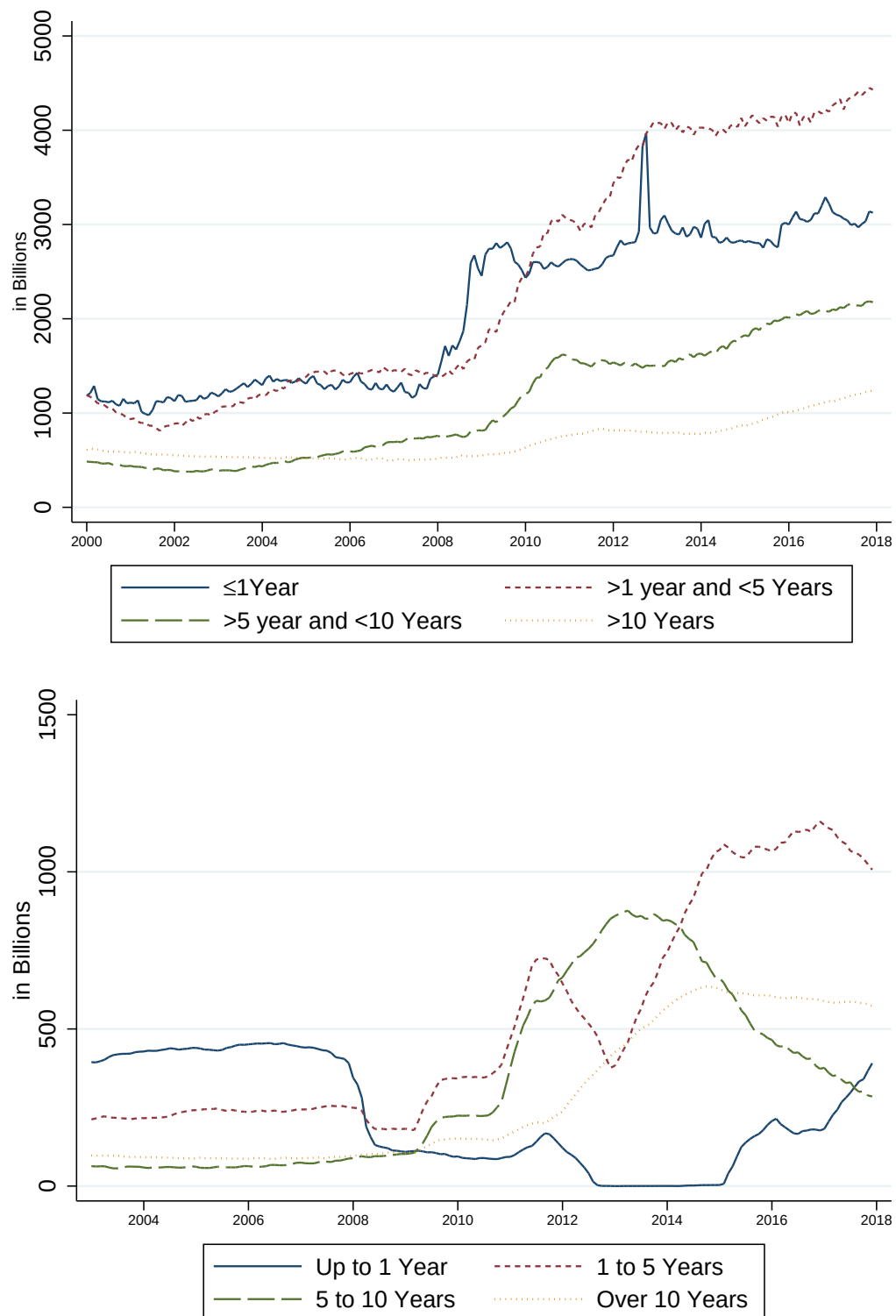


Figure 4: Outstanding Amount of Public Debt Held by Private Investors (Top) and Federal Reserve Holdings of Government Bonds (Bottom)



NOTES: All variables have been adjusted for inflation

Figure 5: An Auction Announcement From the Sale of 2-Year Bonds

Department of the Treasury • Bureau of the Public Debt • Washington, DC 20239

CONTACT: Office of Financing
202-504-3550

TREASURY AUCTION RESULTS

Term and Type of Security	2-Year Note	
CUSIP Number	912828HX1	
Series	X-2010	
Interest Rate	2-1/8%	
High Yield ¹	2.225%	
Allotted at High	50.99%	
Price	99.805441	
Accrued Interest per \$1,000	None	
Median Yield ²	2.190%	
Low Yield ³	2.147%	
Issue Date	April 30, 2008	
Maturity Date	April 30, 2010	
Original Issue Date	April 30, 2008	
Dated Date	April 30, 2008	
	Tendered	Accepted
Competitive	\$65,661,000,000	\$29,428,870,000
Noncompetitive	\$546,207,900	\$546,207,900
FIMA (Noncompetitive)	\$25,000,000	\$25,000,000
Subtotal⁴	\$66,232,207,900	\$30,000,077,900⁵
SOMA	\$2,751,815,900	\$2,751,815,900
Total	\$68,984,023,800	\$32,751,893,800
	Tendered	Accepted
Primary Dealer ⁶	\$52,638,000,000	\$19,370,870,000
Direct Bidder ⁷	\$286,000,000	\$161,000,000
Indirect Bidder ⁸	\$12,737,000,000	\$9,897,000,000
Total Competitive	\$65,661,000,000	\$29,428,870,000

⁵ Awards to combined Treasury Direct systems = \$451,301,900.

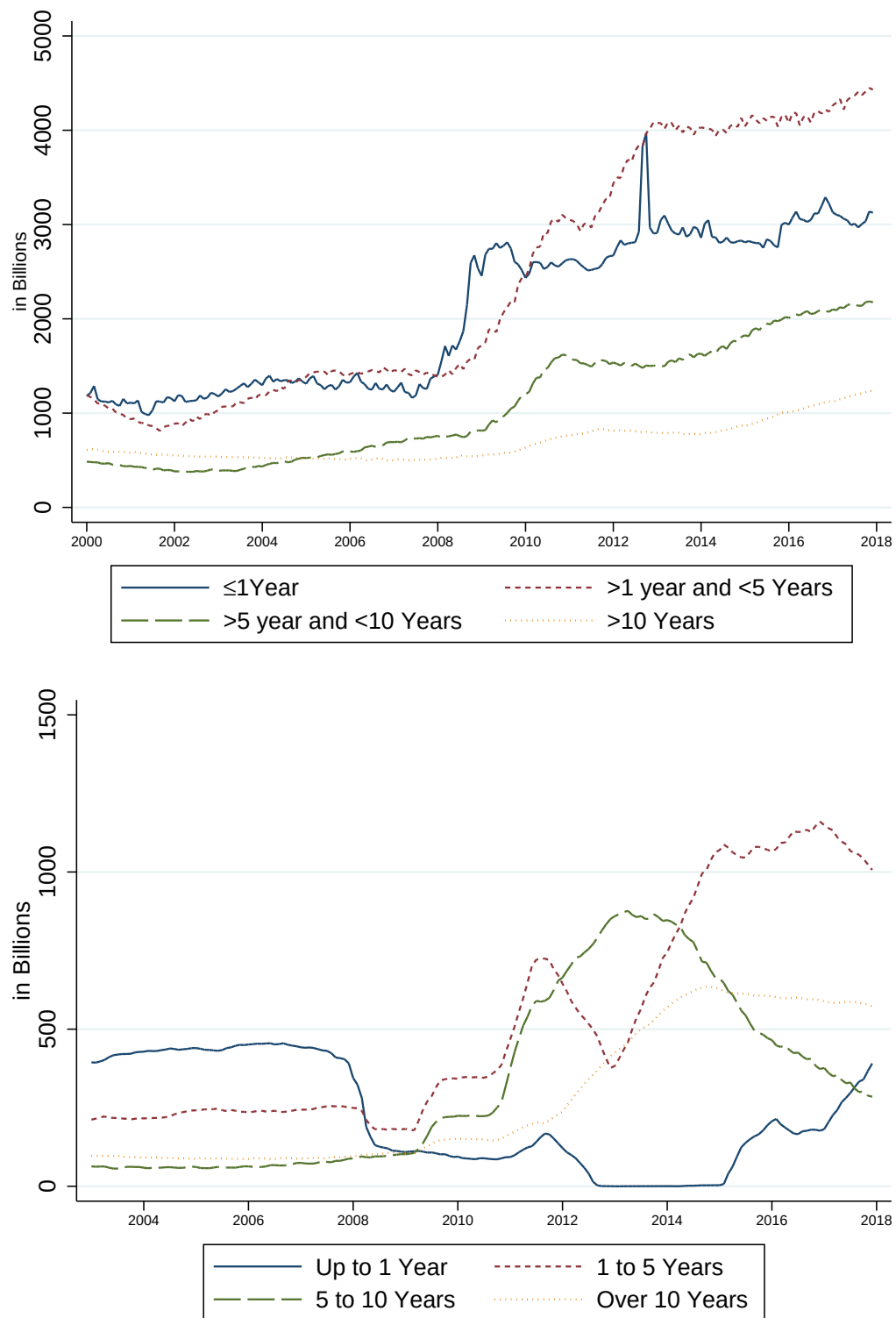
⁶ Primary dealers as submitters bidding for their own house accounts.

