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. At the current supply of Treasury debt, we estimate the convenience yield to be around 100 *bps*. The superior trading liquidity of Treasuries accounts for 50 *bps* of this convenience yield. Treasuries are also widely viewed as the lowest risk asset class, and this surety of Treasuries confers an additional 50 *bps* of convenience yield. We show that regulatory demanders of Treasuries, including foreign central banks, have inelastic demand curves for Treasuries and estimate the effect that these buyers have on Treasury yields. In addition to these implications for understanding bond yields, our results have bearing for important questions in finance and macroeconomics. We discuss implications for the aggregate value of Treasury convenience, the financing of the US deficit, the behavior of interest rate swap spreads, and investors' portfolio choices.

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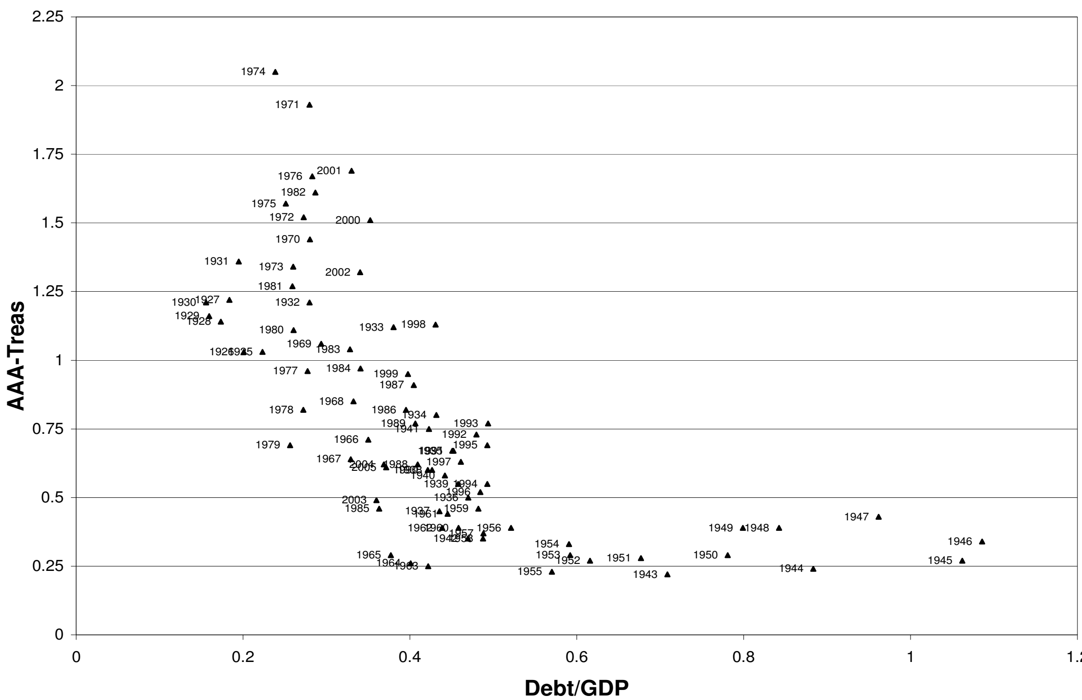
1 Introduction

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 observations 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 1.8*bps* (Table I, Panel B, column (2)) and 4.4*bps* (Table V, column (4)), relative to corporate bond yields. At the current Debt/GDP ratio of 0.37, we estimate that Treasury yields are about 100 *bps* lower than they would otherwise be if Treasuries provided no convenience value.

After laying out a simple theoretical framework in Section 2, we present these results relating the aggregate supply of Treasury securities to the spread between corporate and Treasury bond yields in Section 3. 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 short-maturity corporate bonds and Treasury bonds, 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 what attributes of Treasury securities drive their convenience value, and which groups of investors value these convenience attributes. We offer three motives behind investors' Treasury preference: The first is a *liquidity* motive. Treasury securities are extremely liquid in comparison to corporate bonds. For example, Chen, Lesmond and Wei (2008) document for 1995 to 2003 that the spread between bid and ask prices on investment grade corporate bonds are close to 50 *bps*. Studying a similar sample period, Longstaff (2004) reports spreads of near 10 *bps* on 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 governmental investors such as the Federal Reserve or foreign central banks as well as private investors such as banks and households (including mutual funds) the liquidity of Treasuries may be very important. The second motive is a *regulatory* 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 long-term investors such as pension funds and insurance companies.

