The Aggregate Demand for Treasury Debt

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Abstract

We show that the US Debt/GDP ratio is negatively correlated with the spread between corporate bond yields and Treasury bond yields. The result holds even when controlling for the default risk on corporate bonds. We argue that the corporate bond spread reflects a convenience yield that investors attribute to Treasury debt. Changes in the supply of Treasury debt trace out the demand for convenience by investors. We show that the aggregate demand curve for the convenience provided by Treasury debt is downward sloping and provide estimates of the elasticity of demand. We analyze disaggregated data from the Flow of Funds Accounts of the Federal Reserve and show that individual groups of Treasury holders also have downward sloping demand curves. Groups for whom the liquidity of Treasuries is likely to be more important have steeper demand curves. The results have bearing for important questions in finance and macroeconomics. We discuss implications for the behavior of corporate bond spreads, interest rate swap spreads, the riskless interest rate, and the value of aggregate liquidity. We also discuss the implications of our results for the financing of the US deficit, Ricardian equivalence, and the effects of foreign central bank demand on Treasury yields.

1 Introduction

Figure 1 graphs the yield spread between AAA rated corporate bonds and Treasury securities against the US government debt-to-GDP ratio (i.e. the ratio of the face value of publicly held US government debt to US GDP). The figure suggests that the corporate bond spread is high when the stock of debt is low, while the spread is low when the stock of debt is high.

Figure 1: Corporate Bond Spread and Government Debt
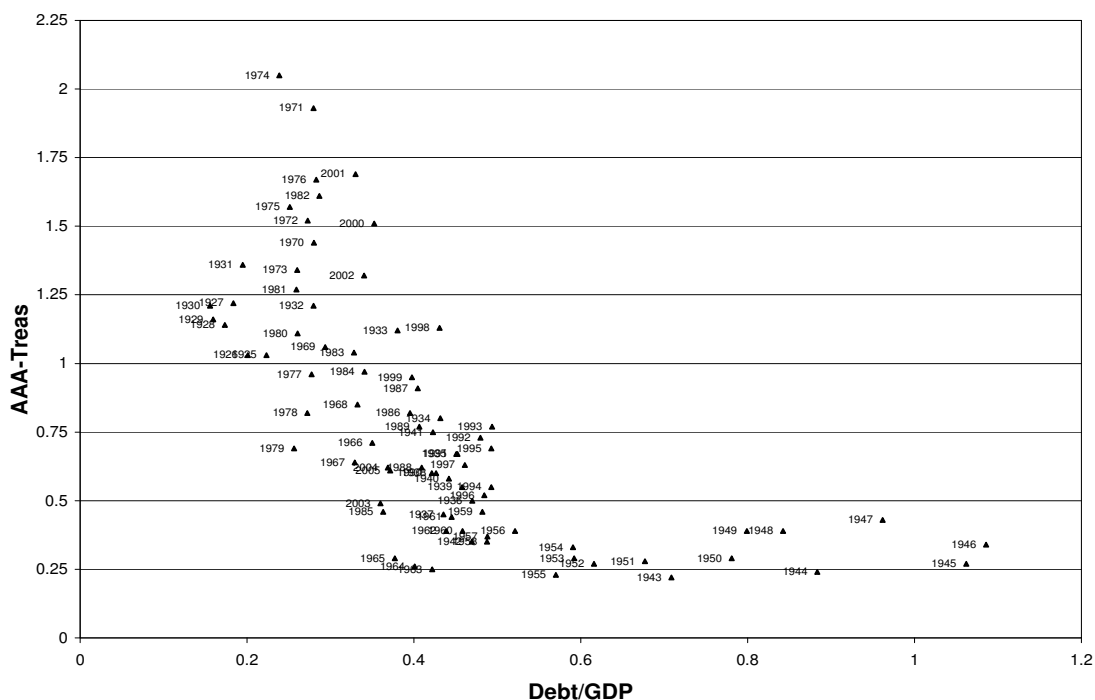
The corporate bond spread (y-axis) is graphed versus the $Debt/GDP$ ratio (x-axis) based on annual ob-
servations from 1925 to 2005. The bond spread is the difference between the percentage yield on Moody's
AAA long maturity bond index and the percentage yield on long maturity Treasury bonds.

In the next sections of the paper, we argue that the negative correlation between the debt-to-GDP ratio and the corporate bond spread arises because of variation in the "convenience yield" on Treasury securities, rather than variation in the default risk of corporate borrowers. Investors place a value on Treasury securities – the convenience value – above and beyond the securities' cash flows. When the stock of debt is low, the marginal convenience valuation of debt is high. Investors bid up the price of Treasuries relative to other

securities such as corporate bonds, causing the yield on Treasuries to fall further below corporate bond rates, and the bond spread to widen. The opposite applies when the stock of debt is high. Variation in the supply of Treasury securities traces out a downward sloping demand curve for Treasuries. We estimate the semi-elasticity of the corporate bond spread to the Debt/GDP ratio, finding that a hypothetical increase in the Debt/GDP ratio from the current level of 0.37 to a new level of 0.38 will raise long term Treasury yields by between between 1.7bps (Table I, Panel B, column (2)) and 3.6bps (Table IV, Panel B, column (6)), relative to corporate bond yields. At the current Debt/GDP ratio of 0.37, we estimate that Treasury yields are 72 bps lower than they would otherwise be if Treasuries provided no convenience value.

Sections 2, 3, and 5 present these results relating the aggregate supply of Treasury securities to the spread between corporate and Treasury bond yields. We show that the results are robust to adding controls for corporate default risk. We also show the results hold when the dependent variable is the spread between a short-maturity corporate bond and Treasury bond, or is the spread between the realized excess returns of corporate bonds over Treasury bonds. These results along with a number of other robustness checks presented in Section 7 strongly support the existence of a convenience yield on Treasury securities.

Section 4 of the paper examines which groups of investors are the strongest drivers of the convenience value of Treasury securities. We first argue that different groups of Treasury owners likely have different motives for holding Treasuries. We then estimate which groups have the least elastic demand curves in order to determine which of the various motives are likely to contribute substantially to the convenience yield on Treasuries. We offer three motives: The first is a *liquidity* motive. Treasury securities are extremely liquid in comparison to corporate bonds. For example, Reinhart and Sack (2000) note that bid-ask spreads on corporate bonds are four to six times larger than those of Treasury bonds. The liquidity motive is analogous to the demand for holding money. Like Treasuries, money offers a low rate of return and yet is held in equilibrium. Theories of money demand suggest that this is because agents derive special liquidity services from holding money. For official groups (foreign central banks, US regional Federal Reserve banks and US state and local governments) and for groups such as banks and households (including mutual funds) the liquidity of Treasuries may be very important. The second motive is a *neutrality* motive. Kohn (2002) suggests that a key reason for why the US federal reserve banks mainly hold Treasury securities is that they do not wish to favor any non-governmental borrower over another. A similar motive may apply to state and local governments and foreign central banks. The third motive is that Treasuries are widely considered the lowest risk interest bearing asset. The *surety* of Treasuries may be attractive for unsophisticated investors who are unable to assess the risk in corporate assets and conservative investors such as pension funds and insurance companies.

We study disaggregated data from the Flow of Funds Accounts and estimate demand curves for each of the main groups that hold Treasuries. We find that the Treasury demands of official groups (foreign central

banks, US regional Federal Reserve banks and US state and local governments) are the least sensitive to the corporate bond spread. Banks, households and the foreign private sector have somewhat more elastic Treasury demands, while groups who likely have very long investment horizons (state/local government retirement funds, private pension funds and insurance companies) have the most elastic Treasury demands. These findings suggest the liquidity and neutrality motives are primary factors behind the "convenience value" from holding Treasuries.

Our results have bearing for important questions in both finance and macroeconomics. In section 6 of the paper we discuss implications of our findings for the behavior of corporate bond spreads, interest rate swap spreads, the riskless interest rate, the value of aggregate liquidity, and the financing of the US deficit. We also use our demand curve estimates to quantify the effects of foreign central bank demand on Treasury yields.

Relation to Literature

Our finding of a significant non-default component in the corporate bond spread is consistent with some recent papers in the corporate bond pricing literature (see Collin-Dufresne, Goldstein, and Martin (2001), Huang and Huang (2001), and Longstaff, Mithal, and Neis (2005)). Duffie and Singleton (1997), Grinblatt (2001), He (2001), Liu, Longstaff, and Mandell (2004), Li (2004), and Feldhutter and Lando (2005) argue for a significant non-default component in the interest rate swap spread. Papers in the prior literature use information from the corporate bond market to estimate the default component of interest rate spreads, and label the residual as a non-default component. Compared to the prior literature, the novelty of our work is to offer a direct test of the convenience yield hypothesis by documenting that the amount of Treasuries outstanding is a key driver of the non-default component of the corporate bond spread and of the interest rate swap spread.[1]

We are aware of only a few papers in the literature that have noted a correlation between the supply of government debt and interest rate spreads. Cortes (2003) documents a correlation between the US Debt/GDP ratio and swap spreads over a period from 1994 to 2003. Longstaff (2004) documents a correlation between the supply of Treasury debt and the spread between Refcorp bonds and Treasury bonds over a period from 1991 to 2001.[2] Relative to both Cortes and Longstaff we study a longer sample, provide a theoretical basis to

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[1]Some of the papers in the prior literature show that the non-default component is related to the specialness of particular Treasury securities. A particular Treasury bond is "special" if the cost of borrowing the bond in the repurchase market exceeds that of other Treasury bonds with similar maturity and cash-flow characteristics. Specialness leads to the yield on the special Treasury bond to fall below comparable Treasury bonds. See Krishnamurthy (2002) for further discussion of specialness. In a sense, we show that the entire Treasury market is "special" relative to other asset markets, and not just that one Treasury is special relative to another Treasury.

[2]There is a related fixed income literature documenting that the auctioned amount of a specific Treasury security affects the value of this security relative to other Treasury securities (Krishnamurthy (2002) and Sundaresan and Wang (2006) are examples). We show an effect relative to non-Treasury securities.

study the relation, and present a more detailed empirical analysis. In particular, we use several approaches to rule out that the relation could be driven by time-varying default risk, and we estimate group level demand curves to shed light on which motives drive the relation between the corporate bond spread and the supply of Treasuries at the aggregate level. [3]

There is a closely related literature that seeks to examine whether the relative supplies of long and short-term Treasury debt has an effect on the term structure of Treasury yields. Early work in this literature was motivated by the 1962-64 "operation twist," where the government tried to flatten the term structure by shortening the average maturity of government debt (see for example Modigliani and Sutch, 1966). More recently, Reinhart and Sack (2000) show that the projected government deficit is positively related to the slope of the Treasury yield curve, suggesting that this is evidence of a supply effect. More systematic evidence of a relative supply effect is provided in Greenwood and Vayanos (2007), who examine data from 1952 to 2005 and show that relative supply is related to the slope of the yield curve as well as the excess return on long-term bonds over short-term bonds. These papers suggest that the Treasury convenience yield varies by maturity, and are complementary to our study.

In macroeconomics, there is a large literature exploring the Ricardian equivalence proposition (Barro, 1974), that the financing choices of the government used to fund a given stream of government expenditures is irrelevant for equilibrium quantities and prices. One implication of the Ricardian equivalence proposition is that the size of government debt has no causal effect on interest rates. Despite a large amount of research devoted to studying this topic, there is yet no clear consensus on the effects of debt on interest rates (see, for example, the survey by Elmendorf and Mankiw (1999)). Barro (1987), Evans (1986) and Plosser (1986) find little or no effect of government debt on interest rates. Laubach (2005) does find such an effect when using forecast levels of government debt rather than currently measured levels (Laubach reports a $4-5$ bps effect per one percentage point increase in Debt/GDP). We provide evidence that the stock of debt affects the interest rates on government bonds. But it is important to note that the effect we identify is on the spread between government interest rates and corporate interest rates. It is possible that Ricardian equivalence fails in a way that government debt has an effect on the general level of interest rates, both corporate and government. Since we focus on spreads, we are unable to isolate such an effect. On the other hand, as we focus on spreads, we can be certain that the effect we identify on government interest rates is over and above any possible effects of government debt on the general level of interest rates. From an empirical standpoint, the advantage of focusing on spreads rather than the level of interest rates is that the spread measure is unaffected by other shocks (such as changes in expected inflation) that affect the level of interest rates and

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[3]Dittmar and Yuan (2006) study a sample of sovereign and corporate bonds in emerging markets and show that the issuance of new sovereign bonds lowers yield spreads and bid-ask spreads of existing corporate bonds. Their result is suggestive that the convenience yield in government bonds may be an international phenomenon.

complicate inference. We also bypass endogeneity issues stemming from government behavior, since it is unlikely that the government chooses debt levels based on the corporate bond spread.

At a broad level, our evidence is consistent with theories that ascribe a unique value to government debt relative to private debt. Bansal and Coleman (1996) present a theory in which short-term debt, but not equity claims, are money-like and carry a convenience value. They argue that the theory can account for the high average equity premium and low average risk-free rate in the US. Aiyagari and Gertler (1990), Heaton and Lucas (1996), and Vayanos and Vila (1999) present general equilibrium models in which an illiquid asset (i.e. stocks) carries a transaction cost while a liquid asset (bonds) do not. In equilibrium, the liquid asset return is lowered by its liquidity feature. Woodford (1990) and Holmstrom and Tirole (1998) argue that the government's credibility gives its securities unique collateral and liquidity features relative to private assets and thereby induces a premium on government assets.

2   The Convenience Yield on Treasury Securities

We articulate the convenience yield theory in the context of a standard representative agent asset-pricing model. Consider first a setting without a convenience value of Treasury securities. The representative agent has utility:

$$\sum_{s=1}^{\infty} \beta^s u(c_s).$$

The Euler equation for the agent pins down the prices of the assets at date t. We price a zero-coupon corporate and Treasury bond at date t for maturity at date $t+\tau$. Let $\pi_{t+\tau}$ be the rate of inflation between t and $t+\tau$. A nominal Treasury bond that pays $1/\pi_{t+\tau}$ units of consumption at date $t+\tau$ has price:

$$P_t^T = E_t\left[M_{t+\tau}^{\pi}\right],$$

where,

$$M_{t+\tau}^{\pi} \equiv \beta^{\tau} \frac{u'(c_{t+\tau})}{u'(c_t)} \frac{1}{\pi_{t+\tau}}$$

is the τ-period nominal pricing kernel at date t. That is, it is the real pricing kernel $\left(\beta^{\tau} \frac{u'(c_{t+\tau})}{u'(c_t)}\right)$ adjusted by inflation. A corporate bond with face value of one pays $\frac{1+D_{t+\tau}^C}{\pi_{t+\tau}}$ units of consumption at date $t+\tau$, where $D_{t+\tau}^C = 0$ in the absence of default and $D_{t+\tau}^C < 0$ if there is default on the bond. The price of this bond is:

$$P_t^C = E_t\left[M_{t+\tau}^{\pi}(1 + D_{t+\tau}^C)\right]$$

We compute the continuously compounded yield spread between corporate and Treasury bond yields in this model as follows. First, we define,

$$i_t^T = -\frac{1}{\tau}\ln P_t^T \quad \text{and,} \quad i_t^C = -\frac{1}{\tau}\ln P_t^C$$

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as the yields on the corporate and Treasury bonds. Then, the yield spread is equal to,

$$
\begin{aligned}
i_t^C - i_t^T &= \frac{1}{\tau}\left(lnE_t[M_{t+\tau}^\pi] - lnE_t[M_{t+\tau}^\pi(1+D_{t+\tau}^C)]\right) \\
&\approx \frac{1}{\tau}\left(E_t[M_{t+\tau}^\pi] - E_t[M_{t+\tau}^\pi(1+D_{t+\tau}^C)]\right) \\
&= \frac{1}{\tau}E_t[-D_{t+\tau}^C]E_t[M_{t+\tau}^\pi] + \frac{1}{\tau}cov_t(M_{t+\tau}^\pi, -D_{t+\tau}^C)
\end{aligned}
$$

The approximation going from the first to second line uses the relation that $ln(1+x) \approx x$ for small x. For high grade corporate and government debt on which interest rates are low, bond prices may be close to one.