⁷ Non-Primary dealer submitters bidding for their own house accounts

⁸ Customers placing competitive bids through a direct submitter, including Foreign and International Monetary Authorities placing bids through the Federal Reserve Bank of New York.

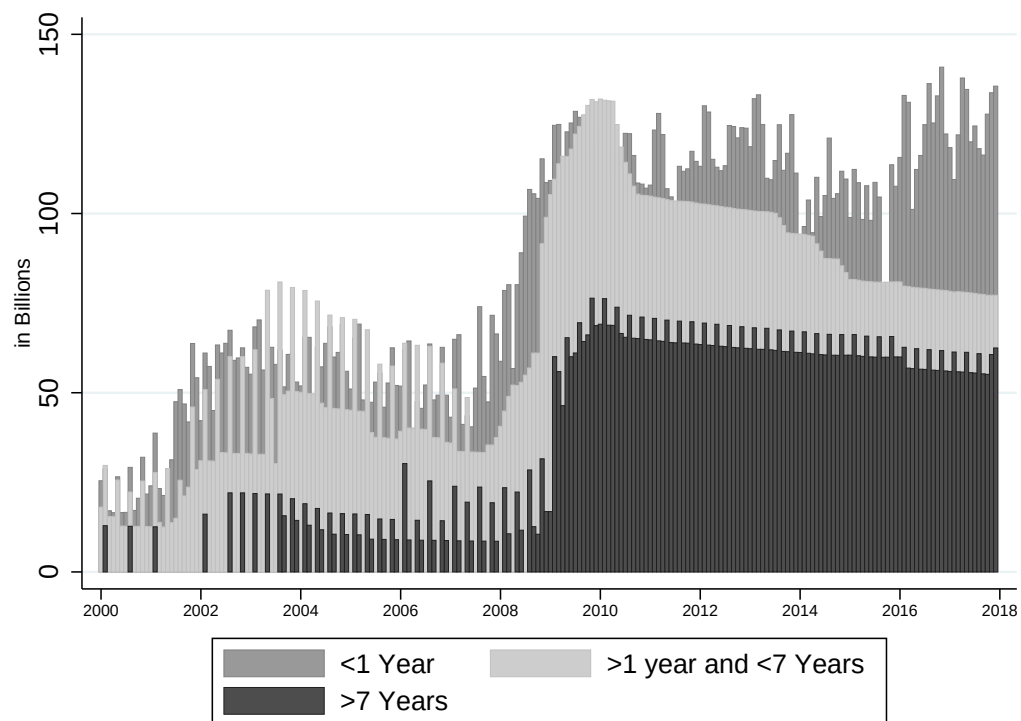
NOTES: Note that in Figure 5, SOMA stands for the System Open Market Account of the Federal Reserve. These are purchases of treasuries by the Federal Reserve due to open market operations and the amount tendered by the Fed is always the amount sold to it by the Treasury (the Fed's bid-to-cover ratio is always 1). In addition, the Fed is not a private investor. Hence, any SOMA purchases in individual auctions are excluded from the calculation of the bid-to-cover ratio.

Figure 6: Outstanding Amount of Public Debt Held by Private Investors (Top) and Federal Reserve Holdings of Government Bonds (Bottom)



NOTES: All variables have been adjusted for inflation

Figure 7: Newly Issued Debt (Top) and Bid-to-Cover ratio (Bottom) by maturity class between Jan.2000- Dec.2017



NOTES: The amount of newly issued debt has been adjusted for inflation.