We examine quantitatively how much each of the different Treasury holders matters for the overall convenience yield. For example, we find that the regulatory holders of Treasuries (foreign central banks, U.S. Federal Reserve banks, state and local governments) have essentially inelastic demands for Treasuries and moreover account for over half of the current holdings of Treasuries. We perform a counterfactual exercise which shows that if these holders were to sell their Treasuries and exit the market, the convenience yield on Treasuries would drop by 50 *bps* and hence Treasury yields will rise by the same amount relative to corporate yields.

We also decompose the 100 *bps* current convenience yield into components due to each of the motives for holdings Treasuries. Our finding that the regulatory demand for Treasuries is price inelastic implies that regulatory demanders are infra-marginal; they buy a fraction of the Treasury stock to satisfy their regulatory demand, but are at the margin not the investors who set prices. Hence the convenience yield only reflects a surety component and a liquidity component, with regulatory demand indirectly inflating the surety and liquidity components. We estimate that each of these components account for roughly 50 *bps* of the convenience yield. These computations and the theoretical arguments from which they derive are explained in Section 4.

Our results have bearing for important questions in both finance and macroeconomics. In addition to their implications for understanding bond yields, we discuss implications for the aggregate value of Treasury convenience, the financing of the US deficit, the behavior of interest rate swap spreads, and investors' portfolio choices.

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

[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. 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.

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. Friedman and Kuttner (1998) show a correlation between the commercial paper to Treasury Bill spread and the relative supply of these assets over the period 1975 to 1996.[2] Relative to these papers we study a longer sample, provide a theoretical basis to 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, we estimate group level demand curves to shed light on which holders drive the convenience yield, and we decompose the convenience yield into a surety and liquidity component.[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. Focusing on forward Treasury rates and projected future Debt/GDP levels, Laubach (2007) reports a $3-4$ *bps* effect per one percentage point increase in projected 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

[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.

[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.

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 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 help to 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 Convenience Yield and Treasury Supply

2.1 Theory

We articulate the convenience yield theory by modifying a standard representative agent asset-pricing model to include a term whereby agents derive utility directly from Treasury holdings. The modification is along the lines of Sidrauski (1967) and Lucas (2000) who consider models where agents derive utility from their holdings of money. We consider a representative agent who maximizes,

$$E\sum_{t=1}^{\infty}\beta^t u(c_t,\theta_t^T)$$

where θ_t^T is the agent's real holdings of Treasury assets.

In the monetary economics literature, utility is presumed to derive from the liquidity services provided by money. Likewise, we can motivate the utility from Treasury holdings in terms of the services provided by these securities. As noted in the introduction, some agents are motivated to buy Treasuries for liquidity reasons, some for regulatory reasons, and others for the surety that Treasuries offer. We use the word "convenience" value to encompass the many services provided by holding Treasuries. Section 4 of the paper digs deeper into the different sources of convenience demand.

Suppose that holding Treasury securities reduces costs that would otherwise be incurred by transacting in a less liquid security, or reduces the explicit or implicit costs of violating a regulatory mandate, or reduces the costs that would otherwise be paid in order to understand investments in more complex assets such as defaultable corporate bonds. Define these costs as,

$$v(\theta_t^T, GDP_t),$$

where, $v(\cdot)$ is decreasing in the real holdings of Treasury assets, θ_t^T. GDP_t is the real income of the agent. The transaction costs are in consumption units, so that the effective consumption of the agent is:

$$C_t \equiv c_t - v(\theta_t^T, GDP_t).$$

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

$$C_t = c_t - v\left(\frac{\theta_t^T}{GDP_t}, 1\right) GDP_t$$

Analogous to the similar measure for money, $\frac{\theta_t^T}{GDP_t}$ may be thought of as the reciprocal of the "velocity" of Treasuries. Thus, the agent utility function is,

$$E \sum_{s=1}^{\infty} \beta^t u(C_t),$$

with C_t described as the net-of-cost consumption of the agent.