We define,

$$
\Delta_t^* = \overbrace{\frac{1}{\tau}E_t[-D_{t+\tau}^C]E_t[M_{t+\tau}^\pi]}^{\text{Default Risk}} \quad + \quad \overbrace{\frac{1}{\tau}cov_t(M_{t+\tau}^\pi, -D_{t+\tau}^C)}^{\text{Risk Premium}} \tag{1}
$$

as the "C-CAPM" value of the spread between corporate bonds and Treasury bonds. The spread has two components.[4]

The first term on the right-hand side reflects the expected losses due to default on corporate bonds ("default risk"). Higher expected defaults leads to a higher yield spread. The second term on the right hand side reflects the economic "risk premium" attached to default states. Depending on how default covaries with the marginal utility of the representative agent, default may carry an additional risk premium.

We next modify this model to introduce a convenience value of Treasury securities. We observe that Treasury securities offer unique services to agents in the economy. As noted in the introduction, some agents are motivated to buy Treasuries for liquidity reasons, some for neutrality reasons, and others for the surety that Treasuries offer. These motives will be reflected in the aggregate demand for Treasury securities. We use the word "convenience" value to encompass the many motives for holding Treasuries. Section 4 of the paper offers disaggregated evidence on the different sources of convenience demand.

The convenience demand theory is analogous to theories of money demand. Agents hold money despite the fact that it is a dominated asset because it offers unique liquidity services. At any point in time, the convenience yield on money can be inferred from the overnight federal funds rate, since that is the price at which an agent can obtain the services of money for one day. Similarly, we argue that the convenience yield on Treasury securities can be inferred from asset prices.

We modify the representative agent utility function to,

$$
\sum_{s=1}^{\infty} \beta^s u(c_s, \theta_s^T; X_s)
$$

where θ_s^T is the agent's real holdings of Treasury assets and X_s is a time s preference shock, which can capture shifts in agents' demand for Treasury assets. The two examples of such a shift which we pursue later

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[4]There is a third component in the spread of equation (1) that arises if we consider the differential tax treatment of corporate and Treasury bonds. We discuss the tax component in Section 7.1.

is a flight to liquidity, as during the subprime crisis, and a change in foreign central bank accumulation of Treasuries.

We motivate our specification of the utility function following the logic of money-demand functions. Suppose that holding Treasury securities reduces transactions costs that would otherwise be incurred because of liquidity needs. Define these transaction costs as,

$$\mu(\theta_s^T, GDP_s; X_s),$$

where, $\mu(\cdot)$ is decreasing in the real holdings of Treasury assets, θ_s^T. GDP_s is the real income of the agent. Rather than a liquidity cost, we may also think of this function as capturing the costs incurred by a central bank that violated its neutrality mandate.

Suppose that these transaction costs are in consumption units, so that the effective consumption of the agent is:

$$C_s \equiv c_s - \mu(\theta_s^T, GDP_s; X_s).$$

We assume that the transaction cost function is homogeneous of degree one in GDP_s and θ_s^T. This captures the idea that the transaction costs double if both the size of the economy and Treasury assets double. Then,

$$C_s = c_s - \mu\left(\frac{\theta_s^T}{GDP_s}, 1; X_s\right) GDP_s$$

Analogous to the similar measure for money, $\frac{\theta_s^T}{GDP_s}$ may be thought of as the reciprocal of the "velocity" of Treasuries.

Define the τ-period pricing kernel at date t as $M_{t+\tau}^\pi \equiv \beta^\tau \frac{u'(C_{t+\tau})}{u'(C_t)} \frac{1}{\pi_{t+\tau}}$. For this modified model, the first order condition gives:

$$P_t^T = E_t\left[M_{t+\tau}^\pi\right] - E_t\left[\sum_{s=t}^{t+\tau-1} M_s^\pi \frac{\partial \mu\left(\theta_s^T/GDP_s, 1; X_s\right)}{\partial \theta_s^T/GDP_s}\right]. \tag{2}$$

The first term on the right-hand side is the present value of the τ-period cashflow from a Treasury security. The second term is the present value of the stream of convenience services obtained from holding the Treasury security from date t to date $t+\tau$. We assume that in equilibrium θ_s^T/GDP_s, M_s^π and X_s are Markov processes so that the present value in the second term can be written only as a function of time t variables. We define a function,

$$\tau v'\left(\frac{\theta_t^T}{GDP_t}; X_t\right) \equiv -E_t\left[\sum_{s=t}^{t+\tau-1} M_s^\pi \frac{\partial \mu\left(\theta_s^T/GDP_s, 1; X_s\right)}{\partial \theta_s^T/GDP_s}\right],$$

to be equal to the present value. Note that the function $v'(\cdot)$ reflects expectations of the underlying economic variables.

Repeating the steps of converting prices into yields, we find,

$$i_t^C - i_t^T \approx \overbrace{\frac{1}{\tau}E_t[-D_{t+\tau}^C]E_t[M_{t+\tau}^\pi]}^{\text{Default Risk}} + \overbrace{\frac{1}{\tau}cov_t(M_{t+\tau}^\pi, -D_{t+\tau}^C)}^{\text{Risk Premium}} + \overbrace{v'\left(\frac{\theta_t^T}{GDP_t}; X_t\right)}^{\text{Convenience Yield}} \tag{3}$$

As in equation (1), the yield spread has a default risk component and a risk premium component. Since Treasury securities are assumed to provide a convenience value, the bond spread is increased by a convenience yield.

The yield spread in (3) characterizes the agent's demand function for Treasury debt. If the US government supplies Θ_t^T of debt, then the equilibrium spread we should observe in the market is:

$$\Delta_t^* + v'\left(\frac{\Theta_t^T}{GDP_t}; X_t\right) \tag{4}$$

We refer to Δ_t^* as the "default" component of the corporate bond spread, and $v'(\cdot)$ as the "non-default" component of the corporate bond spread.

3 Evidence

This section presents regression evidence in favor of the convenience yield hypothesis for the determination of Treasury yields. The regressions we present involve the time series of the bond yield spread (the yield on corporate bonds minus the yield on Treasuries) as the dependent variable and the log of the ratio of the stock of US government debt to US GDP as the independent variable. The regressions also include a number of controls we discuss below. Comparing equation (4) with (1), we see that under the C-CAPM null, changes in Θ_t^T have no effect on the yield spread, while under the alternative the coefficient on (log) government $Debt/GDP$ in this regression will be negative.

There is one principal difficulty in interpreting this evidence. If changes in Θ_t^T/GDP_t are correlated with changes in Δ_t^* the regression of the bond spread on $log(\Theta_t^T/GDP_t)$ may yield a significant coefficient, despite there being no causal relation running from Θ_t^T/GDP_t to the spread. There are two sources of such a correlation, omitted variable bias and reverse causality.[5]

Our main concern is potential omitted variable bias, which we deal with in three ways. First, we introduce a variety of controls that attempt to directly capture variation in Δ_t^*. We include corporate sector default risk variables as well as a business cycle measure (slope of the yield curve) that may control for changes in default risk and default risk premia. Second, we present regressions where the dependent variable is the realized excess return on corporate bonds over government bonds (as opposed to the yield spread). Since return realizations encompass default and default-related events such as corporate bond downgrades, the return series will not be affected by the default risk term in (3). In these regressions, we also include proxies for marketwide risk premia to control for the risk premium in the corporate bond returns. Last, we study

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[5]The spread, Δ_t^* could also fall if government debt becomes more risky when Θ_t^T rises, holding the risk of corporate debt fixed. This seems implausible on a priori grounds. The government can always print money to pay off its debt. While this possible action may lead to (expected) inflation and thereby raise the interest rate on government debt, it will lead to an equal rise in the interest rate on corporate debt and no effect on our spread measure.

disaggregated data where we present evidence consistent with our theory based on instrumental variables regressions.

Of lesser concern is the possibility of reverse causality where government behavior is an endogenous response to a change in yields. First, note that the price variable in our setting is a corporate bond spread rather than an interest rate. The US government is unlikely to choose the stock of outstanding debt in response to a change in the spread of corporate bonds relative to Treasuries. It seems plausible that the government's decision may respond to a change in the level of interest rates, but not a change in interest rate spreads. Our use of interest rate spreads rather than the level of interest rates to discern the effects of government debt policy avoids a number of difficult issues that prior work testing Ricardian equivalence has had to contend with. Second, note that if the government's behavior is endogenous to the convenience yield, our regressions will likely be biased against finding a negative relation between the yield spread and Treasury supply. Suppose a shock to investor's Treasury demand raises the convenience yield. To the extent that the government responds to this shock, it will increase the supply of debt to partially offset the increase in convenience yield. Then, our estimation will trace a curve from a low convenience yield/low supply point to a high convenience yield/high supply point. That is, we should find a positive relation between convenience yield and supply. In fact, we find a negative relation.[6]

3.1 Demand Function

We adopt the following functional form in the regressions of this section. We assume that $v'(\cdot)$ can be written as:[7]

$$v'(\Theta_t^T; X_t) = \alpha + B \ log \ (\Theta_t^T/GDP_t), \quad \text{where} \quad B < 0,$$

and estimate the following linear regression:

$$S_t = A + B \ log \ (\Theta_t^T/GDP_t) + C \ Y_t + \epsilon_t. \tag{5}$$

S_t is the corporate bond spread (or bond excess return), and Y_t are controls to capture variation in default risk and default risk premia. We are centrally interested in estimating the semi-elasticity B.

The log function specification reflects that the marginal convenience valuation decreases more slowly as Θ_t^T increases. In contrast to our convenience yield theory, the log specification implies that v' may become negative. However, this only happens in two of the years we analyze (1945 and 1946 when the US Debt/GDP

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[6]It is also possible that a shock we have not controlled for causes the government to spend resources (or lower taxes) in a way that increases the revenues of the corporate sector and raises the Debt/GDP ratio. In this case the default risk premium component Δ_t^* will fall when Θ_t^T rises. We deal with this concern as an omitted variable bias.

[7]We use the book value of Treasury debt for Θ_t^T rather than market value because our equilibrium relation, (4), expresses prices (the spread) as a function of quantities (book value of Treasury debt). If we were to use the market value of Treasury debt, the quantity measure would also reflect market prices.

ratio is above one).[8] We adopt the log function primarily so that the coefficient, B, can be interpreted as the semi-elasticity of the bond spread with respect to the stock of debt. We also present regressions based on an exponential specification where v' is always positive in Section 4. Over the range of variation of the Debt/GDP ratio, the results from the exponential specifications are close to those from the log specification.

Note also that for now we suppress shocks to convenience demand (X_t). Alternatively, the error term captures level shocks to convenience demand. After presenting our main evidence to reject the C-CAPM null, we will explore shocks to convenience demand.

3.2   Long-term Corporate Bond Spread

Figure 2 graphs the percentage spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds. Both data series are from the Federal Reserve's FRED database and extend from 1925 to 2005 in the figure. The Moody's index is constructed from a sample of long maturity (> 10 years) industrial and utility bonds. The Treasury yield is available from 1925 - 1999, while the Moody's AAA yield is available from 1919 - 2005. We use the yield on 20 year maturity Treasury bonds for 2000 - 2005. We use annual observations, sampled in October of the year.[9,10]

The figure also graphs the ratio of US GDP to Debt (i.e. velocity) over the same period. The two series in Figure 2 are the same as those represented in Figure 1. Debt is for the end of the third quarter of each year, which corresponds to the government's fiscal year end. GDP is for the year leading up to that quarter. The debt-to-GDP series is downloaded from Henning Bohn's website, and updated until 2005 from the Economic Report of the President and NIPA data. Bohn constructs the measure as the ratio of publicly held Treasury debt (from the WEFA database, Federal Reserve Banking and Monetary Statistics, and recent issues of the Economic Report to the President) relative to either GDP (after 1959) or GNP (prior to 1959). This measure of debt includes debt held by the Federal Reserve, but excludes debt held by other parts of the government such as the Social Security Trust Fund. In Section 7 we present results where we construct the debt measure by also excluding the Federal Reserve's debt holdings.

Our theory suggests that the bond yield spread should be highest when the stock of Treasury debt is low. Figures 1 and 2 suggest such a relation but do not address statistical significance nor control for possible omitted variables, notably changes in corporate default risk and default risk premia. Table I presents

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[8]Omitting these years leads to slightly stronger results, i.e. a steeper relation between the bond yield spread and the Debt/GDP ratio. See Section 7.

[9]The corporate bond and Treasury bond yields are for coupon bonds, not zero-coupon bonds, as derived in our simplified theory.

[10]While both the Moody's AAA yield and Treasury yield correspond to bonds with approximately 20 year maturities, there may be mismatch in the exact maturities between the bonds. We add a covariate measuring the slope of the yield curve to control for any maturity mismatch effect.

Figure 2: Corporate Bond Spread and Government Debt
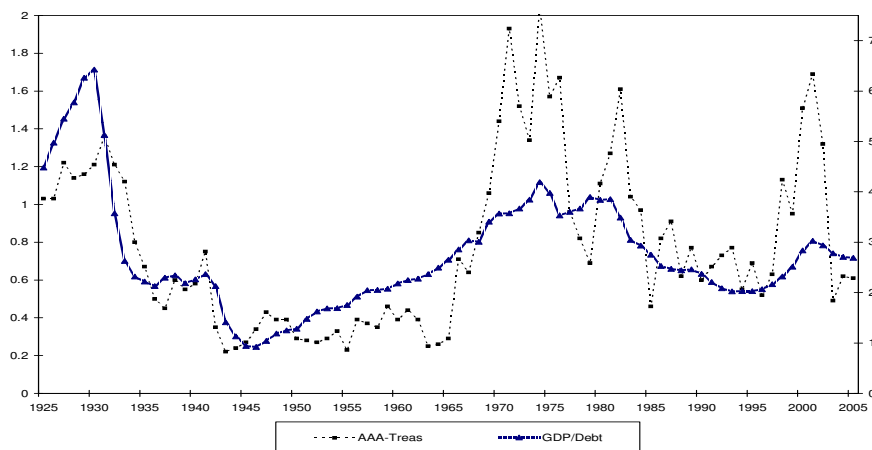
The corporate bond yield spread (labeled "AAA-Treas" and on left y-axis) and $GDP/Debt$ (on right y-axis) are graphed from 1925 to 2005. The corporate bond yield spread is the percentage difference between the yield on Moody's AAA bond index and the yield on long maturity Treasury bonds.

regressions relating the yield spread between AAA rated corporate bonds and Treasury securities, and the log of the ratio of Debt to GDP. Panel A, column (1) of the table confirms that there is a statistically significant negative relation between the variables of interest. The coefficient of -0.78 implies that a one standard deviation (0.42) increase in $log(Debt/GDP)$ reduces the bond yield spread by 33 basis points. Columns (2) - (7) contain a series of controls to measure the default risk of the corporate sector, the risk premium investors charge to bear this default risk, as well as a business cycle control that can further proxy for variation in default.