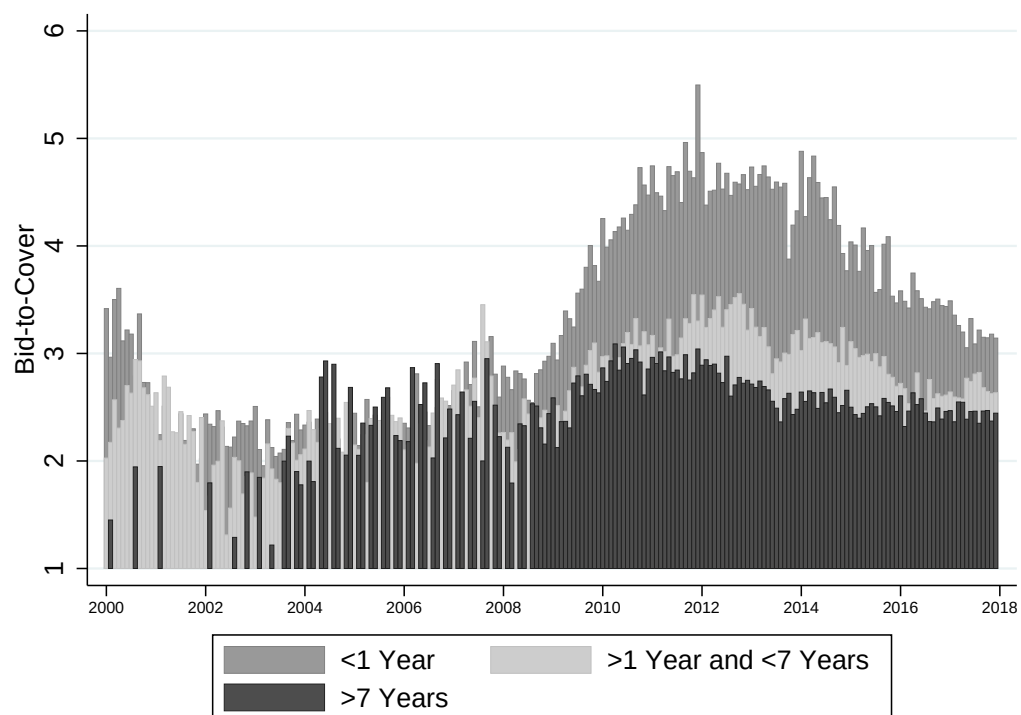
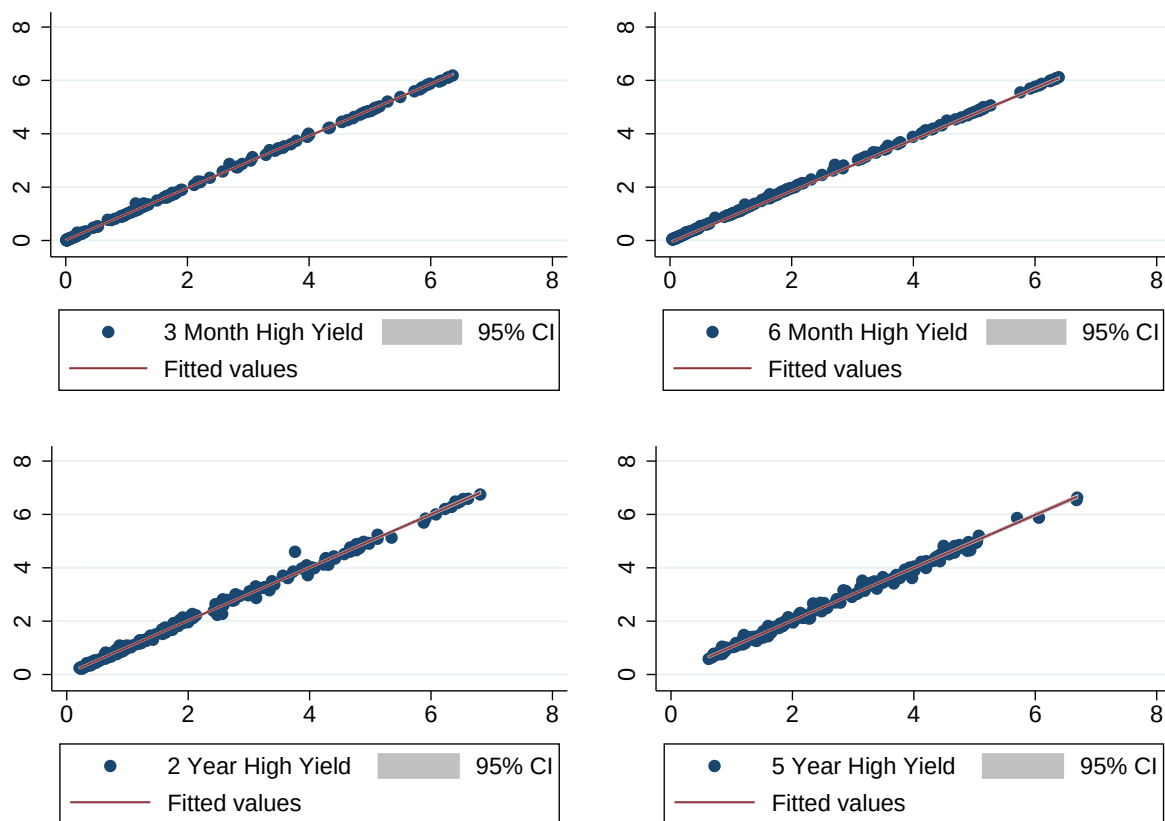
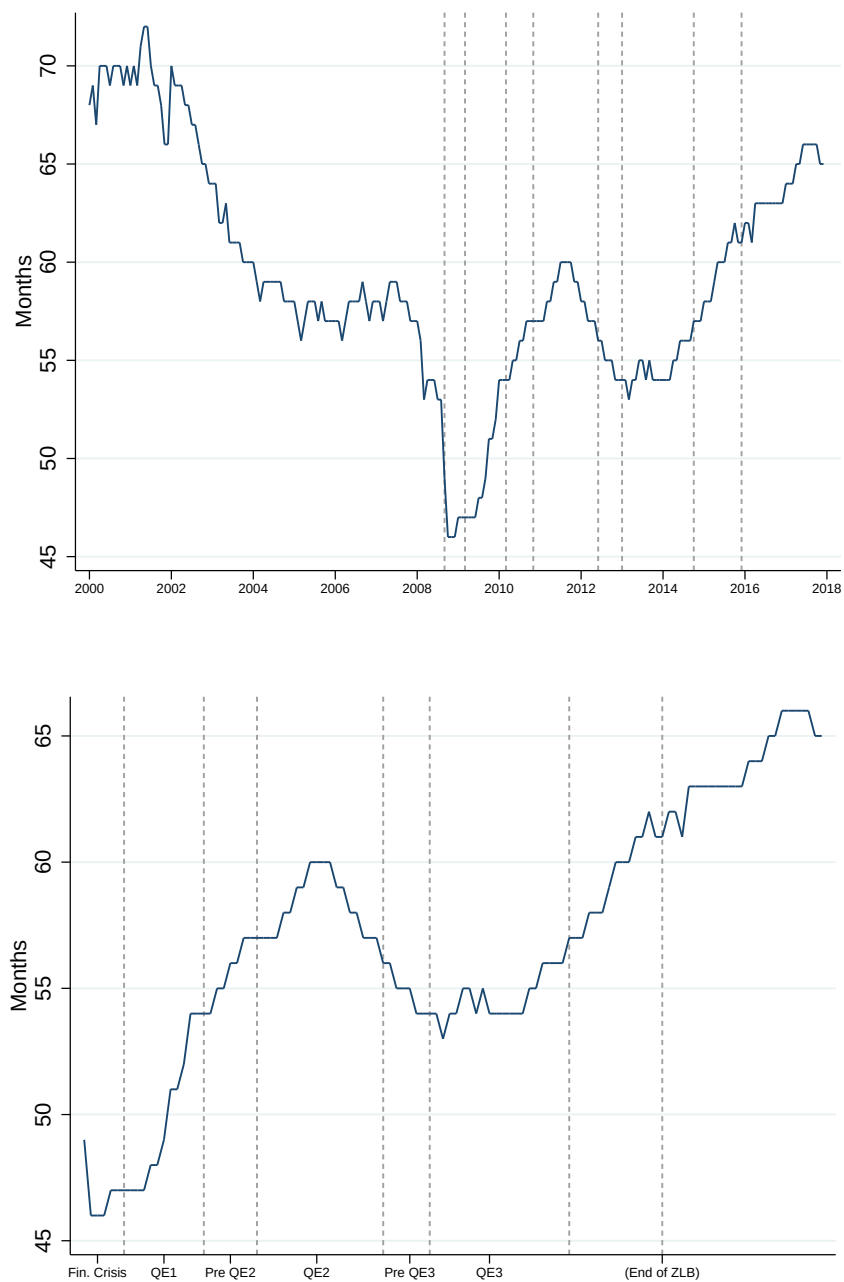


Figure 8: Correlation Between Primary (High Yield) and Secondary Market Interest Rates



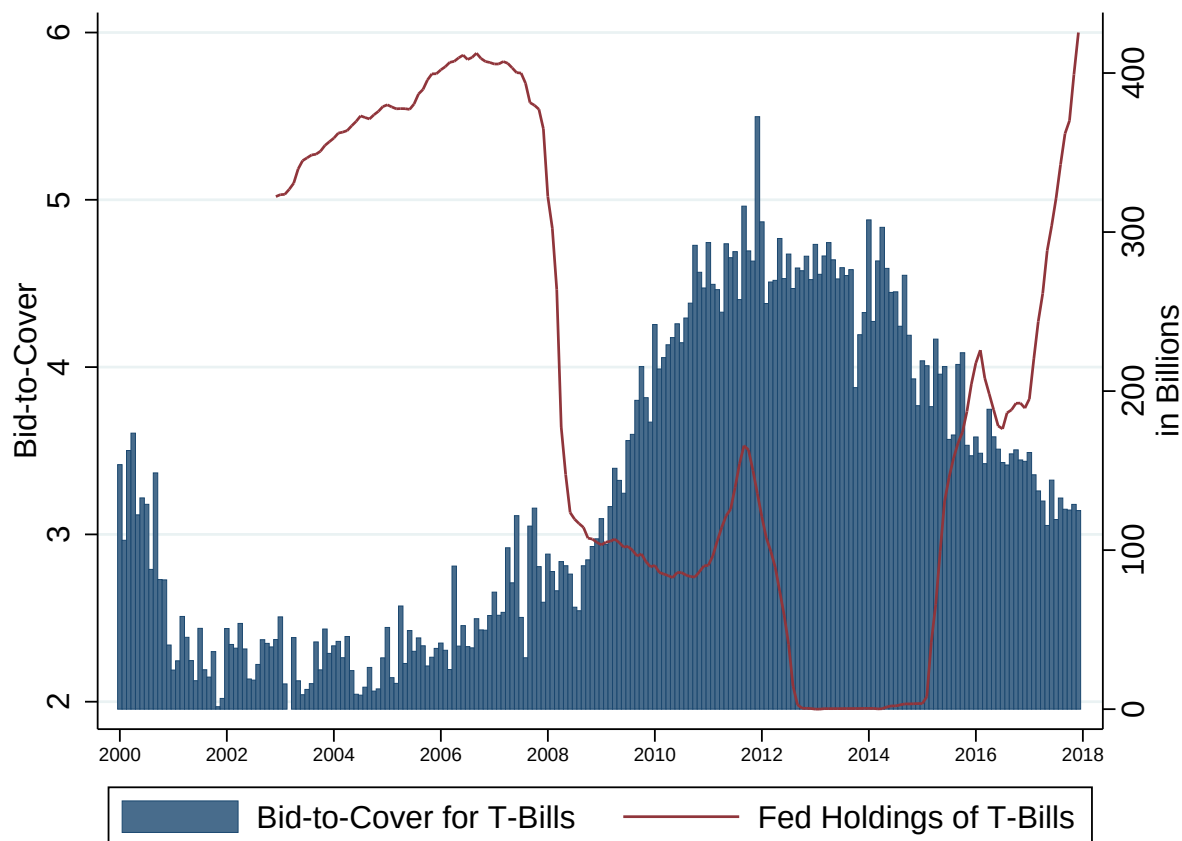
NOTES: Secondary market interest rates are computed as the monthly average of daily yields for each month.