We price assets based on this utility function following the usual steps in asset pricing theory. Define the pricing kernel at date t as,

$$M_{t+1} = \beta \frac{u'(C_{t+1})}{u'(C_t)}.$$

Suppose that the agent holds θ_t^T one-period nominal Treasury bonds with a price at date t of P_t^T.[4] Also, suppose that the realized inflation rate between date t and date $t+1$ is π_{t+1}. Then, the first order condition for the agent's holding of θ_t^T gives,

$$P_t^T = E_t \left[M_{t+1} \frac{1}{1+\pi_{t+1}} \right] + v'(\theta_t^T / GDP_t), \tag{1}$$

where,

$$v'(\theta_t^T / GDP_t) = \frac{\partial v\left(\theta_t^T / GDP_t, 1\right)}{\partial \theta_t^T / GDP_t}$$

[4] For simplicity, we derive prices of one-period bonds. In our empirical work, however, we focus on roughly 20-year maturity bonds. The appendix derives the corresponding expressions for multi-period bonds. There is nothing surprising that comes out of the multi-period derivation.

Note in particular the right hand side of (1). If an agent cuts his consumption at date t to invest in Treasury securities, then he receives the real yield on the securities at date $t+1$ (this is reflected in the first term) and gets a date t benefit, measured in consumption units, directly from the Treasury holdings through increasing $v(\cdot)$ at the margin (this is the second term).

The first order condition in (1) describes how P_t^T depends on the representative agent's holdings of Treasury securities. We can use observations on actual holdings of Treasury securities to estimate this dependence. However, in this case we also have to measure the pricing kernel and the inflation process and any difficulties in doing so will affect our estimation. Our strategy instead is to price a high-grade corporate bond, which we assume to be an asset that is similar to the Treasury bond but that provides none of the convenience services, and express the difference in yields between this corporate bond and the Treasury bond. Since both of these bonds are likely to be equally affected by inflation rates, and similarly sensitive to the exact form of the pricing kernel, the yield spread strategy is econometrically more powerful than just focusing on the Treasury yield.

Consider a one-period corporate bond that pays one at date $t+1$ if there is no default and $1-d_{t+1}$ if there is default, where d_{t+1} is a random variable reflecting the percentage default on the bond. The first order condition for the corporate bond investment gives,

$$P_t^C = E_t\left[M_{t+1}\frac{1}{1+\pi_{t+1}}(1-d_{t+1})\right],$$

where now there is no convenience yield term (i.e, no term involving $v'(\cdot)$).

The yield spread between the Treasury bond and corporate bond is,

$$i_t^C - i_t^T = -(ln\ P_t^C - ln\ P_t^T).$$

Using the approximation that $ln\ P \approx P-1$, we find that

$$i_t^C - i_t^T \approx \overbrace{E_t\left[\frac{M_{t+1}}{1+\pi_{t+1}}\right]E_t[d_{t+1}]}^{\text{Default Risk}} + \overbrace{cov_t\left[\frac{M_{t+1}}{1+\pi_{t+1}}, d_{t+1}\right]}^{\text{Risk Premium}} + \overbrace{v'\left(\frac{\theta_t^T}{GDP_t}\right)}^{\text{Convenience Yield}} \quad (2)$$

The spread has three components.[5] 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. Since Treasury securities are assumed to provide a convenience value, the yield spread is furthermore increased by a convenience yield term (third term). We refer to the sum of the

[5] There is an additional component in the spread of equation (2) that arises if we consider the differential tax treatment of corporate and Treasury bonds. We discuss the tax component in Section 7.2.

default risk and risk premium as the "default" component of the corporate bond spread, and $v'(\cdot)$ as the "non-default" component of the corporate bond spread.

We should expect that holding more Treasury assets, at the margin, reduces the convenience value offered by the next unit of Treasury assets:

$$\frac{\partial^2 v\left(\theta_t^T/GDP_t\right)}{\partial(\theta_t^T/GDP_t)^2} < 0;$$

Moreover, it seems likely – and we also study this empirically – that $v(\cdot)$ has a satiation point:

$$v'(\cdot) = 0 \quad \text{for} \quad \frac{\theta_t^T}{GDP_t} \text{ sufficiently large.}$$

If there are enough Treasury assets available to satisfy all of the motives for holding these assets, at the margin, these assets are priced in exactly the same way as any non-convenience asset.