Columns (2) and (3) control for default risk and the default risk premium using the spread between the Moody's BAA minus Moody's AAA long maturity bond yields, which measures the relative default risk and risk premium of lower and higher grade corporate bonds. We rationalize using this spread to capture default by noting that if default risk of the corporate sector rises, or the risk premium investors demand for absorbing default risk rises, one would expect to see an increase in the yield spread between higher and lower grade corporate bonds. Thus the BAA-AAA spread will capture time variation in corporate default risk as well as time variation in the market price of default risk (equation (1)). The Moody's BAA series is from the Federal Reserve's FRED database and corresponds to the observation for October of a given year.

As expected, the default variable is positively related to the corporate bond spread (column (2)). However, adding the control does not materially alter the importance of $log(Debt/GDP)$.

We next add the slope of the yield curve as a further control. The slope of the yield curve is a measure the state of the business cycle and is known to predict the excess returns on stocks. For example, if investors are more risk averse in a recession, when the slope is high, they will demand a higher risk premium to hold corporate bonds. Thus, the slope of the yield curve serves as a second measure of variation in Δ_t^*. We also note that to the extent that corporate default risk is likely to vary with the business cycle, the slope variable can also control for the default risk component of Δ_t^*. The slope is measured as the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). The interest rate on Treasuries with three month maturity is from FRED from 1934 to 2005 and from the NBER macro data base prior to that. The interest rate on Treasuries with ten year maturity is from FRED from 1953 to 2005 and from the NBER macro data base prior to that. The interest rates correspond to the observation for October of a given year.

The regression including slope is reported in column (3) of the Table and results in a similar coefficient estimate on the $log(Debt/GDP)$ variable. However, the significance of the default control disappears because slope and the BAA-AAA spread contain similar default information. We have also run specifications that include the price/earnings ratio on the stock market to measure investor risk aversion. The inclusion of this control does not alter our findings. The results are available upon request.

Column (4) replaces the BAA-AAA control with a default measure computed by Moody's-KMV, who are the current industry standard in calculating default probabilities for corporate bond pricing. Their computation is based on Merton (1974) which treats the debt of a firm as a riskless asset minus a put option on the firm's assets. Using information on a firm's capital structure and stock market value, Moody's-KMV computes the distance to default on debt (i.e. moneyness of the put option). This information along with stock price volatility is used in a standard option pricing formula to compute the default probability for a given firm. We use the median EDF reported by Moody's-KMV for large firms (defined as firms with book values > \$300 million in current dollars). The EDF measure is available back to 1969. The results in column (4) show that the EDF default measure is as advertised, very informative. Crucially, the coefficient on $log(Debt/GDP)$ remains highly significant and of roughly the same magnitude as in other specifications. The coefficient differs from columns (1)-(3) primarily because the regression covers a shorter sample period, 1969 - 2005.

Columns (5) and (6) contain a default measure that we construct motivated by the success of the EDF measure. The EDF measure has two important inputs: stock price volatility and distance to default. We construct a default measure that we can extend back to 1926 based on stock price volatility. We calculate weekly returns on the value-weighted S&P index based on daily returns. As the volatility measure for a given year, we compute the variance of the weekly log returns over the year leading up to the end of September

of the current year. We annualize the variance of weekly log returns by multiplying by 52. Over the 37 years for which we have both EDF data and stock market volatility estimates, the correlation of these two default measures is 0.78. This provides strong support for the use of stock market volatility as a default control over the full sample from 1926 to 2005.[11] As expected, volatility is significant when introduced alone – indeed, more significant than the BAA-AAA measure from column (2).[12] As with the BAA-AAA spread, the volatility measure loses significance when introduced along with yield curve slope because both measures contain similar default information. The coefficients on $log(debt/GDP)$ are similar in magnitude and significance to the other specifications.

Column (7) presents another default control that is successful in pricing corporate bonds, this one from from Campbell, Hilscher, and Szilagyi (2006) (that is in turn drawn from Chava and Jarrow, 2004). The authors consider a sample of publicly traded firms in the Wall Street Journal Index, the SDC database, SEC filings and the CCH Capital Changes Reporter. If a firm files for bankruptcy, delists, or receives a D rating, over the period January 1963 through December 2003, the firm is labeled as distressed. The percentage of distressed firms in each year is the measure of aggregate default risk. This variable has a correlation of 0.52 with the volatility measure. Once again our results are robust to the inclusion of this default measure. The higher coefficient is due to the sample period from 1963 - 2003 (e.g., using the volatility default measure over this period produces a -1.27 (4.32) coefficient on $log(Debt/GDP)$.

Thus far, we have discussed the robustness of our results to a variety of measures of default risk and risk premia.[13] We next discuss in more detail the statistical significance of the coefficient on $log(Debt/GDP)$. Because the underlying series in these regressions are persistent, one may be concerned that the results about statistical significance are spurious. We provide three approaches to argue that this is not the case. First, all of the regressions in Panel A of Table I report t-statistics based on Newey-West robust standard errors that allow for first order autocorrelation. Second, in Panel B we report results from redoing each of these

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[11]Results are very similar if we use as our volatility measure the variance of daily returns over the same period or the predicted value from a GARCH(1,1) model estimated over the full sample.

[12]The stock market volatility series is significantly higher in the 1920s and early 1930s than in later periods. In particular, there are three years for which the volatility observations are an order of magnitude larger than the average. Thus, the coefficient on stock market volatility varies significantly across subsamples (see Table X). We have experimented with using a censored volatility series. Although censoring increases the magnitude and significance of the volatility control, it has very little effect on the coefficient on $log(Debt/GDP)$. As a result, we present the results from the non-censored series in all Tables.

[13]Callability is an issue we deal with in the robustness section of the paper. Duffee (1988) points out that the Moody's AAA index includes callable corporate bonds. The Treasury, at various times, has also issued callable long-term bonds. Thus, the bond yield spread may also reflect an interest rate option. Duffee proxies for the moneyness of the call option using the level of interest rates and shows that shows that yield spreads vary significantly with the level of interest rates. We add levels of short and long-term interest rates in the robustness section of the paper and show that it has no appreciable effects on the coefficient on $log(Debt/GDP)$. We also note that callability does not affect the results we present in the next two sections on excess bond returns and short-term corporate bond spreads.

specifications using a GLS approach where we explicitly model the time series as AR(1). Specifically, the regressions are Cochrane-Orcutt AR(1) two-step regressions. They uniformly confirm the significance of the findings in Panel A. Third, we compute the decade averages of the data, and run regressions based on nine data points. By decade-averaging, we explicitly only exploit low-frequency movements in the series. Using controls based on the BAA-AAA spread and the yield curve slope, the coefficient on $log(Debt/GDP)$ in this decade average regression estimate by OLS is -1.10 (4.27). If we use volatility and slope, the coefficient is -1.06 (4.82). In both cases, the coefficients are highly significant and of the same order of magnitude as other specifications.

3.3 Excess Bond Returns

We next present evidence using the realized return on corporate bonds relative to Treasury bonds as dependent variable. By using realized returns we bypass any problems arising from the fact that the corporate bond yield spread partly reflects the default risk of corporate issuers. That is, since return realizations encompass default events, including both defaults and corporate bond downgrades, they only measure the economic risk premium and the non-default component of the relative pricing of corporate bonds and Treasury securities. The positive results we present below are further evidence that our results are not being driven by inadequate controls for corporate default risk.

Table II, Panel A presents regressions relating the realized excess returns to the ex-ante yield spread between corporate and Treasury bonds. The yield spreads correspond to observations for September of a given year. The dependent variable is the percentage excess return on long term corporate bonds over long term government bonds, at one, three, and five year horizons. The return data are from Ibottson, beginning in 1926 and ending in 2004. Returns are annual from October to next September. The Ibbotson corporate bond index is based on the total return from holding high grade (typically AAA and AA) corporate bonds with approximately a 20-year maturity. AAAs and AAs almost never default over the next year. The default-events in holding these bonds is that the probability of default rises and the bonds deliver a low return. The latter is the relevant default risk in holding high grade corporate bonds over a short period. If a bond is downgraded during a particular month, Ibbotson includes its return for that month in the computation of the index return before removing the bond from future portfolios. The results confirm that the bond yield spread predicts future excess returns, and is thereby not purely reflective of default risk considerations. These results support our use of the bond spread as dependent variable in the prior regressions.

Table II, Panel B presents regressions analogous to Table I, but using the realized excess return (rather than the corporate bond yield spread) as dependent variable. We include the slope of the yield curve as independent variable. *slope* captures the state of the business cycle, and any possible time variation in investor risk aversion that may drive the expected returns on risky assets. Relative to Table I, we consider

two additional independent variables. *durationhedge* is the realized returns on long term government bonds over short term bonds, and is meant to capture any possible biases due to differences in duration of the underlying corporate bonds and Treasury bonds. We also include the standard four factors used in empirical asset pricing to proxy for other known risk factors driving excess returns: the excess return on the stock market as a CAPM factor, the excess return on high book-to-market stocks over low book-to market stocks, the excess return on small stocks over big stocks, and the excess return on past high-return stocks over past low-return stocks. These latter three factors are the Fama-French factors and the momentum factor. We sum the monthly factor excess returns from Ken French's data library to obtain annual values.[14]

The results largely accord with our previous findings. The $log(Debt/GDP)$ ratio is negatively related to realized returns. Our strongest results are at the three-year and five-year horizons. This may reflect that the Debt/GDP ratio picks up low frequency movements in the convenience yield on Treasury securities. The magnitudes reported for the semi-elasticity are also in line with our previous findings. If we divide the coefficient estimate on $log(Debt/GDP)$ of Table II-B by the coefficient estimates on $AAA - Treasury$ from Table II-A (to convert back into yield equivalents), we arrive at numbers around -1 which are similar to estimates from previous tables.

3.4 Short-term Corporate Bond Spread

Table III presents similar regressions to those reported in Table I, but using a three to six month maturity corporate to Treasury spread as dependent variable, rather than the approximately 20 year spread of Table I. The dependent variable is constructed using commercial paper (CP) and Treasury bills data, and corresponds to October of a given year.[15]

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[14]The fact that corporate bonds offer a higher return than Treasury bonds raises the standard arbitrage question of why an investor who has no convenience demand for Treasuries does not short Treasuries and purchase corporate bonds, and thereby eliminate the return differential. To engage in this transaction, the arbitrageur needs to borrow Treasury securities through a repurchase agreement and sell the borrowed bonds. He borrows Treasury bonds, leaving cash with the bond lender to cover the value of the Treasury security, and then sells the bonds in the market (see Krishnamurthy, 2002, for a description of the repurchase market). Note that the cash proceeds from the short must be left with the bond lender as security for borrowing the bonds, and cannot be used to directly purchase corporate bonds. To go long the corporate bonds, the arbitrageur must purchase a corporate bond, borrowing cash against the corporate bond in the repurchase market. There are limits to carrying out this arbitrage. First, the repo market on corporate bonds is quite limited, involving large capital requirements and expensive repo rates. Moreover, the arbitrageur will also have to post capital in order to short the Treasury bonds. Together these obstacles will limit carrying out the arbitrageur's strategy.

[15]We calculate an annual CP-Bills spread using annualized yield as of October of each year. The specific data series used are as follows: The commercial paper data from 1971 to 2005 is from Global Insight, "INTEREST RATE: COMMERCIAL PAPER, 3-MONTH (PER ANNUM,NSA)." From 1921 to 1970 we use the rate on prime commercial paper of 4-6 month maturity from Banking and Monetary Statistics. The T-Bill data from 1971 to 2005 is from FRED's "3-Month Treasury Bill: Secondary Market Rate." From 1959 to 1970 the T-Bill data is from FRED's "6-Month Treasury Bill: Secondary Market Rate".

The results reported are consistent with those of Table I. Increases in $log(Debt/GDP)$ decrease the CP-Bill yield spread.[16] The effect is statistically significant in all but two of the specifications (the GLS estimations using the EDF control and the $pct-failed$ control). The $BAA-AAA$ and volatility default measures are statistically significantly related to the CP-Bill spread. However, both the EDF measure and the $pct-failed$ measure are insignificant, and have a negative sign, as a default control in these regressions.

In comparing the results from Table I to those in Table III, we note that the coefficient estimates on $log(Debt/GDP)$ are roughly half in the CP-Bill yield spread regressions compared to the long-term spread regressions. The result may be surprising, because prior theoretical work has argued for liquidity premia on short-term debt, but not especially on long-term debt.[17] Our results suggest the opposite: larger convenience yield effects on long-term debt relative to short-term debt.

We think the reason for this pattern is that the relative supplies of short versus long-term debt affect their relative convenience yields, while in our theoretical model only the total supply of Treasury debt matters. The smaller effects on short-term debt are likely driven by the market being more saturated at short maturities. Greenwood and Vayanos (2007), using data from 1952-2005, report that on average 74% of cash-flows from Treasury securities are due within 5 years. Further, there are more private debt substitutes (with convenience properties) for short-maturity Treasury bills than there are for long-maturity Treasury bonds. For example, for a short maturity, an investor can invest in a 3-month repurchase agreement collateralized by mortgage-backed securities. This investment can be easily unwound, is virtually default free, and there is a large stock of mortgage-backed securities that can serve as collateral. The relatively greater supply of short-term convenience assets compared to long-dated convenience assets, implies that a given change in Treasury supply has a proportionately smaller effect on the supply of short-term convenience assets. This can help explain the smaller elasticity of convenience yield with respect to supply, at the short-end.

Greenwood and Vayanos (2007) in their study of debt maturity structure find that the supply of long-term Treasury debt, relative to short-term debt, has greater explanatory power for the term premia and

From 1931-1958 the T-Bill data are from the NBER's series "U.S. Yields On Short-Term United States Securities, Three-Six Month Treasury Notes and Certificates, Three Month Treasury 01/1931-11/1969", and for 1921-1930 the T-Bill data are from the NBER's series "U. S. Yields On Short-Term United States Securities, Three-Six Month Treasury Notes and Certificates, Three Month Treasury 01/1920-03/1934."

[16]Commercial paper is not callable, while long-term corporate bonds are typically callable. Thus, the CP-Bills spread does not have a call option component as does the long term corporate bond yield spread. Moreover, the maturity of commercial paper and T-Bills can be exactly matched, while there may be some maturity mismatch between the Moody's AAA bond yield and the long term Treasury bond yield. It is encouraging that our results hold for the CP-Bills spread suggesting that the call option and maturity mismatch factors are not responsible for the correlation we document.