Figure 9: Average Maturity of the Outstanding Amount of Public Debt Held by Private Investors: Jan.2000- Dec.2017(Top) and Sep.2008-Dec.2017(Bottom)



NOTES: The Dashed lines on the figures correspond to the dates in Figure 2. The first dashed line in the top figure refers to Sep. 2008 and is the cutoff used to plot the bottom Figure.

Figure 10: Bid-to-Cover and Federal Reserve Holdings of T-Bills



NOTES: Bid-to-Cover for T-Bills is constructed by summing across the value of all bids and dividing across the value of all debt sold (the cover) during each auction. According to the figure, Fed holdings of t-bills appear inversely related to demand. See footnote 53.

Table 1: Summary Statistics

	January 2000 - August 2008					September 2008 - December 2017				
	Bid-to-Cover					Bid-to-Cover				
	Obs	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max
Maturity										
1 Month	86	2.69	0.44	1.89	3.90	112	4.07	0.80	2.79	7.71
3 Months	104	2.36	0.32	1.86	3.31	112	4.02	0.61	2.74	4.91
6 Months	104	2.45	0.57	1.73	5.05	112	4.12	0.70	2.53	5.20
1 Year	9	2.67	0.43	1.85	3.30	112	3.97	0.63	2.57	5.34
2 Years	104	2.30	0.42	1.31	3.97	112	3.18	0.43	2.07	4.07
3 Years	17	2.19	0.33	1.32	2.97	110	3.12	0.33	2.15	3.96
5 Years	76	2.33	0.37	1.42	3.39	112	2.60	0.27	1.90	3.20
7 Years	0	N/A	N/A	N/A	N/A	107	2.63	0.20	2.10	3.23
10 Years	48	2.27	0.41	1.21	2.95	112	2.75	0.33	2.13	3.71
30 Years	10	2.17	0.45	1.57	2.98	107	2.46	0.24	2.02	3.04

NOTES: Bid-to-cover by maturity. An observation is an auction for all issues with maturity of 1 year or more. For issues with maturity 1 month, 3 months, and 6 months, an observation represents the average of the four weekly auctions conducted in each month

	January 2000 - August 2008					September 2008 - December 2017				
		Amount Sold (in billions)					Amount Sold (in billions)			
	Obs	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max
Maturity										
1 Month	86	19.4	6.3	8.7	31.5	112	34.6	8.3	5.5	53.3
3 Months	104	18.7	4.0	9.4	28.2	112	29.9	4.3	19.0	40.6
6 Months	104	16.8	4.6	4.9	27.1	112	27.6	3.2	19.0	35.1
1 Year	9	13.6	4.2	9.9	21.0	112	22.9	3.7	9.5	28.5
2 Years	104	24.6	6.8	11.9	33.7	112	32.5	7.0	23.9	46.2
3 Years	17	24.0	4.1	15.1	29.0	110	29.4	6.0	22.0	41.9
5 Years	76	17.0	3.4	9.6	29.2	112	34.6	3.5	25.3	44.0
7 Years	0	N/A	N/A	N/A	N/A	107	28.4	1.9	23.2	33.5
10 Years	48	14.0	4.1	8.6	22.0	112	21.1	2.3	10.5	26.2
30 Years	10	9.6	3.2	5.4	15.7	107	13.6	1.7	10.5	18.4

NOTES: Newly issued debt per maturity. Values have been adjusted for inflation.

Table 2: Regressing Bid-to-Cover on the High Yield (Jan.2000-Dec.2017)

	Interest Rate				
	(1)	(2)	(3)	(4)	(5)
1 Month BC	-0.907*** (0.09)				
3 Months BC		-1.212*** (0.10)			
6 Months BC			-0.909*** (0.10)		
1 Year BC				-1.015*** (0.13)	
2 Year BC					-1.458*** (0.17)
Observations	198	216	216	121	216
R^2	0.3192	0.3915	0.2619	0.3547	0.2501

	Interest Rate				
	(1)	(2)	(3)	(4)	(5)
3 Years BC	-1.652*** (0.15)				
5 Years BC		-1.627*** (0.27)			
7 Years BC			0.102 (0.28)		
10 Years BC				-0.975*** (0.19)	
30 Years BC					0.109 (0.26)
Observations	127	188	107	160	117
R^2	0.5016	0.1604	0.0012	0.1417	0.0015

p<0.10, ** p<0.05, *** p<0.01. NOTES: These numbers should be interpreted in the following way. A one unit increase in the bid-to-cover ratio would decrease the equilibrium auction determined bidder return by (in the case of the 6 month maturity) 90 basis points. However, these results should only be interpreted as correlations!

Table 3: Regressing Bid-to-Cover on the High Yield (Sep.2008-Dec.2017)

	Interest Rate				
	(1)	(2)	(3)	(4)	(5)
1 Month BC	-0.183*** (0.03)				
3 Months BC		-0.363*** (0.03)			
6 Months BC			-0.371*** (0.03)		
1 Year BC				-0.418*** (0.04)	
2 Year BC					-0.689*** (0.06)
Observations	112	112	112	112	112
R^2	0.2825	0.4962	0.5205	0.4594	0.5404

	Interest Rate				
	(1)	(2)	(3)	(4)	(5)
3 Years BC	-0.811*** (0.10)				
5 Years BC		-0.871*** (0.18)			
7 Years BC			0.102 (0.28)		
10 Years BC				0.292 (0.19)	
30 Years BC					0.888*** (0.27)
Observations	110	112	107	112	107
R^2	0.3930	0.1794	0.0012	0.0221	0.0934

p<0.10, ** p<0.05, *** p<0.01. NOTES: These numbers should be interpreted in the following way. A one unit increase in the bid-to-cover ratio would decrease the equilibrium auction determined bidder return by (in the case of the 6 month maturity) 37 basis points. However, these results should only be interpreted as correlations!

Table 4: DID: Estimates for Short and Medium Term Notes

	Bid-to-Cover			
	(1)	(2)	(3)	(4)
<i>Treatment</i> $\times$ <i>Post F.C.</i>	0.889*** (0.08)	0.889*** (0.05)	0.914*** (0.09)	0.930*** (0.05)
<i>Post F.C.</i>	0.667*** (0.05)	-0.355*** (0.11)	0.609*** (0.08)	-0.319** (0.13)
<i>Treatment</i>	0.178*** (0.05)	0.178*** (0.04)	0.113 (0.09)	0.073 (0.08)
<i>HQMCB</i>			-0.011 (0.01)	-0.018 (0.01)
<i>Intercept</i>	2.282*** (0.03)	2.720*** (0.08)	2.394*** (0.12)	2.973*** (0.21)
Observations	432	432	432	432
R^2	0.719	0.903	0.720	0.903
Year Fixed Effects	X	✓	X	✓
Control Group	Medium Term	Medium Term	Medium Term	Medium Term

* p<0.10, ** p<0.05, *** p<0.01. NOTES: I define short and medium term notes by pooling across individual maturities. Specifically, I add all bids for 1 month, 3 month, 6 month and 1 year notes and divide that number by the summation of all akss (or covers) for the same maturities. Thus, I construct a bid-to-cover measure for short-term debt. I do the same for medium term notes, which are defined as notes with maturity of 2, 3 and 5 years.