The yield spread in (2) reflects 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:

$$i_t^C - i_t^T = E_t\left[\frac{M_{t+1}}{1+\pi_{t+1}}\right] E_t[d_{t+1}] + cov_t\left[\frac{M_{t+1}}{1+\pi_{t+1}}, d_{t+1}\right] + v'\left(\frac{\Theta_t^T}{GDP_t}\right) \tag{3}$$

In the next section, we exploit variation in the outstanding amount of Treasury securities to present 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 (functions of) the ratio of the stock of US government debt to US GDP as the independent variable. Under the no-convenience yield null, changes in Θ_t^T have no effect on the yield spread, while under the alternative the coefficient on government Θ^T/GDP in this regression will be negative.

2.2 Alternative Assets

In practice, it is likely that there are other non-Treasury securities that also offer liquidity services, or satisfy a regulatory mandate, or have low information costs. In this case, our distinction between Treasury and non-Treasury assets is not as sharp as depicted in the model. For example, we will show in Section 5 that the debt issued by the Federal National Mortgage Association (FNMA) have some convenience value in common with Treasury securities. Likewise, we will show that some types of corporate debt offer convenience value. Suppose that there are alternative convenience securities, held in amount Θ_t^A, and suppose that these assets offer $0 < k < 1$ fraction of the convenience services of Treasury securities. Then, the yield spread on Treasuries is,

$$i_t^C - i_t^T \quad \approx \quad E_t\left[\frac{M_{t+1}}{1+\pi_{t+1}}\right] E_t[d_{t+1}] + cov_t\left[\frac{M_{t+1}}{1+\pi_{t+1}}, d_{t+1}\right] + v'\left(\frac{\Theta_t^T}{GDP_t} + k\frac{\Theta_t^A}{GDP_t}\right). \tag{4}$$

Thus, we can think of variation in Θ_t^T as picking up changes in a larger convenience aggregate. Indeed, we would expect that changes in Θ_t^T also affects the convenience yield on alternative assets. This is a prediction for which we will provide empirical support.

2.3 Endogeneity of Supply

Both Θ_t^T and Θ_t^A may be endogenous, and this fact can complicate inference. Consider the potential endogeneity of Treasury supply. The price variable in our setting is a corporate bond spread rather than an interest rate level. 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. Thus, our use of interest rate spreads rather than the level of interest rates to discern the effects of government debt avoids a number of difficult issues that prior work testing Ricardian equivalence has had to contend with. Furthermore, even 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. Specifically, suppose a shock to investors' 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.

Consider next the potential endogeneity of bonds supplied by the private sector. We may expect that when the convenience yield is high, the private sector responds by supplying more convenience assets. This behavior also leads to a bias against finding any relation between Treasury supply and the yield spread. For example, suppose that the government reduces Treasury supply, which, ceteris paribus, increases the convenience yield. Then, the private sector is likely to increase alternative supply, thereby lowering the convenience yield. We should interpret our regressions as estimating in reduced form the net effect of Treasury supply given any endogenous response of private sector supply substitutes. If, as one would expect, $\frac{\partial \Theta_t^A/GDP_t}{\partial \Theta_t^T/GDP_t} < 0$, the regressions underestimate the true partial derivative of the convenience yield with respect to Treasury supply. Specifically, the coefficient on Θ^T/GDP in our regressions will estimate,

$$\frac{dv\left(\Theta_t^T/GDP_t + k\Theta_t^A/GDP_t\right)}{d\Theta_t^T/GDP_t} = \frac{\partial v(\cdot)}{\partial \Theta_t^T/GDP_t}\left(1 + k\frac{\partial \Theta_t^A/GDP_t}{\partial \Theta_t^T/GDP_t}\right) < \frac{\partial v(\cdot)}{\partial \Theta_t^T/GDP_t}.$$

3 Evidence for Convenience Yield on Treasuries

3.1 Controlling for Default Risk and Default Risk Premium

This section presents regressions where the dependent variable is the time series of the bond yield spread (the yield on corporate bonds minus the yield on Treasuries) and the independent variable is functions of the ratio of the stock of US government debt to US GDP.