[17]See for example, Heaton and Lucas (1996) and Bansal and Coleman (1996), who study models in which short-term debt, and not long-term assets, provide liquidity services that lead, in equilibrium, to a lower yield on these assets. These models can help to explain the high equity premium – that is, the high return on stocks compared to Treasury bills. For empirical evidence of liquidity premia on T-bills, see Duffee (1996).

excess returns of bonds of longer maturities. This finding is similar in spirit to our results of stronger supply effects on the long-term corporate bond spread.

Finally, as a revealing example of the relative supply effect, consider the events of October 31, 2001. On that day, the Treasury announced that they would discontinue issuance of the 30-year bond. Upon announcement, the yield of the 30-year Treasury bond fell by 34 bps. There was little effect on the yields of short-term Treasuries.

The results from the last three sections – using the long-term bond spread, the excess return on long-term bonds, and the short-term corporate bond spread – provide three consistent pieces of evidence that there is a significant convenience yield affecting Treasury interest rates. Further, an important part of the corporate bond spread is due to variation in the supply of Treasury securities, suggesting that the corporate bond spread has a significant "non-default" component. This result accords with some evidence from the finance literature on corporate bond pricing. In a recent analysis of corporate bonds using prices from the credit-default swap market, Longstaff, Mithal, and Neis (2005) conclude that the default component is important, but does not account for the entire corporate spread. They find evidence of a significant nondefault component ranging from about 19 to 105 *bps* depending upon the bond. Other recent papers in the literature reach similar conclusions (see, for example, Elton *et al* (2001), Collin-Dufresne, Goldstein, and Martin (2001), or Huang and Huang (2001)). Our results not only confirm the existence of a non-default component over a long time period, but tie this non-default component to the supply of Treasury securities.

3.5   Demand Shock: Flight to Liquidity

So far we have exploited variation in Treasury supply to provide evidence of a convenience yield on Treasuries. In this section we provide further evidence based on a shock to agents' demand for convenience. Documenting that shocks to convenience demand generates fluctuations in the corporate-Treasury yield spread is econometrically more difficult than our main Treasury-supply based approach. While Treasury supply is observable, fluctuations in Treasury demand are not directly observable. One approach to address this issue is to focus on periods commonly thought to be characterized by flight-to-Treasury-liquidity and document whether spreads widen substantially during such periods. Below we focus on the period around the subprime mortgage crisis in 2007.

Figure 3 (top panel) graphs the CP-Bills spread (3 month Financial Commercial Paper minus 3 month Treasury Bills) and the long-term corporate bond spread (AAA Moody's index yield minus 20 year Treasury yield) using daily observations over the year 2007. This period includes the subprime mortgage crisis. Both spreads widen around August of 2007, at the onset of the crisis. The average CP-Bill spread from January 1, 2007 up to August 1, 2007 is 33 bps. After August 1, the spread averages 109 bps. For the corporate bond spread, these numbers are 49 bps (early) and 77 bps (late).

Figure 3: Spreads and Yields in 2007
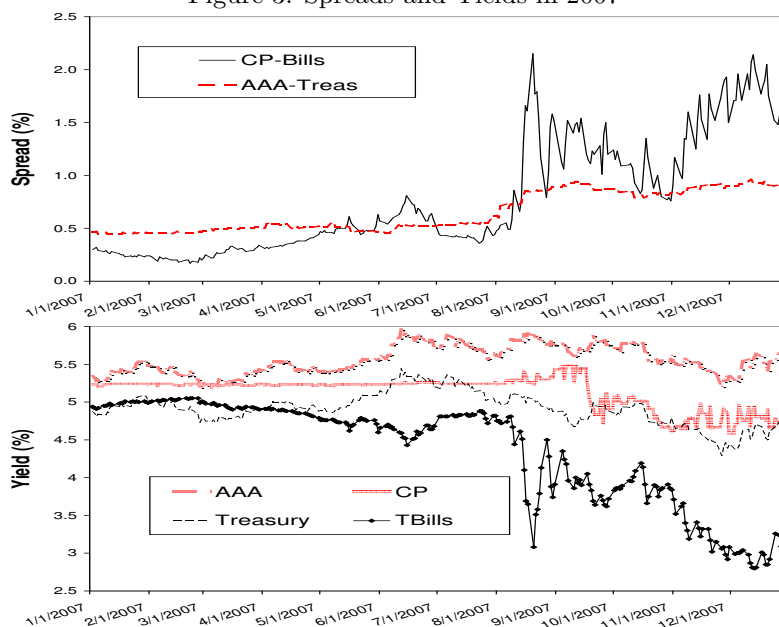
The figure presents yields and spreads during the year 2007, including the subprime mortgage crisis. The top panel graphs short and long-term corporate bond spreads, while the bottom panel graphs the individual interest rate series represented in the spreads.

The bottom panel of the figure graphs the individual series represented in the spreads. Note the behavior of the Treasury Bill yield when compared to the commercial paper yield. It is very striking that almost all of the movement in the CP-Bills spread is a reflection of movements in the Treasury Bill yield, rather than movements in the commercial paper yield. This is another piece of evidence for our hypothesis that there is a unique demand for Treasury securities.

In order for the pattern of relatively flat commercial paper yields and dramatically lower Treasury yields to *not* be driven by a convenience demand shock for Treasuries, the default risk of commercial paper and the general level of the riskfree interest rate would have to move by exactly the same amount in opposite directions. This seems unlikely, which is why the graph is evidence of a Treasury-specific demand shock.

Note that it is harder to detect a similar demand effect for the long-term Treasury bond from the graphs. The long-term spread rises, but this change is not obviously due to movements in the long-term Treasury yield. This should be expected. Flight to liquidity episodes are short-lived – typically lasting from a few weeks to at most one year. The maturity of a short-term bond, as in the CP-Bill spread, is of the same order of time as the duration of the high demand episode. For a long-term bond, one specific high demand

episode constitutes a small fraction of its life. Thus, the short-term yield spread is much more responsive than the long-term yield spread to a high-frequency demand shock. Note from the figure that the CP-Bill spread is more volatile than the long-term bond spread. Also, from Tables I and III, we note that the regression R^2s in the CP-Bill spread are lower than that of the long-term spread. Our regressions do not have adequate measures for the demand shocks, and these shocks play the larger role in explaining movements in the CP-Bills spread. Indeed, drawing from the subprime example, perhaps the greater significance of stock market volatility in the CP-Bills spread regression is because volatility partly captures crises periods and liquidity-demand shocks, albeit imperfectly.

These observations suggest that our study of supply effects is better served by focusing on long-term spreads, which is how we proceed in the rest of this paper. The long-term spread reflects the expected demand shocks over the entire life of the long-term bond. This expected demand is likely to be stable, certainly far more stable than the demand for the short-term bond. Thus, the long-term spread serves as the sharper laboratory for isolating the effects of supply, since our measured variation in supply traces along a relatively stable convenience demand curve.

3.6   Treasury Substitutes and the Full Effect

Our results so far suggest that investors assign a convenience value to Treasury securities which lowers their yield relative to corporate securities with similar cashflow properties, and this value rises as the stock of Treasury debt falls. As the stock of Treasury debt falls, we would expect that investors substitute some of their demand into other low risk securities that may offer some, but perhaps not all, of the convenience service of Treasury securities. Such substitutes may include high grade corporate bonds and agency debt. Then, as the supply of Treasury assets falls, agents will bid up the price of substitute securities. We present results consistent with this prediction based on corporate bonds. Our regressions do not exploit changes in the supply of corporate debt – such changes are likely to be endogenous to the corporate bond spread – but only exploit changes in the supply of Treasury debt.

In Table IV, Panel A, we use the BAA-AAA yield spread as the dependent variable and regress this measure against $log(Debt/GDP)$ with various controls. The controls include the slope of the yield curve and the volatility default control. The volatility and slope controls are, not surprisingly, more important in explaining the BAA-AAA spread than the AAA-Treasury spread. However, the negative and significant coefficient on $log(Debt/GDP)$ indicates that the BAA-AAA spread is also affected by the same convenience yield effects we have shown for Treasury bonds, consistent with the idea that the AAA bond is a convenience substitute for Treasury bonds. In Table IV, Panel B, we redo our main regressions but now use the $BAA - Treasury$ spread as dependent variable. Since the results of Table IV Panel A suggest that the AAA rate is also affected by changes in the supply of Treasury debt, the regressions using the $AAA - Treasury$

spreads underestimate the full convenience demand effect. Consistent with this statement, we find that the coefficient estimates in Table IV, Panel B are almost twice as large as those reported in Table I. These coefficients represent our estimate of the full convenience yield effect.

We note that the evidence that AAA-rated corporate bonds have convenience properties implies that the BAA-AAA yield spread may not be a valid control for default risk in our previous regressions for AAA-Treasury yield and return spreads. This will be the case if convenience demand shocks affect both the BAA-AAA spread and enter the error term in the regressions. The volatility default control is not affected by such concerns so we present estimates only using the volatility control in the tables that follow.

4   Sources of Convenience Demand

Using a variety of measures, we have shown that the aggregate demand curve for Treasury debt is downward sloping. We have argued that the demand curve is not perfectly elastic because Treasury securities provide a convenience service. We next turn to analyzing disaggregated data from the Flow of Funds Accounts of the Federal Reserve to shed light on the sources of this convenience demand. We first argue that different groups of Treasury owners likely have different motives for holding Treasuries. We then estimate which groups have the least elastic demand curves in order to determine which of the various motives are likely to contribute substantially to the convenience yield on Treasuries.

4.1   Who Holds Treasury Debt and Why?

Table V presents statistics on the fraction of Treasury securities held by different groups in the economy. The data are from Table L.209 in the Flow of Funds Accounts of the Federal Reserve. They are annual from 1945 to 1951. From 1952 onwards the data are quarterly, and we use the values for the end of the third quarter. Table V presents the average fraction of Treasury holdings across these years.[18]

The mean holdings of each group is reported in the second column. There are two groups with strong trends, for which the means are misleading. The Foreign Official Holdings (i.e. central banks) category is an important recent holder of Treasury securities. This group's holdings rise from 1971 with the abandonment of the Bretton Woods system. The maximum holding of 0.29 is in 2005. The Banks/Credit Institutions group has its maximum holdings of 0.42 in 1945, which subsequently decreases in the 1950s and 1960s. The Fed-Treasury Accord (Wicker, 1969) incentivized banks to hold Treasury securities during World War II

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[18]For simplicity, Table V omits a few small categories of Treasury owners. The omitted categories are nonfinancial corporate business, nonfarm noncorporate business, Federal government retirement funds (for whom reported holdings of Treasuries are zero up to 1986), government-sponsored enterprises, and brokers and dealers. The total share of Treasuries owned jointly by these groups averages 4.8% with a maximum of 9.4% and a minimum of 1.4%

because the Fed, in pegging Treasury interest rates, had agreed to allow the private sector to freely exchange Treasury securities for reserves.

We offer three motives behind the Treasury holdings, reflected differently across the groups in Table V. First, a number of observers have noted the superior liquidity of Treasury securities over other assets such as corporate bonds. For example, Reinhart and Sack (2000) note that bid-offer spreads on corporate bonds are four to six times larger than those of Treasury bonds. Krishnamurthy (2002) shows that the spread between commercial paper and Treasury bills is highly correlated with the spread between more and less liquid Treasury securities. Krishnamurthy suggests that the comovement in spreads reflects economy-wide variation in agents' desire to hold liquid securities. Changes in agents' demand for liquidity drives both the liquidity spreads within the Treasury market as well as the spread between less liquid commercial paper and Treasury securities. These observations suggest that a *liquidity motive* is an important factor driving Treasury holdings. Managers of large reserve positions (foreign central banks, Federal Reserve banks) and those with short-term liquidity needs (households, banks and credit institutions) are likely to purchase Treasuries because of their superior liquidity. Banks and credit institutions also face capital requirements that favor the liquidity/low risk of Treasury securities over other assets.

Second, Kohn (2002) notes that Treasury securities best satisfy the Federal Reserve's portfolio objective of "liquidity, safety, and neutrality in private credit allocation." A *neutrality motive* is important for governmental holders of Treasury securities (including foreign central banks and state/local governments). Were these entities to invest in private assets, questions arise about which particular private assets to choose, the possibility of sub-optimal speculation/ mis-management arises, etc. Thus, an implicit mandate of avoiding investments in private assets may be in the best interests of taxpayers for these governmental entities.

Third, Treasury securities carry a halo of surety that may motivate the holdings of some groups. For example, unsophisticated households who are unable to assess the risk in corporate assets may be drawn to Treasuries by a *surety motive* (see Vissing-Jorgensen, 2003, on costs that may limit household participation in the stock market). The same motive may apply to some of the foreign private sector's demand for Treasury securities. Desiring to hold assets in US Dollars, some foreign investors may choose to hold the dollars in the form of Treasury securities rather than corporate assets.

State/local retirement funds, private pensions, and insurance companies are an interesting group for our analysis. Since these groups have a long-term objective and no explicit regulatory requirements, the liquidity and neutrality motives are unlikely to be important for them. Comparing the demands of groups that are driven by liquidity and neutrality motives (i.e. official groups, banks, and households) to that of the long-term investors provides a gauge as to the importance of the liquidity and neutrality motives. As we show below, we find that the long-term investor groups have the most elastic demand curves (as well as smallest mean holdings from Table V). This points us to the conclusion that the liquidity and neutrality motives are

the primary determinants of the convenience yield.

It is difficult to say exactly why state/local retirement funds, private pensions, and insurance companies hold any Treasuries at all. One possibility is that the surety motive applies indirectly to these groups. Insurance companies' business depends on the perception by their customers of a stable balance sheet. If these customers think that balance sheet stability is enhanced by holdings of Treasury securities, insurance companies may demand Treasuries. A similar argument can be applied to the retirement saving groups who make defined benefit promises to their claimants.

Our strategy in this section is to estimate demand curves for each of the groups of Table V. We assume that group-i's demand can be expressed in the same log-linear functional form as earlier specifications:

$$S_t = A^i + B^i log(\theta_t^i/GDP_t) + C^i\ Y_t + \epsilon_{i,t}. \tag{6}$$

We are interested in estimating B^i, the demand elasticity for group-i. The demand elasticities can help to shed light on which of the groups – and indirectly, which of the motives – are important in determining the convenience yield.

4.2 IV Using Total Stock of Debt

In equilibrium, shocks to group i's demand will affect both the spread and group i's holdings. This implies that in (6) both S_t and θ_t^i are endogenous and correlated with $\epsilon_{i,t}$. Thus, we cannot estimate B^i in (6) using OLS and need an instrument to proceed. As we explain next, we use the total stock of Treasury debt as an instrument.