Table 5: DID: Estimates for 3 Month and 6 Month T-Bills

	Bid-to-Cover	
	(1)	(2)
<i>Treatment</i> $\times$ <i>Post F.C.</i>	-0.006 (0.11)	-0.006 (0.05)
<i>Post F.C.</i>	1.669*** (0.09)	0.126 (0.09)
<i>Treatment</i>	-0.089 (0.06)	-0.089** (0.04)
<i>Intercept</i>	2.450*** (0.06)	3.302*** (0.14)
Observations	432	432
R^2	0.683	0.933
Year Fixed Effects	X	✓
Control Group	Medium Term	Medium Term

* p<0.10, ** p<0.05, *** p<0.01. NOTES: There is no corporate bond sport rate with a maturity of 3 months, thus I cannot control for HQMCB when I use the 3 month t-bill.

Table 6: DID: Estimates for 1 Month and 3 Month T-Bills

	Bid-to-Cover	
	(1)	(2)
<i>Treatment</i> $\times$ <i>Post F.C.</i>	-0.276** (0.11)	-0.326*** (0.08)
<i>Post F.C.</i>	1.663*** (0.07)	0.334*** (0.13)
<i>Treatment</i>	0.325*** (0.06)	0.375*** (0.05)
<i>Intercept</i>	2.361*** (0.03)	2.818*** (0.10)
Observations	414	414
R^2	0.642	0.834
Year Fixed Effects	X	✓
Control Group	1 Month	1 Month

* p<0.10, ** p<0.05, *** p<0.01. NOTES: There is no corporate bond sport rate with a maturity of 3 months, thus I cannot control for HQMCB when I use the 3 month t-bill.

Table 7: DID: Estimates for 2 Year and 5 Year Notes

	Bid-to-Cover			
	(1)	(2)	(3)	(4)
<i>Treatment</i> $\times$ <i>Post F.C.</i>	0.602*** (0.08)	0.565*** (0.06)	0.588*** (0.08)	0.560*** (0.06)
<i>Post F.C.</i>	0.276*** (0.05)	-0.310** (0.14)	0.221*** (0.06)	-0.280* (0.15)
<i>Treatment</i>	-0.021 (0.06)	0.016 (0.05)	-0.038 (0.06)	0.006 (0.06)
<i>HQMCB</i>			-0.026 (0.02)	-0.013 (0.03)
<i>Intercept</i>	2.326*** (0.04)	2.541*** (0.12)	2.459*** (0.10)	2.643*** (0.28)
Observations	404	404	404	404
R^2	0.476	0.717	0.480	0.718
Year Fixed Effects	X	✓	X	✓
Control Group	Medium Term	Medium Term	Medium Term	Medium Term

* p<0.10, ** p<0.05, *** p<0.01

Table 8: DID: Continuous Maturity Estimates

	Bid-to-Cover			
	(1)	(2)	(3)	(4)
$\frac{1}{\text{Maturity}} \times \text{Post F.C.}$	4.123*** (0.22)	4.123*** (0.15)	3.806*** (0.26)	3.793*** (0.18)
<i>Post F.C.</i>	0.544*** (0.04)	-0.528*** (0.09)	0.606*** (0.05)	-0.482*** (0.10)
<i>Intercept</i>	2.363*** (0.02)	2.976*** (0.11)	2.252*** (0.03)	2.833*** (0.09)
Observations	836	836	836	836
R^2	0.600	0.779	0.658	0.836
Year Fixed Effects	X	✓	X	✓
Maturity Fixed Effects	X	X	✓	✓

* p<0.10, ** p<0.05, *** p<0.01 Notes: Maturity is specified in months. Hence, a three month maturity takes the value $\frac{1}{3}$ and so on. A higher value on the estimates coefficient indicates a higher preference for maturity.

Table 9: DID Event Study: Short Maturity and Long Maturity

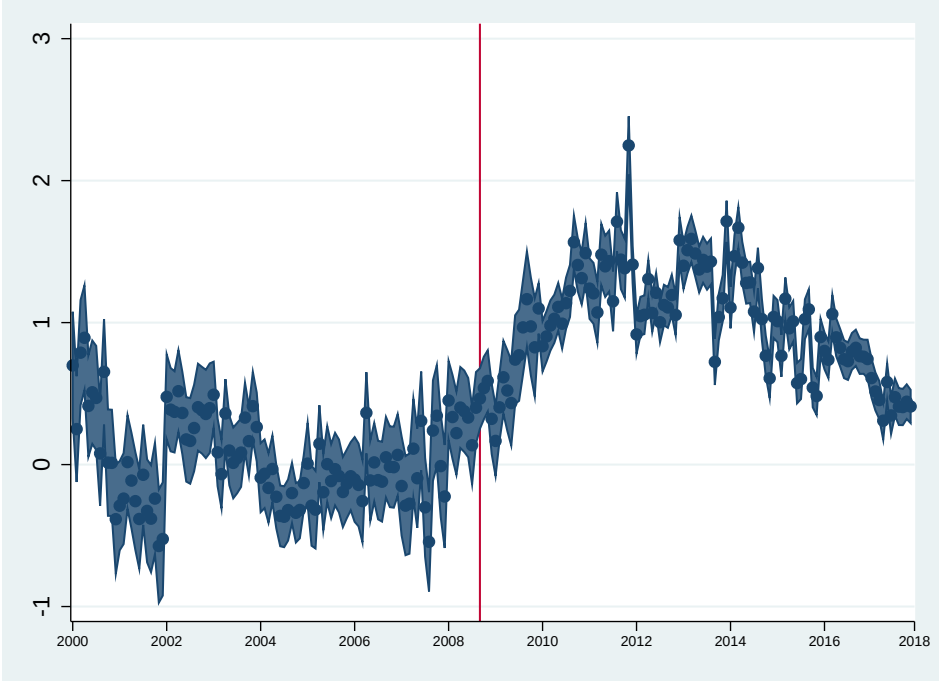


Table 10: DID Event Study: 3 Month and 6 Month



NOTES: These plots are the estimates of equation (2) in the text. Each dot in Tables 8 and 9 represents the DID coefficient between the respective maturities relative to their difference in August 2008. The area is the 95% confidence interval. The solid line denotes September 2008.