The principal difficulty in interpreting our regressions is an omitted variable bias. If changes in Debt/GDP are correlated with changes in the default component the regression of the bond spread on Debt/GDP may yield a significant coefficient, despite there being no causal relation running from Debt/GDP to the spread.[6,7] We deal with the omitted variable bias in two ways. First, we introduce a variety of controls that attempt to directly capture variation in the default component of corporate bond yields. 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 (4). In these regressions, we also include proxies for marketwide risk premia to control for the risk premium in the corporate bond returns.

3.2 Demand Function

We adopt the following functional form in the regressions of this section. We assume that $v'(\cdot)$ can be written as:[8]

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

and estimate the following linear regression:

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

[6] A concrete example of this omitted variable bias is 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 component will fall when Θ_t^T rises.

[7] The spread 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.

[8] We use the book value of Treasury debt for Θ_t^T rather than market value because our equilibrium relation, (3), 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. Using data from 1973 to 2005 from Lehman Brothers, we find that the correlation between the market value of outstanding Treasuries and the face value is 0.99.

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.

We do not directly measure variation in the supply of alternative assets, Θ_t^A, absorbing such variation into the error term. We present data in Section 5 to show that variation in Θ_t^A for most of the sample has been small compared to variation in Θ_t^T.

Also for now we are assuming that convenience demand is stable over time, so that variation in Θ_t^T/GDP_t traces along a constant $v'(\cdot)$ function. That is, we are not allowing A and B to vary with "demand conditions." The error term picks up any shocks to convenience demand. Plausibly, demand conditions do vary over time. At a high frequency, we can imagine a "flight-to-Treasury-liquidity" during a financial crisis that shifts the demand for Treasury liquidity for a few weeks or months. This type of demand variation does not pose a significant problem for our analysis. Most of the regressions we present are based on a roughly 20-year bond spread for which it is the expected demand over the entire 20 years of the bond that is captured by $v'(\cdot)$. A demand shock that lasts in the order of months will have a small effect on this expected demand. At a lower frequency, structural shifts such as the increased desire by foreign central banks to hold Treasury bonds, or the shedding of Treasuries by commercial banks after World War II (see Section 4) may constitute a significant change in demand conditions. Table XI shows how A and B have varied across sub-samples.

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 ratio is above one).[9] We adopt the log function primarily because it is parsimonious: it only requires us to estimate a single parameter, B, which can moreover 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. Over the range of variation of the Debt/GDP ratio, the results from the exponential specifications are close to those from the log specification.

3.3 Long-term Corporate Bond Spread

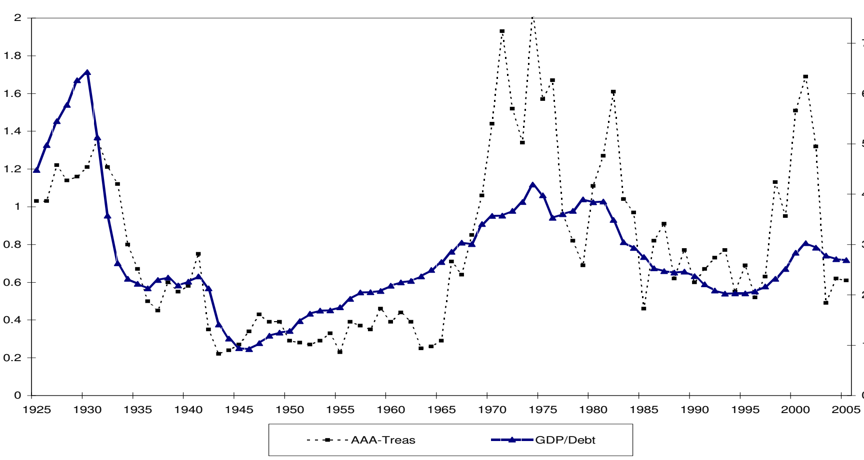
Figure 2 graphs the percentage spread between the Moody's *Aaa* long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds. Both data series are from the Federal Reserve's FRED database and extend from 1925 to 2005 in the figure. The Moody's index is constructed from a sample of long maturity (> 20 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

[9] 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.

bonds for 2000 - 2005. We use annual observations, sampled in October of the year.[10,11]

The figure also graphs the ratio of US GDP to Debt 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.