We rewrite (6) to express the quantity as a function of price:

$$log(\theta_t^i/GDP_t) = \alpha^i + \beta^i S_t + \gamma^i Y_t + e_{i,t},$$

where the constants are defined appropriately and $e_{i,t} = -\epsilon_{i,t}/B^i$. Summing the left and right hand side of this equation across all groups, $i = 1...N$, and dividing both sides by N, we find

$$log\left(\theta_t^1 \times \theta_t^2 \times \cdots \theta_t^N\right)^{1/N} - logGDP_t = \sum_i \frac{\alpha^i}{N} + S_t \sum_i \frac{\beta^i}{N} + Y_t \sum_i \frac{\gamma^i}{N} + \sum_i \frac{e_{i,t}}{N}. \tag{7}$$

The market clearing condition for Treasury debt implies,

$$\sum_i \frac{\theta_t^i}{N} = \frac{\Theta_t^T}{N}.$$

Because we have assumed a log-linear demand curve for each group, the left hand side of (7) involves the product of each of the group's holdings of Treasuries. However, if we make the approximation that the geometric average of holdings is equal to the arithmetic average of holdings:

$$\left(\theta_t^1 \times \theta_t^2 \times \cdots \theta_t^N\right)^{1/N} \approx \sum \frac{\theta_t^i}{N} = \frac{\Theta_t^T}{N},$$

we can rewrite (7) as

$$S_t = A + B \, log(\Theta_t^T/GDP_t) + C \, Y_t + D \sum e_{i,t}. \tag{8}$$

$A, B, C,$ and D are functions of the sums of the demand coefficients across the groups.[19] The approximation error involved becomes larger if the holdings are more dissimilar across groups. If we use the mean holdings of each group from Table V, the geometric average is 10.6% and the arithmetic average is 8.0%.

Equation (8) is the demand curve we have estimated in earlier sections. If we assume that changes in the total stock of Treasury debt (Θ_t^T) are not correlated with unobserved shifts $(\epsilon_{i,t})$ in a group's demand for Treasury bonds, beyond the controls of our regressions, then Θ_t^T can be used as instrument to estimate equation (6). In words, shifts in the total stock of debt shift the supply curve facing group-i, and can thereby be used to trace out group-i's demand curve. We use two stage least squares (2SLS), instrumenting $log(\theta_t^i/GDP_t)$ with $log(\Theta_t^T/GDP_t)$. In the first stage we regress $log(\theta_t^i/GDP_t)$ on $log(\Theta_t^T/GDP_t)$ and Y_t. We use the fitted values to estimate the group's demand curve:

$$S_t = A^i + B^i \, log(\widehat{\theta_t^i/GDP_t}) + C^i \, Y_t + \epsilon_{i,t}. \tag{9}$$

Table VI, Panel A presents estimates of the semi-elasticity B^i for each of the groups. The controls (Y_t) in this regression include stock market volatility and *slope*. We also include a linear and squared time trend as a control in these regressions because the holdings for many of the groups contain strong trends (the foreign official holders and banks/credit institutions as noted above). Finally, note that the sample period for these regressions begins in 1945, because the group holdings data is from the Flow of Funds Accounts of the Federal Reserve, which are only available beginning in 1945.

There is a clear ranking in the demand elasticities across the categories. Insurance Companies, State/Local Retirement Funds, and Private Pensions have much more elastic demand curves than groups like Banks/Credit Institutions or State/Local Governments. The former groups make larger changes in their holdings of Treasury securities in response to a change in the corporate bond spread generated by a shift in the total supply of Treasuries. In other words, when the total supply of Treasuries shifts, the equilibrium holdings of groups with more elastic demand curves change more. This can be seen directly in the first stage of the IV estimation which is also shown in Table VI.

The governmental groups (Federal Reserve Banks, Foreign Official Holdings, State/Local Governments) are the largest holders of Treasuries. Note that for the Federal Reserve Banks and Foreign Official Holdings, the first stage coefficients are negative, and the demand estimates imply a positively sloped demand curve (significant only for the Federal Reserve Banks). While it is possible that these results are due to a specification problem in our regressions, we believe that the explanation is that the holdings for these groups are just

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[19]We do not impose the restrictions that A, B and C are functions of the group demand coefficients because of the approximation error we have introduced in aggregating the demand curves across groups.

insensitive to conditions in the Treasury market. That is, these groups are inelastic demanders of Treasuries. The results suggest that the neutrality and liquidity motives are principal determinants of the convenience yield. Banks/Credit institutions follow closely behind the governmental groups in the inelasticity of demand. As noted earlier, this group is driven by the liquidity motive.

If the convenience yield is driven mainly by the neutrality and liquidity motives then we would expect that groups for which these motives matter less should have the most elastic Treasury demands. This is what we find. The groups with more elastic demands are the Households and Mutual Funds, the Foreign Private Sector, and the long-term investor groups (State/Local Retirement Funds, Private Pensions, and Insurance Companies). These groups are likely motivated by a combination of the liquidity and surety motive. The most elastic demanders are the long-term investor groups, who we conjecture are not affected by the liquidity and neutrality motives and are probably indirectly driven by the surety motive of their claimants. These observations suggest that the surety motive is secondary to the liquidity and neutrality motives in determining the convenience yield.

4.3   IV Using Foreign Official Holdings and Stock of Debt

In the first stage of the IV estimation reported in Table VI, the ability of $log(Debt/GDP)$ to explain movements in groups' Treasury holdings differs across groups. The t-statistics are the lowest for Federal Reserve Banks and Foreign Official Holdings, suggesting that the majority of the variation in these groups' holdings are generated by other factors. If these other factors are exogenous in the sense of being uncorrelated with shocks affecting other (more elastic) groups' demand, then holdings of Federal Reserve Banks and Foreign Official Holdings can serve as additional instruments for the estimation of the other groups' demand curves, over and above the instrument used above (the total supply of Treasuries).

Importantly, the availability of several instruments allows us to perform tests of the overidentifying restrictions in order to test the validity (exogeneity) of the instruments. In what follows we focus on two instruments, total Treasury supply/GDP and Foreign Official Holdings/GDP. Tests of overidentifying restrictions rejected Federal Reserve Bank holdings as a valid instrument, but did not reject the Foreign Official Holdings as a valid instrument. We note that on a priori grounds, this is what one may expect. Federal Reserve Holdings are driven by monetary policy which is likely to be correlated with US demand conditions. On the other hand, changes in the reserve holdings of foreign central banks are largely driven by capital inflows into foreign countries and the exchange rate policies of these countries, which are plausibly exogenous to US demand conditions. If foreign central banks hold their dollar reserves in Treasury securities[20], then changes in the capital account will lead to changes in foreign central banks' holdings of Treasury securities and changes to the equilibrium in the Treasury market.

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[20]In practice, foreign central banks hold the dollar reserves in Treasury securities and Agency securities.

We rewrite equation (7) to reflect the Foreign Official Holdings (FOH):

$$log\left(\theta_t^1 \times \theta_t^2 \times \cdots \theta_t^N\right)^{1/N} - logGDP_t = \frac{1}{N}log(\theta_t^{FOH}/GDP_t) + \sum_{i \neq FOH}\frac{\alpha^i}{N} + S_t\sum_{i \neq FOH}\frac{\beta^i}{N} + Y_t\sum_{i \neq FOH}\frac{\gamma^i}{N} + \sum_{i \neq FOH}\frac{e_{i,t}}{N}$$

Then, approximating the geometric average with the arithmetic average we have,

$$S_t = A_1 + B_1\ log(\Theta_t^T/GDP_t) + B_2\ log(\theta_t^{FOH}/GDP_t) + C_1\ Y_t + D_1\sum_{i \neq FOH}e_{i,t}. \tag{10}$$

If we assume that changes in θ_t^{FOH} are uncorrelated with $e_{i,t}$ ($i \neq FOH$), given the controls, then $log(\theta_t^{FOH}/GDP_t)$ can be used as a second instrument for the demand system.

We use 2SLS to estimate group i's demand curve using $log(\Theta_t^T/GDP_t)$ and $log(\theta_t^{FOH}/GDP_t)$ as instruments. In the first stage, we regress $log(\theta_t^i/GDP_t)$ on $log(\Theta_t^T/GDP_t)$ and $log(\theta_t^{FOH}/GDP_t)$, as well as controls Y_t. The controls Y_t include stock market volatility, *slope*, *year* and *year*-squared. The fitted values are used to estimate the demand curve:

$$S_t = A^i + B^i\ log(\widehat{\theta_t^i/GDP}_t) + C^i\ Y_t + \epsilon_{i,t}.$$

Table VI, Panel B presents the first stage estimates. The coefficient estimates on $log(\Theta_t^T/GDP_t)$ is positive for all groups, and the coefficient estimate on $log(\theta_t^{FOH}/GDP_t)$ is negative for most groups. An increase in the total stock of Treasuries is a rightward shift of the supply curve facing a group. Thus we would expect that the coefficient on total stock is positive. The second coefficient estimate should be negative because as FOH hold more Treasury securities, the residual supply facing a group shifts leftward. Note that group i's holdings are not equal to total supply less FOH holdings (this relation only holds for the sum over all groups). Thus, the sign patterns in the first-stage regressions are not driven by some mechanical relation (indeed they do not hold for two of the groups).

Table VI, Panel B also presents the estimates of the slope of the demand curve, by group. The slope estimates are similar to those reported in Panel A.

Because these regressions have two instrumental variables, the demand systems are overidentified and we can test the validity (exogeneity) of the instruments. The last column in Panel B reports the p-values from the test of the overidentifying restrictions. The p-values are high in all but one case, confirming that our instruments are not endogenous. Note that this result is also comforting for the regressions we reported in the previous section, where we only used total stock of government debt as an instrument.

4.4   Steepening of Demand Curve

Over the last 60 years, foreign holders of Treasuries have increased their holdings from 1% to 46% of the stock of Treasuries. The largest change is due to foreign official holders who have increased their holdings

from 1% to 29%. Over the same period, banks and credit institutions have decreased their holdings from 42% to 3% while insurance companies have decreased their holdings from 9% to 3%. These patterns suggest a shift over time in the composition of Treasury holders from more elastic holders to less elastic holders, perhaps causing the aggregate demand for Treasuries to steepen over time.

To verify this conjecture, we go back to the regressions of Table I, and estimate the semi-elasticy of the aggregate demand curve broken down by subsample. The breakpoint is 1971, which is the year when the Bretton-Woods system was abandoned. The foreign official holdings increase markedly beginning in 1971, and thus the abandonment of the Bretton-Woods system is a natural breakpoint for the sample. The controls in the regression are stock market volatility and yield curve slope. Consistent with our conjecture, we find that the slope coefficient on $log(Debt/GDP)$ is -0.57 (5.94) prior to 1971 and -1.19 (4.10) after 1971.

5   Exponential Specification

Thus far we have reported regressions for log-linear specifications involving $log(Debt/GDP)$. However, as the data presented in Figure 1 suggest, the relation between the corporate bond yield spread and the $Debt/GDP$ ratio may involve an asymptote which the log specification does not accommodate. The figure suggests that as $Debt/GDP$ becomes large, the spread asymptotes to a non-negative number. Such asymptote behavior can also be justified on theoretical grounds: for a sufficiently large value of $Debt/GDP$, the convenience demand of agents is satiated so that the convenience yield goes to zero. The asymptote value of the corporate bond spread can be interpreted as the part of the spread that is due purely to default, default risk premium, and tax differences between AAA corporate bonds and Treasuries, rather than a convenience yield on Treasuries. The $log(Debt/GDP)$ specification implies that the spread will become negative for sufficiently large $Debt/GDP$ ratios. In this section we estimate a regression specification with the property that the spread asymptotes to a constant.

We consider the following exponential specification estimated using non-linear least squares:[21,22]

$$S_t = b_0 + b_1 e^{b_2 \times (Debt/GDP)} + c\, Y_t + \epsilon_t.$$

Table VII reports the results where S_t is $AAA - Treasury$ spread in columns (1) and (2) and the $BAA - Treasury$ spread in columns (3) and (4). Columns (1) and (3) report the results with no default controls, while columns (2) and (4) present results where we introduce the controls we have considered in other regressions. The controls are stock market volatility and the slope of the yield curve. The control variables have been demeaned so that b_0 can be interpreted as the asymptote value of the corporate bond spread.

The results are consistent with intuition. b_2 is negative to fit the inverse relation between the yield spread and the $Debt/GDP$ ratio. b_0 is small, but positive, consistent with the point we have noted about the spread asymptoting to a positive value.

For the $AAA - Treasury$ spread, the asymptote values are 6 bps and 10 bps (although not statistically different from zero). Our results thus suggest that the default, risk premium, and tax component of the spread is small, which seems plausible given the existing literature on corporate bond valuation. For example, Elton *et al* (2001) consider actual default rates and bankruptcy recovery rates on AAA corporate debt and show that a risk neutral investor will require at most 5 bps default premium to buy a 10 year corporate bond. Taking into account the differential state tax treatment of corporate and government bonds (see Section 7.1) can increase this spread to at most 35 bps according to Elton *et al* (2001)'s calculations.

For the $BAA - Treasury$ spread, the asymptote values are much larger at 48 bps and 83bps, consistent with the fact that default considerations are more important for the $BAA - Treasury$ spread. Elton *et al* (2001) compute that for Standard & Poors BBB companies (roughly the equivalent of Moody's BAA rate), actual default rates can rationalize a maximum spread of 43 bps. Accounting for tax effects puts the total spread at 73 bps, which is similar to the numbers we find.

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[21]We have also considered a specification where the $Debt/GDP$ term is $b_1 (Debt/GDP)^{b_2}$. The latter specification yields a worse fit.

[22]The exponential specification can be motivated structurally as follows. Suppose that,

$$v'(\cdot) = e^{-\beta_1 \Theta_t^T + \beta_2 GDP_t} \quad \text{and,} \quad u'(\cdot) = e^{-\alpha c_t}$$

then,

$$v'(\cdot)/u'(\cdot) = e^{-\alpha c_t \frac{GDP_t}{c_t} \left(\frac{\beta_1}{\alpha} \frac{\Theta_t^T}{GDP_t} - \frac{\beta_2}{\alpha} - \frac{c_t}{GDP_t} \right)}.$$

Note that αc_t is the coefficient of relative risk aversion, γ_t. If we take γ_t as well as c_t/GDP_t to be approximately constant over time then we can write the above expression as,

$$v'(\cdot)/u'(\cdot) \simeq b_1 e^{-\left(\gamma \frac{GDP}{c} \frac{\beta_1}{\alpha} \right) \times \Theta_t^T /GDP_t}$$

which is the specification we adopt.

Figure 4: Exponential Specification of Demand Curve
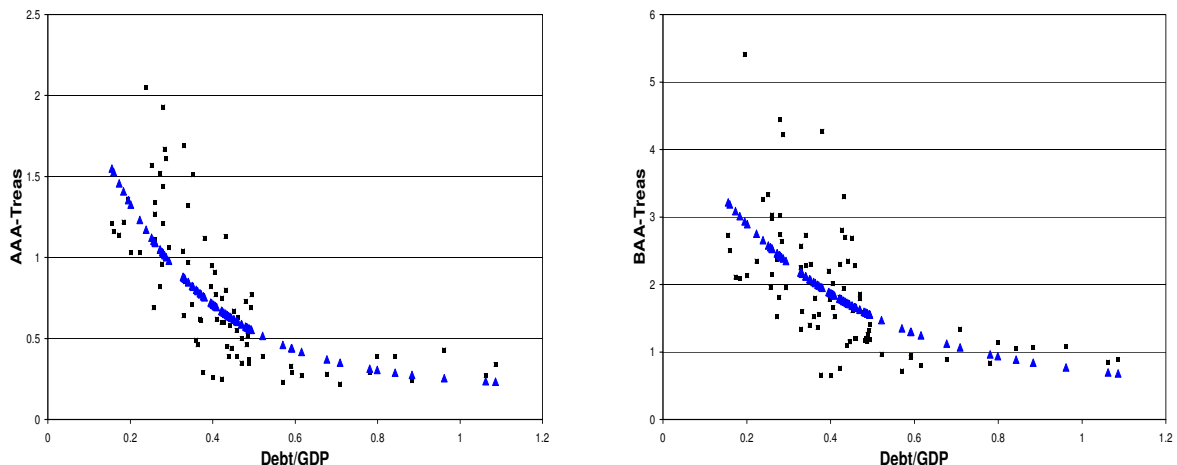
The figure on the left presents a scatter plot of the $AAA-Treasury$ corporate bond yield spread (y-axis)and the $Debt/GDP$ ratio (x-axis), using annual data from 1925 to 2005. Also pictured in the figure are the predicted values from the exponential specification of the relation between the yield spread and Debt/GDP ratio (Table VII, Column (1)). The figure on the right presents a similar result, but for the $BAA-Treasury$ yield spread (Table VII, Column (3)).