Table 11: DID Event Study: 2 Year and 5 Year

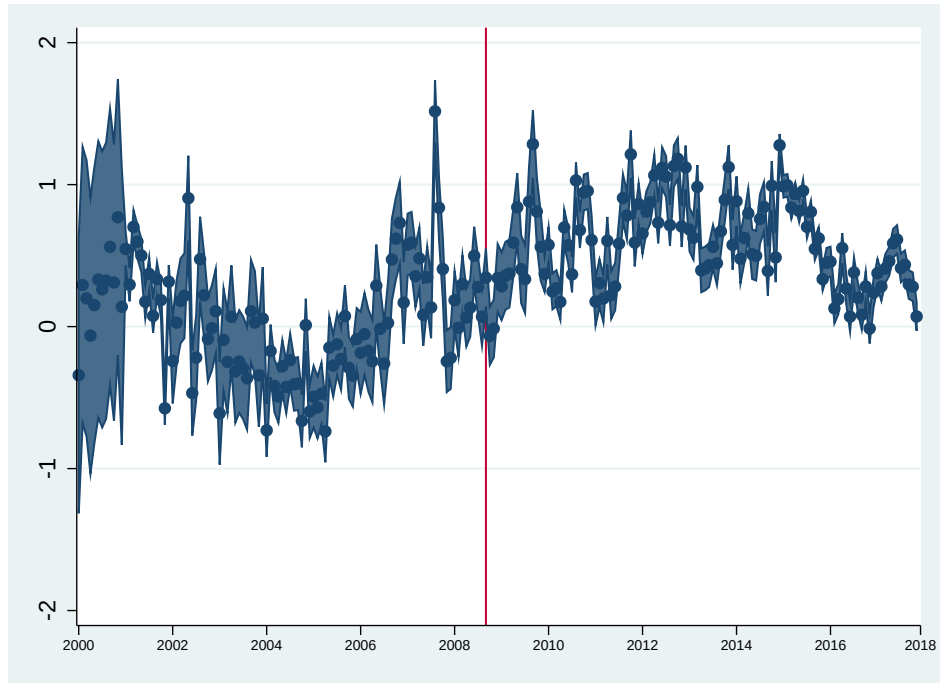
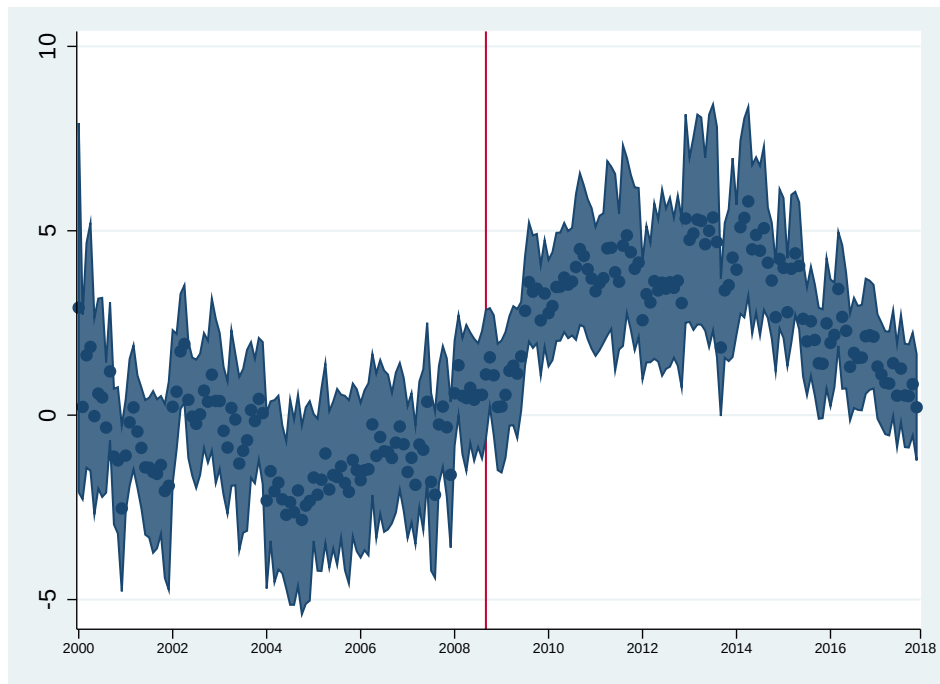


Table 12: DID Event Study: Continuous Maturity Measure



NOTES: These plots are the estimates of equation (2) in the text. Each dot in Tables 10 and 11 represents the DID coefficient between the respective maturities relative to their difference in August 2008, while the area is the 95% confidence interval. The solid line denotes September 2008.

Table 13: Newly Issued Debt by the Treasury During QE

	Newly Issued Debt					
	Short	Short	Medium	Medium	Long	Long
QE1	0.075 (0.05)	-0.025 (0.04)	0.095 (0.06)	0.140*** (0.02)	0.222 (0.19)	0.327 (0.20)
QE2	0.011 (0.03)	-0.038 (0.02)	0.103*** (0.02)	-0.026 (0.02)	0.136* (0.07)	0.042 (0.05)
QE3	-0.032 (0.03)	-0.088** (0.03)	0.123*** (0.02)	0.073*** (0.01)	0.034* (0.02)	-0.047 (0.04)
$\frac{Debt_{t-1}}{GDP_{t-1}}$	1.018 (1.52)	0.527 (1.20)	1.372 (1.32)	0.040 (0.64)	-1.636 (1.74)	-2.629 (2.24)
$\frac{Debt_{t-2}}{GDP_{t-2}}$	-0.593 (1.55)	-1.643 (1.50)	0.097 (1.62)	0.272 (0.84)	3.117 (1.99)	4.188** (1.84)
$\frac{Debt_{t-3}}{GDP_{t-3}}$	2.277 (1.85)	2.121 (1.50)	-1.993 (1.68)	-0.391 (0.66)	-3.783 (4.30)	-1.737 (2.85)
$\frac{Debt_{t-4}}{GDP_{t-4}}$	-2.180* (1.29)	-0.513 (1.20)	-1.258 (1.27)	-0.032 (0.49)	3.211 (4.02)	3.960 (3.56)
Intercept	4.451*** (0.19)	4.612*** (0.24)	5.437*** (0.19)	4.715*** (0.15)	3.598*** (0.62)	2.305** (1.10)
Observations	108	108	108	108	108	108
R^2	0.0494	0.4471	0.7923	0.9644	0.1920	0.5131
Year Fixed Effects	X	✓	X	✓	X	✓

* p<0.10, ** p<0.05, *** p<0.01. NOTES: The coefficients on QE1, QE2, and QE3 represent the average change in newly issued debt (monthly) throughout the duration of each QE operation relative to periods with no QE. Short-term debt is defined as debt with maturity ≤ 1 year. Medium-term debt includes debt with maturity of 2, 3, and 5 years. Long-term debt includes debt with maturity of 7, 10, and 30 years. Debt to GDP is defined as the monthly real outstanding amount of privately held debt divided by real monthly GDP.

Table 14: Newly Issued Debt by the Treasury During QE

	Newly Issued Debt					
	2 Year	2 Year	3 Year	3 Year	5 Year	5 Year
QE1	0.072 (0.06)	0.104*** (0.02)	0.106 (0.08)	0.158*** (0.02)	0.113** (0.05)	0.165*** (0.02)
QE2	0.137*** (0.02)	-0.036** (0.01)	0.157*** (0.03)	-0.027 (0.02)	0.034* (0.02)	-0.015 (0.02)
QE3	0.176*** (0.02)	0.116*** (0.02)	0.186*** (0.02)	0.118*** (0.02)	0.029*** (0.01)	0.001 (0.01)
Intercept	4.769*** (0.18)	3.958*** (0.14)	4.421*** (0.25)	3.457*** (0.17)	3.854*** (0.17)	3.368*** (0.16)
Observations	108	108	108	108	108	108
R^2	0.8206	0.9762	0.7708	0.9714	0.6688	0.8803
Year Fixed Effects	X	✓	X	✓	X	✓

* p<0.10, ** p<0.05, *** p<0.01. NOTES: Interpretation of coefficients is the same as in Table 12. See the notes in Table 12. For expositional purposes, I have suppressed the coefficients on the debt-to-GDP ratio from displaying on the table.

Table 15: Newly Issued Debt by the Treasury During QE

	Newly Issued Debt					
	7 Year	7 Year	10 Year	10 Year	30 Year	30 Year
QE1	0.045 (0.08)	0.157*** (0.03)	0.017 (0.06)	0.074 (0.05)	-0.087 (0.05)	-0.016 (0.04)
QE2	0.055* (0.03)	0.005 (0.02)	0.066** (0.03)	0.014 (0.03)	0.042 (0.03)	0.009 (0.05)
QE3	0.039*** (0.01)	-0.002 (0.01)	0.036* (0.02)	-0.025 (0.06)	0.043 (0.03)	-0.021 (0.10)
Intercept	3.507*** (0.29)	2.748*** (0.21)	3.207*** (0.20)	2.665*** (0.30)	3.013*** (0.18)	2.631*** (0.30)
Observations	107	107	108	108	106	106
R^2	0.3830	0.8166	0.2130	0.4433	0.2019	0.2665
Year Fixed Effects	X	✓	X	✓	X	✓

* p<0.10, ** p<0.05, *** p<0.01. NOTES: Interpretation of coefficients is the same as in Table 12. See the notes in Table 12. For expositional purposes, I have suppressed the coefficients on the debt-to-GDP ratio from displaying on the table.

Appendix A Model

In light of the findings in this paper, I build a stylized model which incorporates several new features that are relevant in analyzing the real effects of quantitative easing and the determination of long-term interest rates. Although the model is stylized, I show that it can be fully expanded into a proper general equilibrium framework.