Figure 4 presents the results of the exponential specification in graphical form. The figures plot the predicted values of the spread for the $AAA-Treasury$ and $BAA-Treasury$ cases, without controls. Also pictured are scatter plots of the corporate bond yield spread (y-axis) and the $Debt/GDP$ ratio (x-axis).

6   Implications

The main finding of this paper is that the demand curve for convenience provided by Treasury debt is downward sloping. In earlier sections of the paper, we have discussed the implications of this finding for corporate bond pricing and the interpretation of the spread between corporate bond and Treasury bond yields. We have also argued that the liquidity motive is likely to be one of the main drivers of the convenience yield on Treasuries. In this section, use our estimates to quantify the value of convenience and discuss implications of our findings for a number of important issues in finance and macroeconomics.

The exponential estimation reported in Table VIII provides a way to quantify the Treasury convenience

yield. Since b_0 reflects the average value of the pure default/tax component of the corporate bond spread (i.e. Δ^*), the term $b_1 e^{b_2 \times (Debt/GDP)}$ represents the convenience yield on Treasuries. Then the average value of the convenience yield at the current Debt/GDP ratio is given by $2.48 e^{-3.19 \times 0.37} = 0.76$ percentage points ($b_1 = 2.48, b_2 = -3.19$, from Table VII, column (1) and current Debt/GDP= 0.37), or 0.72 percentage points using Table VII, column (2) estimates. If we use the estimates from the $BAA - Treasury$ regression of Table VII, column (4), the convenience yield computes to 1.12 percentage points. We call these *average* values because as we have noted in earlier discussions, it is likely that at any given time the demand for convenience also varies (e.g., during a flight to liquidity), so that the computation provides an estimate that is not conditioned on the state of demand.

The range of estimates, from 72 *bps* to 112 *bps*, of the non-default component of corporate bond spreads deriving from supply considerations is comparable to estimates in the literature. Longstaff, Mithal and Neis (2006) approach the problem by estimating the default component of the corporate bond spread, and subtracting this component from the actual spread to arrive at the non-default component. Their estimates (see Section 6 of the paper) put the average non-default component at 65 *bps*, with a range across the bonds in their sample of 19 *bps* to 105 *bps*.

6.1 Value of Treasury Liquidity/Convenience to Investors

Investors purchase Treasury securities despite the fact that these securities offer a low return because they convey liquidity/convenience benefits. In this subsection we quantify the total annual value that investors place on the benefits of Treasuries. Because of the evidence that AAA corporate bonds are substitutes for Treasury debt, this total annual value is a lower bound on the value of aggregate bond market liquidity to investors.

Table VIII presents the results. We ask how much investors will pay, as a yearly flow cost (percentage of GDP), in order to enjoy the benefits of a particular level of Treasuries/GDP, starting from a scenario with a Treasury/GDP ratio of zero. The calculations are based on the exponential specification with $b_1 = 2.73$ and $b_2 = -3.61$. Results are shown for different values of relative risk aversion for the utility function $u(c)$.

The first number in the third column is 0.20%. The interpretation of this number is that investors with a relative risk aversion of one will pay 0.20% of GDP every year in order to enjoy the benefits of having a Treasury/GDP ratio of 0.10. To compute this number, we ask how much annual consumption agents will be willing to forgo in order to increase Θ^T/GDP from $\Theta^{T,0}/GDP = 0$ to $\Theta^{T,1}/GDP = 0.10$.[23]

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[23]Referring back to equation (2), we note that the pricing expression can be derived from the first order condition for an agent with utility function, $u(c_t) + \beta^\tau u(c_{t+\tau}) + \tau GDP_t v(\Theta_t^T/GDP_t)$. That is taking the first order condition from this utility function with respect to Θ_t^T generates the pricing equation (2). Define $D_t \equiv \Theta_t^T/GDP_t$. We are interested in computing the utility benefit of increasing the supply of Treasury debt from some D_t^0 to D_t^1. For comparison purposes, we compute this as a

Of particular interest is the value investors place on the current stock of Treasuries. The Debt/GDP ratio is currently about 0.37. Across the different values of relative risk aversion, the value investors put on this amount of aggregate liquidity is between 0.20% and 0.56% of GDP per year. With US GDP for 2005 at $12.5 Trillion, this corresponds to between $27 and $70 Billion in benefits for the year 2005. Finally, we note that these figures are flow benefits that are enjoyed annually. As a back-of-the-envelope calculation, if we take the present value of a $27 billion ($70 billion) real perpetuity at a real discount rate of 2%, the stock value of the benefit is $1.34 trillion ($3.48 trillion).

6.2 Value of Convenience to Taxpayers

Because investors value the convenience features of Treasuries, the US Treasury is able to sell Treasury bonds at a premium. We have argued that this is a key driver of the substantially lower yield on Treasuries than on AAA corporate bonds. It is interesting to evaluate how much taxpayers benefit from being able to finance the US federal debt with securities that have special benefits to investors.

As a simple partial equilibrium calculation, consider that at the current convenience yield of 72 bps, the yield on Treasuries would be about 72 bps higher if Treasuries did not provide convenience benefits over and above AAA corporate bonds. That would imply increased interest expenses to the Treasury of $0.72 \times 0.37 = 0.27\%$ of GDP per year, assuming the Debt/GDP ratio was kept constant at 0.37.

To put this number in perspective, consider the benefits taxpayers enjoy from households' willingness to hold fiat money at no interest. The monetary base at the end of 2005 was $787 Billion, corresponding

per-annum benefit by dividing by τ. Thus, we wish to compute,

$$GDP_t(v(D_1) - v(D_0)).$$

From the agent's first order condition, the convenience yield, in terms of the bond yield spread, is equal to,

$$\frac{1}{u'(c_t)} \frac{dv(D_t)}{dD_t} \equiv G(D_t).$$

The regressions we present use the bond yield spread as dependent variable and D_t as independent variable. Thus these regressions estimate the function $G(\cdot)$. To use the regression estimates, we note that $\frac{dv(D_t)}{dD_t} = G(D_t)u'(c_t)$. Then,

$$GDP_t \left(v(D_t^1) - v(D_t^0) \right) = GDP_t \times u'(c_t) \int_{D_t^0}^{D_t^1} G(D)dD.$$

This computation gives the per-annum utility benefit from holding bonds for τ-years. We convert from utility units into annual consumption equivalents by solving for δ:

$$GDP_t \left(v(D_t^1) - v(D_t^0) \right) = u(c_t) - u(c_t - \delta \times GDP_t).$$

Using these two equations, and a second-order Taylor expansion of utility, we arrive at an expression that can be solved for δ:

$$\int_{D_t^0}^{D_t^1} G(D)dD = \delta \left(1 - \frac{1}{2} \frac{u''(c_t)}{u'(c_t)} \delta \times GDP_t \right) = \delta \left(1 + \delta \frac{\gamma}{2} \frac{GDP_t}{c_t} \right),$$

where γ is the coefficient of relative risk aversion in the utility function $u(c_t)$. We report δ for $D_t^0 = 0$, various values of γ, and a value of GDP_t/c_t of 1.5 in the table.

to 6.3% of GDP. Suppose the federal government had to repurchase the monetary base by issuing Treasury bills and that these Treasury bills had a 5% nominal yield. Then the annual interest expense to taxpayers of this additional debt would be $5 \times 0.063 = 0.32\%$ of GDP per year.

Together, these calculations suggest that the annual benefit to taxpayers from being able to finance the current level of debt with securities that have a convenience yield are about as large as the annual benefit to taxpayers resulting from the public's willingness to hold money at no interest.

6.3   The Effect of Foreign Official Demand on Treasury Yields

Some recent papers in international finance argue that the US government has a special ability to supply financial assets to the world's savers (see Caballero, Farhi, and Gourinchas (2006), and Dooley, Folkerts-Landau and Garber (2003)). These papers tie the US current account deficit to the demand for US assets by foreign savers (see also Bernanke (2005)).

Our finding that the demand for Treasury debt from foreign official holders is very inelastic is consistent with these theories. Our estimates of the slope of the Treasury demand curve also offers some insight into the interest rate effect of the demand by foreign investors. If foreign official investors exit the US Treasury market, they will sell roughly 29% of the debt back to US investors. Based on the log-linear demand curve we estimate, the sale will raise Treasury yields, relative to corporate bond yields, by between 23 bps and 49 bps. Using the exponential demand curve gives a value of 35 bps.

We arrive at these numbers as follows. Currently the Debt/GDP ratio is 0.37 of which foreign official investors own 0.11 and the rest of investors own 0.26. If foreign official investors sell their 0.11, then the rest of investors have to increase their holdings to 0.37. We have shown that foreign official investors have inelastic demand curves for Treasury debt. Thus the slope of the aggregate demand curve for Treasury convenience must reflect the preferences of the rest of investors. We evaluate our estimated aggregate demand curve at points 0.26 and 0.37, computing the difference in the convenience yield between these points to arrive at the numbers we present. The range for the log-linear estimate comes from using estimates from Table I, Panel B, column (2) and Table IV, Panel B, column (6). For the exponential demand case we use $b_1 = 2.73$ and $b_2 = -3.61$.

6.4   Benefits to Retirement Savers from Investing in Corporate Bonds

Our results suggest that investors who purchase Treasuries earn a substantially lower yield than they would earn had they instead purchased AAA corporate bonds. Indeed, our exponential specification implies that only around 10 bps of the yield spread between AAA corporate bonds and Treasury bonds is due to differences in risk and tax treatment. The bulk of the spread is (negative) compensation for the liquidity and neutrality features of Treasuries.

Therefore, investors who do not place much value on the liquidity features of Treasuries would be better off buying AAA corporate bonds than Treasury bonds. As an example, consider a conservative investor who is saving for retirement. Suppose the investor is 30 years old, plans to invest $15,000 in real terms for retirement at the end of each year up to age 60, and expects to live to age 80. If the investor invests in Treasuries with an expected real return of 2% (say), then the annual real consumption per year in retirement will be $37,215. If the investor instead invested in AAA corporate bonds and earned an extra 0.72% in annual return (our estimate of the convenience yield on Treasuries at the current Debt/GDP ratio), then the person could enjoy an annual real consumption of $44,671 per year in retirement, a 20% increase over the annual consumption in the first scenario.

## 6.5 Implications for Interest Rate Swap Spreads

The literature on interest rate swaps has prominently raised the possibility that there may be a convenience yield on Treasury securities (see Duffie and Singleton (1997), Grinblatt (2001), He (2001), Liu, Longstaff, and Mandell (2004), Li (2004), and Feldhutter and Lando (2005)).

A τ-year interest rate swap is a string of forward contracts between today ($s = t$) and $s = t + \tau$ years. The payment on date s is equal to $R^s - \tilde{r}_s$, where R^s is the fixed interest rate known as the 10 year swap rate, and $\tilde{r}_s$ is a variable interest rate that is set at a date just prior to date s. The variable or floating interest rate is indexed to LIBOR, and the reset frequency as well as the frequency of swap payments can range from overnight to one-year. A typical swap contract may be indexed to 3-month LIBOR and require payments every 3 months for 10 years. The LIBOR rate itself reflects the borrowing rate for a AA rated financial institution. Thus, ignoring the uncertainty in the realized path of LIBOR rates for the next τ years, the τ-year swap rate (R^s) is roughly equal to the τ-year interest rate at which a financial institution that is sure to be AA rated for the next 10 years can borrow (Collin-Dufresne and Solnik (2001)). LIBOR rates are typically slightly higher than Federal Funds rates and the borrowing rates on short-term collateralized loans (the repo rate).

The τ-year interest rate swap spread is defined as the spread of the τ-year interest rate swap rate over the τ-year Treasury bond yield. Using sophisticated pricing models that incorporate estimates of default rates as well as risk premia due to the uncertainty in realized LIBOR rates, the current literature finds that there is a large unexplained component of the swap spread (see Duffie and Singleton (1997), Grinblatt (2001), He (2001), Liu, Longstaff, and Mandell (2004), Li (2004), and Feldhutter and Lando (2005)). Feldhutter and Lando (2005), studying a sample from 1997 to 2003, find that the default component of swap spreads averages around 40 bps.

Figure 5 graphs the 10-year US Dollar swap spread and the negative of the $log(Debt/GDP)$ ratio over the period from 1987 to 2005. The swap data is from Global Financial Data (series ISUSA10D). The 10-year US

Figure 5: Swap Spread and Government Debt
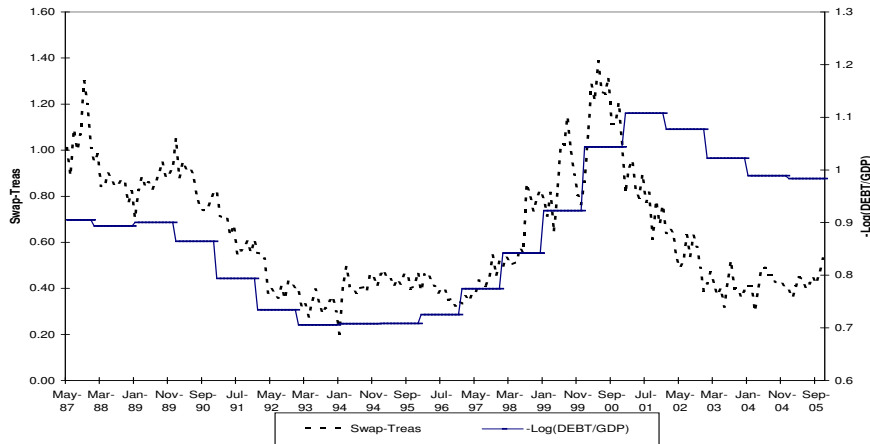
The 10-year interest rate swap spread (left y-axis)and $-log(Debt/GDP)$ ratio (right y-axis) are graphed from 1987 to 2005. The swap spread is monthly and measured as a percentage, while the Debt/GDP ratio is annual.

Dollar swap spread is the difference between the fixed rate in a 10-year fixed-for-floating interest rate swap and the yield on 10-year Treasury notes. We switch the sign on $log(Debt/GDP)$ following on our previous results that spreads and Treasury supply is negatively correlated. As one can see in Figure 5, swap spreads are typically much higher than the 40 bps upper bond suggested by the literature when only accounting for default risk. Thus, the weight of evidence in the interest rate swap literature points to a substantial nondefault component in the swap spread. Figure 5 suggests that this non-default complement is driven by variation in the convenience yield on Treasuries, which in turn is driven by variation in the supply of Treasury debt.

6.6 Implications for the "Riskless" Interest Rate

Our finding of a convenience demand for Treasury debt suggests caution against the common practice of identifying the Treasury interest rate with models' riskless interest rate. We have argued that the observed Treasury rate is $\left(\frac{u'(c_t)}{\beta E_t[u'(c_{t+1})+v'(\theta_t^T;X_t)]} - 1 \right)$, with $v'(.)$ positive. It is lower than the "true" riskless interest rate of $\left(\frac{u'(c_t)}{\beta E_t[u'(c_{t+1})]} - 1 \right)$ implied by the standard discrete-time C-CAPM model. In order to recover the true riskless rate from the data (the rate that can meaningfully be compared to the riskless rate from a model that ignores the convenience benefits of Treasuries), one has to estimate the convenience yield and

adjust Treasury rates by this convenience yield. Our estimated demand curves may be used to measure the convenience yield and make the adjustment.

Duffie and Singleton (1997) make a similar point about riskless rates in the context of the term structure literature, and advocate using interest rate swap rates instead of Treasury rates. Hull, Predescu, and White (2004) use data on credit default swaps in conjunction with corporate bond data to conclude that the true riskless rate is approximately $10bps$ below swap rates.

Our results also have bearing for puzzles regarding high measured return spreads and excess comovement of spreads. Since many asset market return spreads are measured relative to Treasury interest rates, the demand for Treasury liquidity and variation in this demand will generate high average asset yield spreads over Treasuries as well as comovement in spreads and excess returns across different asset classes. There is empirical support for both of these observations. As noted earlier the magnitude of corporate bond and swap spreads are hard to reconcile based purely on default considerations. The literature also has documented patterns of unexplained comovement. Collin-Dufresne, Goldstein, and Martin (2001) show that credit spread changes within the corporate bond market are highly correlated. Boudoukh, Richardson, Stanton, and Whitelaw (1997) document similar evidence from the mortgage backed securities market. Gabaix, Krishnamurthy, and Vigneron (2006) show that corporate bond spreads and mortgage backed spreads comove. Variation in the Treasury convenience yield is one possible explanation for the comovement phenomena.

7 Robustness

This section present a series of robustness checks of our main regressions.

7.1 State Tax Effects

Corporate bonds are taxed at the federal, state and local levels, while Treasury bonds are only taxed at the federal level. Thus, the difference in yields between corporate and Treasury bonds will in part reflect state and local tax rates. Loosely speaking our expression in (3) applies to yields where the two bonds are taxed equivalently. If the measured pre-tax yield on corporate bonds is $\hat{y}_t^C$, then the effect of state and local taxes is to reduce this yield to $y_t^C = \hat{y}_t^C(1 - tax)$, where tax is the tax rate. y_t^C is the after state and local tax yield and is now comparable to the Treasury yield.

The pre-tax yield spread is then given by

$$\hat{y}_t^C - y_t^T = \left(y_t^C - y_t^T\right) + tax \ \hat{y}_t^C.$$

We can think of our previous expression in (3) as applying to the difference between y_t^C and y_t^T. Therefore,

we need to introduce an independent variable equal to $tax\ \hat{y}_t^C$ to control for the state and local tax effect.[24]

We construct a time series of estimated state and local tax rates for high-income tax filers for the years 1944-2003 based on data in the IRS publication Statistics of Income. Households who itemize deductions on their 1040 tax forms list taxes paid on Schedule A along with its four components, "state and local income taxes," "real estate taxes," "personal property taxes," and "other taxes." Beginning in 1972, the Statistics of Income lists the state and local income tax component separately. For earlier years, only the total taxes paid deduction is listed.

Furthermore, for each year, the Statistics of Income lists both "adjusted gross income less deficit" and "taxes paid", tabulated by income category. We focus on households in the income category $1,000,000 and higher. This is done for two reasons. First, high-income households are likely more relevant for the pricing of bonds than less wealthy households. Second, for high-income households the vast majority (88.7% on average across the years 1972-2003) of taxes paid are state and local income taxes.[25]

From this data, we estimate a state and local tax rate time series for high-income households going back to 1944. We do this by multiplying taxes paid for each year by 0.887 to measure the state and local income taxes paid by the high income filers. Our estimated tax rate is computed by taking the ratio of these state and local taxes paid to adjusted gross income less deficit.[26]

The results are reported in the first two columns of Table IX. Our results are robust to the state tax controls. In column (1), the coefficient on the tax rate is 0.37 and not significant at the 10% level. Theory suggests the coefficient should be one if the high-income households are the only agents who determine the bond yield spread. When we include the volatility and slope controls (column (2)), the coefficient on the state tax rate shrinks further. Finally, we note that the average value of the tax rate is 5.2% and the average value of the tax rate variable is 35 bps. Even if taxes are a significant determinant of the corporate bond spread, taxes can at most explain only 35 bps of the spread.

7.2 Level of Interest Rates and Callability

Table IX reports regressions where we include the level of interest rates as an additional covariate. Duffee (1988) points out that the Moody's AAA index includes callable corporate bonds. The Treasury, at various times, has also issued callable long-term bonds. Thus, the bond yield spread may reflect an interest rate

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[24]This adjustment is probably too large for some investors since some states do not exempt capital gains from trading Treasury bonds, and only exempt the interest income. See page 7 of Longstaff (2004).

[25]This is not the case for the full set of households for which the ratio of state and local income taxes paid to total taxes paid averages 53.7% across the years 1972-2003 and is much less stable across years than for high-income filers.

[26]For the years 1951, 1955, 1957, 1959, 1961, 1963, 1965, 1967, 1969, 1971, and 1974 the Statistics of Income does not provide the taxes paid information we need and for 1978 adjusted gross income less deficit is not provided by income category. For these years we linearly interpolate the state and local income tax rate based on the prior and subsequent year of data.

option. Duffee proxies for the moneyness of the call option using the level of interest rates and shows that yield spreads vary significantly with the level of interest rates. We follow the same strategy, considering short-term real and nominal Federal Funds rates, as well as a long-term nominal rate (the AAA rate). The level of the short-term Federal Funds rate may also proxy for the stance of monetary policy. As noted above, the state tax effect is proportional to the AAA rate. Thus, if one thinks that our tax rate in the tax-effect regression is mismeasured, then only including the AAA rate may be a better control for tax effects.

Columns (3) and (4) include a measure of the real Federal Funds rate. The ex-post real rate in column (3) is based on the nominal Federal Funds rate for October minus the annual CPI inflation rate from October to the following October. The ex-ante real rate in column (4) is based on the nominal Federal Funds rate for October minus the annual CPI inflation rate over the year leading up to that month. Column (5) includes the AAA nominal rate, sampled in October of a given year, as covariate. Uniformly the results in the table show that our results are robust to including the level of interest rates as control.

7.3   Regressions, by Subsample

Figure 6: Fitted and Actual Corporate Bond Spread
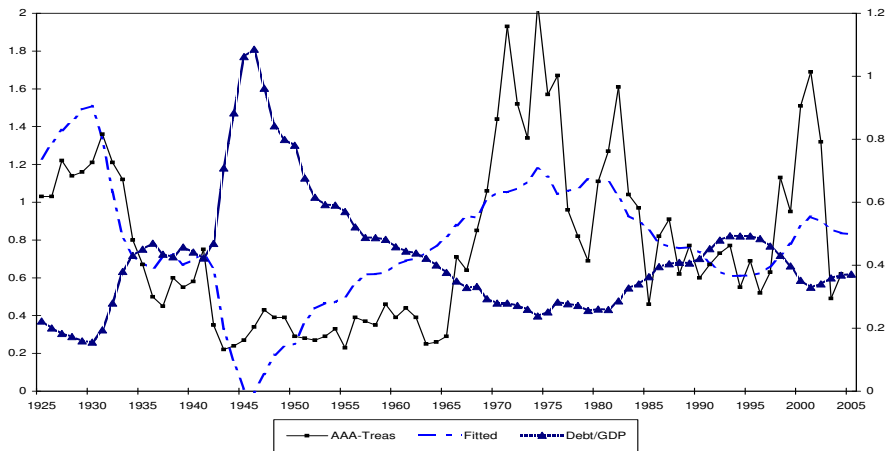
The corporate bond yield spread (labeled "AAA-Treas" and on left y-axis), fitted yield spread from Table I, Panel A, Column (1) (labeled "Fitted" and on left y-axis), and $Debt/GDP$ ratio (labeled "Debt/GDP" and on right y-axis) are graphed from 1925 to 2005. The corporate bond yield spread is the percentage difference between the yield on Moody's AAA bond index and the yield on long maturity Treasury bonds.

Our basline estimation covers a very long sample over which it is likely that demand conditions varied in ways not captured by our controls. For example, the point we made earlier about a change in demand around 1971, probably also applies to other period. To get a sense for this variation, Figure 6 graphs the fitted AAA-Treasury yield spread using estimates from Table I, Panel A, Column (1). The specification here is our most basic and only includes $log(Debt/GDP)$ as covariate, thereby only controlling for demand shifts that are proportional to GDP.

While broadly speaking the fitted and actual lines move together, there are some points of departure one can see from comparing the two lines. First, the elasticity with respect to debt has varied over the sample. Early on in the sample the fitted line varies more than the actual, while later in the sample it moves less than the actual. This suggests that the demand curve may have steepened over the sample so that a change in debt has a bigger effect later than earlier.

As we have remarked in the period after 1971, foreign central banks have been large and inelastic demanders of Treasury bonds, driving a shift in the slope of the aggregate demand curve from -0.60 before 1971 to -1.28 after. When we force a uniform coefficient across the entire sample, as we do in Table I, we overestimate early and underestimate later.

Second, at first glance it seems that behavior during the period from 1943 to 1960 is a failure of the convenience yield theory. The $Debt/GDP$ ratio rises from 0.71 in 1943 to a high point of 1.09 in 1946 before falling to 0.46 in 1960. During this period, the AAA-Treasury spread remains within a tight band from 20 to 40 bps and shows little relation to the $Debt/GDP$ ratio.

This lack of correlation is not as puzzling if one refers back to Figure 1. There, we can see evidence of an asymptote effect. For values of the $Debt/GDP$ ratio around 0.50 and greater, the corporate bond spread is roughly constant. All of the datapoints in Figure 1 to the right of 0.50 correspond to the years from 1943 to 1960. As we have noted, the asymptote effect should be expected from our theory. The corporate bond spread is composed of default risk, risk premium, tax premium, and convenience yield components. If the $Debt/GDP$ ratio is large enough to meet investors' convenience demand, the convenience yield component shrinks and eventually becomes negligible, so that any variation in the corporate bond spread can be attributed to components other than the convenience yield. Thus, for high values of the $Debt/GDP$ ratio, changes in the $Debt/GDP$ ratio should have little relation to changes in the corporate bond spread.

The World War II period and its immediate aftermath are also a historically unusual period. From 1942-1951 the Fed-Treasury Accord (Wicker, 1969) may have introduced a non-market element into interest rates. The accord effectively fixed government bond interest rates by incenting banks to purchase Treasury securities and, if needed, exchange them for reserves with the Federal Reserve. In the early 1950s, commercial banks held close to 40% of the Treasury debt outstanding.

Table X presents results for the main corporate bond spread regression by subsample. The first column

reports the results of the regression if we exclude the years 1942 to 1951. The evidence in column (1) confirms that our results are not driven by any idiosyncrasies due to this period.

Many Treasury bonds that were issued in the 1910s, 1920s and 1930s were exempt or partially exempt from Federal taxes (Homer, 1977). These tax effects could drive a wedge between Treasury and corporate bond yields. Column (2) reports results from excluding the years 1925-1941. Column (3) reports results from excluding the years 1925-1951. Again, our main findings are not driven by these periods. The semi-elasticity coefficients are significant and of the same order of magnitude as in previously reported regressions. One point that is noticeable from the table is the change in the coefficient on stock market volatility, between column (1) and columns (2) and (3). Volatility is far more important if the regressions exclude the period 1925-1941, which is a period of unusually high volatility. We have experimented with incorporating regressors that are non-linear functions of volatility. Our semi-elasticity estimates are unaffected by the addition of such regressors.

7.4 Excluding Fed Holdings

Table XI presents results from excluding the Federal Reserve Banks' holdings when constructing the stock of Treasury debt measure. In previous regressions, the stock of debt exclude government holdings in the Social Security Trust Fund but included Federal Reserve Banks' holdings. We construct the debt measure from Banking and Monetary Statistics (1925 - 1970), Annual Statistical Digest (1971 - 2000), and the Economic Report of the President (2001 - 2005). Debt values are as of the end of June. GDP is annual (end of year) up to 1947 from Economic History Services and annual (end of June) from 1948 onwards from NIPA. Columns (1) and (2) present the results from excluding the Fed holdings, while columns (3) and (4) include the Fed holdings. It is apparent that the including or excluding the Fed holdings does not affect the results.

8 Conclusion

We show that the demand curve for convenience provided by Treasury debt is downward sloping and provide estimates of the elasticity of demand. A hypothetical rise in the Debt/GDP ratio from its current value of 0.37 to a new value of 0.38 will decrease the spread between corporate bond yields and Treasury bond yields between 1.7bps (Table I, Panel B, column (2)) and 3.6bps (Table IV, Panel B, column (6)).

We also analyze disaggregated data from the Flow of Funds Accounts of the Federal Reserve and find that demand curves are steeper for groups for whom liquidity motives for holding Treasuries are likely to be more important.

Our results suggest that US government debt is a special asset that offers a convenience yield to investors. We estimate the convenience yield at the current level of Treasury debt outstanding to be 72 bps. Our

estimates also imply that the value of the liquidity provided by the current level of Treasuries is between 0.21 and 0.56% of GDP per year.

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Table I

Explaining the Corporate Bond Yield Spread

The dependent variable is the corporate bond yield spread, measured as the spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measured in percentage units. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, and a number of controls for the default risk and risk premium on corporate bonds. All regressions include a constant. Panel A presents OLS regressions with t-statistics based on Newey-West robust standard errors in parentheses. Panel B presents GLS regressions; specifically, Cochrane-Orcutt AR(1) iterated regressions (ρ reported below). Data are annual. Sample period varies across the specifications.