The model consists of private investors who derive convenience benefits from holding short and long-term government bonds. The government is divided into a fiscal authority and a central bank. The fiscal authority (i.e. Treasury) issues short and long-term bonds in accordance with its fiscal needs. The central bank (i.e. Federal Reserve) is constrained by the zero lower bound (zlb) and engages in quantitative easing.

A.1 Private Investors

I assume that private investors derive convenience benefits from holding short and long-term government bonds as in Krishnamurty and Vissing-Jorgensen (2012). A representative investor maximizes:

$$E_t \sum_{t=0}^{\infty} \beta^t \left(\log\left(\frac{C_t}{P_t}\right) + \alpha_t^s \log\left(\frac{B_t^{h,s}}{P_t}\right) + \alpha_t^l \log\left(\frac{P_t^l B_t^{h,l}}{P_t}\right) \right)$$

In the expression above, B_t^s and $P_t^l B_t^{h,l}$ are private investor's holdings of short and long-term bonds (in market value) respectively. I model long-term debt as in Cochrane (2000). That is long-term debt is composed of a portfolio of long-term bonds with a geometrically declining rate ρ^j . In the expression above, P_t^l is the price of that portfolio. With a geometric rate of decline, the average maturity of the portfolio of long-term debt is therefore:

$$m = \frac{1}{1 - \beta\rho}$$

Although I assume that the average maturity of the portfolio is fixed (ρ is constant) ρ can also

be endogenized. The terms α_t^s and α_t^l govern the contribution of short and long-term treasury bonds in the utility of the representative investor. I interpret large and sudden change in α_t^j for $j = s, l$ as significant shifts in the demand for government debt.⁴⁸ In addition, according to my findings these demand shocks may differ in magnitude. Since, I showed that demand for shorter duration assets has been greater relative to longer duration assets, it follows that $\alpha_t^s > \alpha_t^l$. The budget constraint faced by a representative household is:

$$C_t + B_t^{h,s} + B_t^{h,l}P_t^l + T_t = B_{t-1}^{h,s}R_{t-1}^s + B_{t-1}^{h,l}(1 + \rho P_t^l) + P_t Y$$

where the price and yield of the portfolio of long-term bonds are related according to:

$$P_t^l R_t^l = (1 + \rho P_t^l) \tag{6}$$

Every period agents receive a constant endowment Y which they use to make consumption expenditures and buy short and long-term government bonds. In addition, they pay lump sum taxes to the government.

A.2 Government

The government is composed of a fiscal authority and a central bank. The two branches of the government have different objectives and their actions have different effects on treasury yields. Hence, I present each branch separately.

A.2.1 Fiscal Authority

The fiscal authority issues short and long-term debt in order to finance its deficit. Its budget constraint is given by:

$$G_t - T_t = B_t^{g,s} - B_{t-1}^{g,s}R_{t-1} + P_t^l B_t^{g,l} - P_t^l R_t^l B_{t-1}^{g,l} + D_t$$

⁴⁸Weder (2006) makes a similar argument in studying the role of preference shocks in the Great Depression.

In the expression above, D_t denotes profits (or dividends) that the central bank makes to the Treasury every period. In addition, I assume a simple rule whereas the fiscal authority issues long-term debt as a function of its outstanding amount of short-term debt. That is:

$$P_t^l B_t^{g,l} = \gamma_t B_t^{g,s} \quad (7)$$

where γ_t manages the growth in the market value of long-term debt as a function of short-term debt. In the simple case where γ is just a constant, a value of 0 indicates that the government doesn't issue any long-term debt and finances its expenditures through short-term debt only. With $0 < \gamma < 1$, the government reduces the share of long-term debt overtime. Finally, with $\gamma > 1$, the fiscal authority increases the share of long-term debt as a fraction of total outstanding obligations.⁴⁹ In addition, the fiscal authority collects taxes T in order to fund its expenditures and debt servicing costs. Taxes evolve according to:

$$\frac{T_t}{T} = \left(\frac{B_{t-1}^{g,s}}{B^{g,s}} + \frac{P_{t-1}^l B_{t-1}^{g,l}}{P^l B^{g,l}} \right)^{\phi_T} \quad (8)$$

A.2.2 Central Bank

The short-term interest rate is constrained by the zero lower bound. I model this by assuming that the short-term rate R_t is pegged at its steady state value R .⁵⁰ Since conventional monetary policy has been exhausted, the central bank attempts to reduce long-term interest rates. To that end, it engages in quantitative easing by purchasing long-term government debt in the secondary market (from private investors). Specifically, the central bank buys a fraction of the outstanding amount of debt held by investors:

⁴⁹As evidenced by Figure 5, the government's management of its long-term debt can best be described by $0 < \gamma < 1$ before the financial crisis and with $\gamma > 1$ post-financial crisis

⁵⁰In a log-linearized model where one often studies the dynamics of an economy around a non-stochastic steady state assuming that the central bank has pegged or is unable to influence the short-term rate is observationally equivalent in reality where the central bank has reduced rates to zero and is incapable of further affecting rates.

$$P_t^l B_t^{c,l} = \kappa_t P_t^l B_t^{h,l} \quad (9)$$

where κ_t is chosen by the central bank and is bounded between 0 and 1. The case of $\kappa_t = 0$ corresponds to no purchases of long-term debt (i.e. normal times when the central bank controls the short-term rate). The extreme case of $\kappa_t = 1$ corresponds to a case where the central bank fully monetizes government debt.⁵¹ In order to pay for these purchases it issues reserves M_t . Hence, the central bank's budget constraint is given by:

$$P_t^l B_t^{c,l} + M_{t-1} + D_t = R_t^l P_t^l B_{t-1}^{c,l} + M_t$$

Every period, the central bank remits its profits (or dividends) to the fiscal authority. In that case, the budget constraints of the fiscal authority and the central bank can be consolidated to give:

$$B_t^{g,s} + P_t^l (B_t^{g,l} - B_t^{c,l}) + M_t = B_{t-1}^{g,s} R_{t-1} + P_t^l R_t^l (B_{t-1}^{g,l} - B_{t-1}^{c,l}) + M_{t-1} - T_t + G_t \quad (10)$$

Since in this model Ricardian Equivalence fails (because investors value treasury bonds), the behavior of the central bank and its choice of unconventional monetary policy matters separately from the behavior of the Treasury.⁵²

⁵¹I assume that private investors, the central bank and the government exchange long-term debt of the exact same maturity (i.e. same ρ). Of course, that is not the case in reality. However, although this assumption can be easily relaxed, the point of the analysis is to evaluate the holdings of long-term debt (in market values) across the different agents in the economy. In the model, that can happen through either variation in the nominal quantity of bonds, ρ or both.

⁵²This distinction is an important one. In studying the effects of lower yields on treasury bonds, [Chen, Curdia and Ferrero \(2012\)](#) assume that QE is a shock that reduces the outstanding amount of debt held by private investors. As shown in the previous section, this is not consistent with the data and their shock is essentially a counterfactual (based on their interpretation of the shock).

A.3 Equilibrium and Model Solution

The equilibrium is a set of allocations that satisfy (6) to (10) together with investors' first order conditions ⁵³

$$\frac{1}{C_t} = \beta E_t \frac{1}{C_{t+1}} \frac{R_t}{\pi_{t+1}} + \alpha_t^s \frac{n_t}{B_t^{h,s}} \quad (11)$$

$$\frac{1}{C_t} = \beta E_t \frac{1}{C_{t+1}} \frac{P_{t+1}^l}{P_t^l} \frac{R_{t+1}^l}{\pi_{t+1}} + \alpha_t^l \frac{(1 - n_t)}{P_t^l B_t^{h,l}} \quad (12)$$

the following market clearing conditions ⁵⁴

$$C_t = Y \quad (13)$$

$$B_t^{h,s} = B_t^{g,s} = B_t^s \quad (14)$$

$$B_t^{g,mv} = B_t^{h,mv} + B_t^{c,mv} \quad (15)$$

and processes for $G_t, M_t, \kappa_t, \alpha_t^j$ and γ_t . In order to guarantee a unique equilibrium in this model, I assume that the central bank pledges to keep the interest rate fixed for a specific number of periods H , after which it resumes control over the short-term rate. Specifically:

$$R_t^s = \begin{cases} R^s, & \text{if } t \leq H \\ \left(\pi_t^{\phi_\pi} \right), & t > H \end{cases}$$

In that case, the short-term interest rate is pegged to its steady state value. Note that although the interest rate is not technically at a value of 0, in a linearized model this

⁵³Note that I have taken the first order condition with respect to the market value of long-term debt: $P_t^l B_t^{h,l}$

⁵⁴In (13), a variable $B_t^{j,mv} = P_t^l B_t^{j,l}$ denotes the market value (mv) of the portfolio of long-term debt held by each agent type.

condition is sufficient since the central bank cannot respond to the state of the economy by affecting the short-term rate. Hence, "pegging" the short-term rate is observationally equivalent to the Federal Reserve facing the zero lower bound after the financial crisis. For periods in which the zlb does not bind $\phi_\pi = 1.5$. That is, the central bank maintains an active monetary policy stance. If that is not the case, the model becomes inconsistent with rational expectations and an equilibrium does not exist.