Panel A: OLS

	1925 - 2005			1969 - 2005	1926 - 2005		1963 - 2003
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$log(Debt/GDP)$	-0.78 (7.33)	-0.75 (6.28)	-0.80 (6.06)	-1.04 (3.92)	-0.76 (6.87)	-0.81 (6.91)	-1.55 (5.49)
$BAA - AAA$		0.09 (1.68)	0.03 (0.47)				
EDF				0.78 (4.42)			
$volatility$					1.52 (2.39)	0.96 (1.22)	
$pct - failed$							0.13 (1.80)
$slope$			0.06 (1.53)	0.01 (0.23)		0.05 (1.38)	0.06 (1.07)
R^2	0.52	0.53	0.55	0.64	0.54	0.56	0.52
N	81	81	81	37	80	80	41

Panel B: GLS

	1925 - 2005			1969 - 2005	1926 - 2005		1963 - 2003
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$log(Debt/GDP)$	-0.75 (5.14)	-0.66 (4.37)	-0.68 (4.35)	-0.93 (2.85)	-0.76 (4.66)	-0.78 (4.85)	-1.48 (4.16)
$BAA - AAA$		0.13 (2.44)	0.18 (2.26)				
EDF				0.86 (3.76)			
$volatility$					1.07 (1.27)	0.96 (1.11)	
$pct - failed$							0.11 (1.30)
$slope$			0.01 (0.37)	0.01 (0.04)		0.02 (0.69)	0.03 (0.58)
R^2	0.21	0.24	0.25	0.53	0.24	0.26	0.33
ρ	0.66	0.67	0.67	0.38	0.64	0.63	0.39
N	80	80	80	36	79	79	40

Table II

Explaining Bond Returns

The dependent variable is the percentage excess return on long term corporate bonds over long term government bonds, at one, three, and five year horizons. Return data are from Ibottson, beginning in 1926 and ending in 2004. In Panel A, the independent variables are the spread between Moody's AAA long maturity bond yields and the average yield on long maturity (> 10 years) Treasury bonds, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). In Panel B, independent variables are based on the real book value of Treasury debt outstanding, real US GDP, and yield curve slope. Additional independent variables include the realized returns on long term government bonds over short term bonds (*durationhedge*) and the four factor controls (market, HML, SMB, momentum). All regressions include a constant. For horizons of three (five) years, the regressions report *t*-statistics based on Newey-West robust standard errors allowing for autocorrelation up to order two (four).

	Panel A: Excess Returns and Yield Spread				
	1-year	3-year	5-year		
$AAA - Treasury$	1.73 (2.19)	5.34 (3.66)	7.32 (2.97)		
R^2	0.05	0.20	0.20		
N	79	77	75		

	Panel B: Excess Returns and Treasury Supply					
	1-year Excess Returns			3-year Excess Returns		
$log(Debt/GDP)$	-0.86 (0.90)	-1.04 (0.97)	-1.13 (1.34)	-3.95 (2.96)	-4.48 (2.86)	-5.05 (2.43)
slope		0.33 (0.72)			0.89 (1.02)	
durationhedge			-0.11 (2.27)			-0.02 (0.35)
Four-factor Controls	NO	NO	YES	NO	NO	YES
R^2	0.01	0.02	0.17	0.09	0.12	0.19
N	79	79	77	77	77	76

	5-year Excess Returns					
$log(Debt/GDP)$	-7.49 (2.66)	-7.40 (2.29)	-6.47 (2.20)			
slope		-0.15 (0.13)				
durationhedge			-0.04 (1.38)			
Four-factor Controls	NO	NO	YES			
R^2	0.19	0.19	0.37			
N	75	75	74			

Table III

Explaining the CP-Bills Yield Spread

The dependent variable is the annualized yield differential between short-term commercial paper and Treasury Bills, constructed as described in the text. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, and a number of controls for the default risk and risk premium on corporate bonds. All regressions include a constant. Panel A presents OLS regressions, with t-statistics based on Newey-West robust standard errors in parentheses. Panel B presents GLS regressions; specifically, Cochrane-Orcutt AR(1) iterated regressions (ρ reported below). Data are annual. Sample period varies across the specifications.

	1920 - 2005			1969 - 2005	1926 - 2005		1963 - 2003
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: OLS							
$log(Debt/GDP)$	-0.55 (5.10)	-0.42 (3.46)	-0.22 (1.86)	-0.68 (2.00)	-0.45 (3.91)	-0.37 (3.48)	-0.73 (1.94)
$BAA - AAA$		0.18 (2.20)	0.31 (2.88)				
EDF				-0.20 (0.51)			
$volatility$					2.82 (4.17)	3.81 (3.94)	
$pct - failed$							-0.04 (0.32)
$slope$			-0.16 (2.39)	-0.14 (1.63)		-0.10 (1.51)	-0.07 (0.79)
R^2	0.21	0.26	0.35	0.64	0.27	0.31	0.17
N	86	86	86	37	80	80	41
Panel B: GLS							
$log(Debt/GDP)$	-0.51 (3.50)	-0.43 (3.01)	-0.30 (2.09)	-0.69 (1.48)	-0.45 (3.08)	-0.38 (2.67)	-0.71 (1.42)
$BAA - AAA$		0.12 (1.54)	0.22 (2.74)				
EDF				-0.11 (0.28)			
$volatility$					2.85 (2.32)	3.63 (2.88)	
$pct - failed$							-0.08 (0.59)
$slope$			- 0.10 (2.20)	- 0.12 (1.59)		-0.09 (1.83)	-0.08 (1.11)
R^2	0.13	0.17	0.23	0.17	0.19	0.23	0.14
ρ	0.30	0.25	0.18	0.19	0.26	0.22	0.32
N	85	85	85	36	79	79	40

Table IV

BAA-AAA and BAA-Treasury Spreads

The dependent variable in Panel A is the spread between the Moody's BAA long maturity bond yield and Moody's AAA long maturity bond yield, both measured in percentage units. In Panel B, the dependent variable is the spread between the Moody's BAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measured in percentage units. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, the spread between the 10 year Treasury yield and the 3 month Treasury yield ($slope$), and stock market volatility. All regressions include a constant. OLS regressions report t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, with varying start date (1919, 1925, 1926) and ending in 2005.

	Panel A: BAA-AAA Spread					
	OLS			GLS		
	(1)	(2)	(3)	(4)	(5)	(6)
$log(Debt/GDP)$	-0.69 (3.52)	-0.41 (3.11)	-0.57 (4.44)	-0.64 (3.31)	-0.47 (2.95)	-0.58 (4.26)
$volatility$		10.78 (9.71)	8.81 (8.09)		8.60 (6.29)	8.11 (6.29)
$slope$			0.19 (3.60)			0.18 (3.68)
R^2	0.16	0.57	0.65	0.04	0.42	0.58
ρ				0.74	0.25	0.12
N	87	80	80	86	79	79

	Panel B: BAA-Treasury Spread					
	OLS			GLS		
	(1)	(2)	(3)	(4)	(5)	(6)
$log(Debt/GDP)$	-1.38 (5.68)	-1.17 (6.54)	-1.38 (7.76)	-1.38 (5.08)	-1.26 (6.14)	-1.40 (8.22)
$volatility$		12.31 (8.31)	9.78 (6.57)		9.49 (5.59)	8.96 (5.64)
$slope$			0.24 (3.75)			0.23 (3.75)
R^2	0.37	0.66	0.73	0.12	0.52	0.67
ρ				0.71	0.29	0.14
N	81	80	80	80	79	79

Table V

Who holds Treasury Debt?

This table presents statistics on the fraction of Treasury securities held by various groups. The data are from the Flow of Funds Accounts of the Federal Reserve, and are annual (Q3) from 1945 to 2005. Mutual funds include closed-end fudns and exchange traded funds.

Group	Obs	Mean	Std. Dev.	1945	2005
Federal Reserve Banks	61	.14	.04	.10	.16
Foreign Official Holdings	61	.10	.07	.01	.29
State/Local Governments	61	.09	.04	.02	.10
Banks/Credit Institutions	61	.21	.11	.42	.03
Households and Mutual Funds	61	.27	.05	.26	.16
Foreign Private Sector	61	.04	.05	0	.17
State/Local Government Retirement Funds	61	.03	.02	.01	.03
Private Pensions	61	.03	.02	.01	.02
Insurance Companies	61	.05	.02	.09	.03

Table VI

Semi-elasticity of Demand Curves, by Group

This table presents instrumental variables estimates of the semi-elasticity of the demand curve for Treasury securities, by group. In Panel A, the demand curves are estimated using the total stock of Treasury debt as an instrument. We report the coefficient estimate on $log(Debt/GDP)$ in the first stage as well as the semi-elasticity estimate for each group in the second stage. In Panel B, the demand curves are estimated using the total stock of Treasury debt ($log(Debt/GDP)$) and Foreign Official Holdings ($log(\theta^{FOH}/GDP)$) as instruments. We report first stage estimates in the first two columns and second stage estimates in the right columns. The last column in Panel B reports the p-value from the test of the overidentifying restrictions. The price variable is the corporate bond yield spread, measured as the spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measured in percentage units. Controls in the demand estimation include stock market volatility, yield curve slope, year, and year-squared. The Treasury holdings data are from the Flow of Funds Accounts of the Federal Reserve, and are annual (Q3) from 1945 to 2005, except for the Foreign Private Sector for which data begin in 1957. t-statistics based on Newey-West robust standard errors in parentheses.

	Panel A: $log(Debt/GDP)$ as Instrument		
Group	1st Stage Coefficient on $log(Debt/GDP)$	Semi- elasticity	N
Federal Reserve Banks	-0.22 (2.53)	4.80 (3.16)	61
Foreign Official Holdings	-0.22 (1.07)	4.73 (1.20)	61
State/Local Governments	1.30 (4.86)	-0.81 (4.05)	61
Banks/Credit Institutions	1.32 (8.88)	-0.80 (3.71)	61
Households and Mutual Funds	1.41 (10.45)	-0.75 (2.80)	61
Foreign Private Sector	2.51 (7.02)	-0.52 (4.18)	49
State/Local Retirement Funds	2.87 (7.38)	-0.37 (3.75)	61
Private Pensions	2.31 (6.07)	-0.45 (3.58)	61
Insurance Companies	2.73 (25.15)	-0.38 (3.57)	61

	Panel B: $log(Debt/GDP)$ and $log(\theta^{FOH}/GDP)$ as Instruments			
	1st Stage Coefficient on		Semi-	Overid Test
	$log(Debt/GDP)$	$log(\theta^{FOH}/GDP)$	elasticity	p-value
State/Local Governments	1.28 (4.77)	-0.09 (0.73)	-0.82 (4.11)	0.54
Banks/Credit Institutions	1.31 (8.82)	-0.04 (0.91)	-0.81 (2.71)	0.48
Households and Mutual Funds	1.36 (10.36)	-0.19 (2.90)	-0.76 (2.82)	0.89
Foreign Private Sector	2.54 (7.67)	0.08 (0.23)	-0.52 (4.22)	0.74
State/Local Retirement Funds	2.66 (8.79)	-0.93 (3.86)	-0.34 (3.72)	0.72
Private Pensions	2.43 (6.61)	0.57 (1.73)	-0.35 (3.21)	0.01
Insurance Companies	2.69 (28.02)	-0.17 (2.24)	-0.39 (3.58)	0.49

Table VII

Exponential Specification

We estimate the following relation:

$$S_t = b_0 + b_1 e^{b_2 \times (Debt/GDP)} + c\, Y_t + \epsilon_t.$$

where, S_t in columns (1) and (2) is the corporate bond spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measured in percentage units. S_t in columns (3) and (4) is the corporate spread using the Moody's BAA bond yield. Y_t are controls that include stock market volatility and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). The control variables have been demeaned in the regressions. t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1925 and ending in 2005.

	$AAA - Treasury$		$BAA - Treasury$	
	(1)	(2)	(3)	(4)
b_0	0.06 (0.31)	0.10 (0.57)	0.47 (0.79)	0.83 (3.28)
b_1	2.48 (7.51)	2.73 (6.49)	4.21 (6.25)	4.83 (6.16)
b_2	-3.19 (3.32)	-3.61 (3.79)	-2.76 (2.17)	-3.95 (4.05)
volatility		0.78 (0.89)		9.47 (6.57)
slope		0.07 (1.99)		0.27 (4.77)
R^2	0.55	0.59	0.38	0.75
N	81	81	81	81

Table VIII

Value of Aggregate Liquidity/Convenience

This table presents estimates of the value of aggregate liquidity/convenience of Treasury securities. We report how much investors will be willing to pay, as a yearly flow cost (percentage of GDP), in order to enjoy the benefits of a particular level of Treasuries/GDP, starting from a scenario with a Treasury/GDP ratio of zero. We present results for the exponential specification with $b_1 = 2.73$ and $b_2 = -3.61$. Results depend on the coefficient of relative risk aversion of $u(c)$.

Treasuries/GDP	Relative Risk Aversion			
	$\gamma = 0$	$\gamma = 1$	$\gamma = 5$	$\gamma = 10$
0.1	0.23	0.20	0.15	0.12
0.2	0.39	0.31	0.22	0.17
0.3	0.50	0.39	0.26	0.20
0.37	**0.56**	**0.42**	**0.27**	**0.21**
0.5	0.63	0.47	0.30	0.23
1	0.74	0.53	0.33	0.25
3	0.76	0.54	0.34	0.26

Table IX

Tax Effects and Level of Interest Rates

This table presents robustness results from including a control for state tax effects, and controls for level of real or nominal interest rates. The dependent variable is the corporate bond yield spread, measured as the spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measure in percentage units. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, stock market volatility, and yield curve slope. The tax rate variable ($taxrate \times AAA$) is computed from the IRS publication Statistics of Income as described in the text. The real interest rate is computed as the Federal Funds rate for October of the year minus either the CPI inflation for the same year (ex-post real) or the inflation for the preceding year (ex-ante real). The nominal interest rate is the Moody's AAA yield. All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses. The sample for the tax regressions is 1944 to 2003. The real interest rate regressions use data from 1954 to 2005. The nominal rate regression uses data from 1924 to 2005.

	(1)	(2)	(3)	(4)	(5)
$log(Debt/GDP)$	-0.76 (3.38)	-0.77 (3.32)	-1.25 (5.44)	-1.25 (6.94)	-0.63 (5.53)
$taxrate \times AAA$	0.37 (1.33)	0.08 (0.26)			
$volatility$		2.35 (2.81)	10.0 (2.21)	10.0 (3.25)	1.81 (2.08)
$slope$		0.05 (1.08)	0.07 (1.59)	0.07 (1.82)	0.02 (0.49)
Ex-post Real			-0.004 (0.20)		
Ex-ante Real				0.001 (0.04)	
Nominal AAA					0.04 (3.12)
R^2	0.54	0.66	0.66	0.66	0.60
N	60	60	52	52	81

Table X

Regressions, by Subsample

This table presents regressions for different subsamples. The dependent variable is the percentage spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds. Controls include stock market volatility and yield curve slope. All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1926 and ending in 2005.

	(1) Excluding 1942-1951	(2) Excluding 1925-1941	(3) Excluding 1925-1951
$log(Debt/GDP)$	-1.04 (6.29)	-0.81 (5.70)	-1.21 (5.51)
$volatility$	0.63 (0.81)	12.48 (2.91)	10.0 (2.21)
$slope$	0.08 (1.86)	0.05 (1.40)	0.06 (1.57)
R^2	0.54	0.65	0.68
N	70	64	54

Table XI

Publicly held Debt, excluding Fed Holdings

This table presents result from redoing regressions by excluding Federal Reserve holdings from the definition of the stock of outstanding debt. For comparison purposes, we also present the regressions that include the Fed holdings. The dependent variable is the percentage spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds. Controls include stock market volatility and yield curve slope. All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1926 and ending in 2005.

	(1)	(2)	(3)	(4)
$log(Debt/GDP)$			-0.78 (7.33)	-0.81 (6.91)
$log(Debt^{-FED}/GDP)$	-0.78 (7.70)	-0.80 (7.21)		
$volatility$		1.37 (1.93)		0.96 (1.22)
$slope$		0.05 (1.39)		0.05 (1.38)
R^2	0.55	0.60	0.52	0.56
N	81	80	81	80