In addition, determinacy is also conditional on the response to taxes ϕ_T and on a value for $\alpha_t^j < \bar{\alpha}_t^j$ where $\bar{\alpha}_t^j$ are the marginal values for α_t^s and α_t^l for which the equilibrium becomes indeterminate. The procedure for implementing the Perfect Foresight solution and the ZLB commitment is the same as in Chen et al. (2012).

As long as these conditions are met the model can be expanded into a full general equilibrium framework with endogenous production, sticky prices, heterogeneous agents or other frictions. Note that in this framework the behavior of α_t^j , γ_t and κ_t is important for the equilibrium behavior of interest rates (as well as output in a model with endogenous production). However, the best approach to model these processes is a complex task which I leave for future research.

A.4 Linear Approximation

In this section, I show how I derive equations (4) and (5) shown in the text. I linearize the two Euler equations (11) and (12) around their steady state with any variable x_t denoted as $\hat{x}_t$ indicates the deviation of a variable from its steady state. That is: $\hat{x}_t = x_t - x$. In addition, a real variable $x_t = \frac{X_t}{P_t}$

$$\hat{R}_t = \alpha \frac{nC}{\beta R^s b^s} \left(-\hat{\alpha}_t^s + \hat{b}_t^s \right) \quad (16)$$

$$\hat{R}_t^l = \frac{\rho}{R^l} E_t \hat{R}_{t+1}^l + \alpha \frac{(1-n)C}{\beta R^{l^2} b^{h,mv}} (R^l - \rho) \left(-\hat{\alpha}_t^l + \hat{b}_t^{h,mv} \right) \quad (17)$$

Note that since $R_t = R$ it follows that $\hat{R}_t = 0$. Hence, the central bank cannot influence the short-term rate. In addition, in linearizing (12), I have substituted for the price P_t^l as implied by (6).

Define:

$$\theta_1 = \alpha^s \frac{(n)C}{\beta R^s b^s}$$

$$\theta_2 = \alpha^l \frac{(1-n)C}{\beta R^{l^2} b^{h,mv}}$$

Hence, I can rewrite (11) and (12) as:

$$\hat{R}_t = E_t \pi_{t+1} + \theta_1 \left(-\hat{\alpha}_t^s + \hat{b}_t^s \right) \quad (18)$$

$$\hat{R}_t^l = E_t \pi_{t+1} + \frac{\rho}{R^l} E_t \hat{R}_{t+1}^l + \theta_2 (R^l - \rho) \left(-\hat{\alpha}_t^l + \hat{b}_t^{h,mv} \right) \quad (19)$$

Next, using the market clearing condition in the market for long-term debt (15) and plugging in for $b^{h,mv} \hat{b}_t^{h,mv}$ I can derive the expression for the pricing equation for long-term debt from the text:

$$\hat{R}_t^l = E_t \pi_{t+1} + \frac{\rho}{R^l} E_t \hat{R}_{t+1}^l + \theta_2 (R^l - \rho) \left(-\hat{\alpha}_t^l + \left(\frac{b^{g,mv}}{b^{h,mv}} \hat{b}_t^{g,mv} - \frac{b^{c,mv}}{b^{h,mv}} \hat{b}_t^{c,mv} \right) \right) \quad (20)$$

Appendix B Data

B.1 Bid-to-Cover

The bid-to-cover data is constructed by adding the total amount of all bids and dividing it by the total amount of debt the treasury wanted to sell (or the cover amount). Specifically, the bid-to-cover for the auction announcement in Figure 4 is determined by taking the Subtotal Tendered Amount (\$66,232,207,900) and dividing it by the Subtotal Accepted amount (\$30,000,077,900). Hence, in that auction the bid-to-cover is 2.21.

B.2 Newly Issued Debt

Data on newly issued debt by maturity comes from the auction announcements on treasurydirect.gov such as the one displayed in Figure 4. That measure excludes any direct purchases by the Fed during treasury auctions. Specifically, newly issued debt is the value under Subtotal Accepted in each auction.

B.3 High Quality Corporate Bond Spot Rate (HQMCB)

This interest rate is intended to measure the average yield of high quality corporate bonds. The spot rate for any maturity is defined as the yield on a bond that gives a single payment at that maturity. This is called a zero coupon bond. Because high quality zero coupon bonds are not generally available, the HQM methodology computes the spot rates so as to make them consistent with the yields on other high quality bonds. The HQM yield curve uses data from a set of high quality corporate bonds rated AAA, AA, or A that accurately represent the high quality corporate bond market. Source: Department of the Treasury

B.4 Monthly Real GDP

A monthly real GDP measure calculated by IHS Markit. Their Methodology: First, we derive a raw index from various monthly data, most of which is source data that BEA uses to calculate official quarterly GDP. Second, we calculate a monthly residual that reconciles the raw index with official GDP at the quarterly frequency. Source: <https://ihsmarkit.com/products/us-monthly-gdp-index.html>

B.5 *Figure 1*

The yields graphed in Figure 1 are the equilibrium yield (called the high yield) determined during each auction. That value is displayed on the fifth line of all announcements (See Figure 5). Note that graphing the secondary market yields (i.e. Treasury Constant Maturity Yields) would produce a very similar graph since the two yields are very highly correlated.

B.6 *Figure 3*

Monthly data on the outstanding amount of debt held by private investors comes from table OFS-2 in the quarterly issue of the treasury bulletin located at fiscal.treasury.gov. Nominal values are adjusted for inflation using the GDP deflator interpolated to a monthly frequency using the CPI (less food and energy). Monthly real GDP (MGDP) comes from Macroeconomic Advisers at <https://ihsmarkit.com/products/us-monthly-gdp-index.html>.

B.7 *Figure 4*

Monthly data on the outstanding amount of debt held by private investors comes from table FD-5 in the quarterly issue of the treasury bulletin located at fiscal.treasury.gov. Nominal values are adjusted for inflation using the GDP deflator interpolated to a monthly frequency using the CPI (less food and energy). Monthly data on the outstanding amount of Treasury bonds held by the Federal Reserve comes from federalreserve.gov. All values are adjusted for inflation.

B.8 *Figure 5*

Announcements for all auctions are located at:
<https://www.treasurydirect.gov/instit/annceresult/press/press.htm>

B.9 *Figure 7*

Data on newly issued debt by maturity comes from auction announcements on treasurydirect.gov such as the one displayed in Figure 4. That measure excludes any direct purchases by the Fed during treasury auctions. Specifically, the numbers used to construct the top graph in Figure 7 represents the amount under the number at the intersection of Subtotal and Accepted (displayed in Figure 4) in each auction. The Total amount displayed in the next line includes the Fed's System Open Market Account (SOMA) and is thus not the correct measure for bid-to-cover as it includes the Fed, which is not a private agent.

B.10 *Figure 8*

Data on the High Yield comes from the auction results announcements. The secondary market interest rate by maturity are taken from FRED (each yield is maturity specific treasury constant maturity yield).

B.11 *Figure 9*

Monthly data on the maturity of the outstanding amount of debt held by private investors comes from table FD-5 in the quarterly issue of the treasury bulletin located at fiscal.treasury.gov.