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.

Our theory suggests that the bond yield spread should be highest when the stock of Treasury debt

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

[11] 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.

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 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 (2)). 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 the default component. 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 in the yield spread. 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 as well as NBER recession dummies to measure the state of the business cycle. The inclusion of these controls do 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 capital structure information and Merton's option decomposition of capital structure, they infer the firm's asset value and asset value volatility. This information allows them to compute the distance to default on debt (i.e. moneyness of the put option). Using historical default information in a non-linear regression, they estimate how distance-to-default translates into default probabilities. We use the median EDF reported by Moody's-KMV for large firms (defined as firms with book value of assets $> \$300$ 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. Because the EDF measure is option-pricing based, a key input into the measure is stock return volatility. We construct a default measure that we can extend back to 1926 based on stock 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.[12] As expected, volatility is significant when introduced alone – indeed, more significant than the *Baa-Aaa* measure from column (2).[13] 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

[12] 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.

[13] 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 XI). 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.

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 stock 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.[14] 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. An LM test for autocorrelation indicates strong first-order autocorrelation, while the coefficients on the second or higher lags of the residual are small and not statistically significant. To address possible concerns about poor small sample properties of Newey-West standard errors, panel B estimates the relation using GLS, accounting for AR(1) first-order autocorrelation (this is consistent with the recommendation of Cochrane (2008)). Specifically, the regressions are Cochrane-Orcutt AR(1) two-step regressions. They uniformly confirm the significance of the findings in Panel A. Finally, as another approach, 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 in other specifications.

3.4 Excess Returns on Corporate Bonds

We next present evidence using the realized return on corporate bonds relative to Treasury bonds as dependent variable. By using 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

[14] 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. 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.

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 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 one-year percentage excess return on long term corporate bonds over long term government bonds. The return data are from Ibbottson, 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.

In these regressions, we model the error as ARMA(1,1). Risk premia and convenience yield premia are persistent. Thus, to the extent that our independent variables do not fully capture the time variation in these premia, we would expect the error to have an AR(1) component. The MA component stems from expectational error, since the regression uses realized excess returns rather than expected excess returns (see Cochrane, 2008). We have experimented with longer lag structures and our results remain unchanged.

The first column in Panel A shows that the yield spread (weakly) predicts the future excess return and is thereby not purely reflective of default risk considerations. If default risk on corporate bonds at date $t+1$ unexpectedly rises relative to date t, the excess return between t and $t+1$ will fall, but this fall does not reflect anything about the expected excess return at date t. Our regressions can be sharpened if we remove this component of default risk innovations. In column (2) we add a covariate denoted *volatility* innovation. The covariate is based on the stock market volatility measure. We forecast the stock market volatility at date $t+1$ using an AR(1) structure, given information at date t. Then, we compute the difference between the actual stock market volatility and the forecast volatility to proxy for unanticipated changes in default risk. The covariate is significant. The R^2 rises from 0.05 to 0.19. The sign is negative as expected − higher realized default risk causes returns to fall. Including the covariate increases the forecast power of the $Aaa - Treasury$ spread. In column (4) we compute a similar default risk innovation variable based on *Baa-Aaa* spread. As in the results from Table 1, this default risk measure performs worse than the volatility measure. In column (3), we add two more controls. The *slope* control proxies for variation in risk aversion over the business cycle. The *durationhedge* control 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. Overall, these results support our use of the bond spread as dependent variable in the prior regressions by showing that it captures a non-default component of the expected excess return on corporate bonds over Treasuries.

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. The first three columns mirror those of Panel A. The results largely accord with our previous findings. The coefficient on $log(Debt/GDP)$ is negative and statistically significant after adding the default risk controls. The coefficient in column (3) of -1.91 implies that one standard deviation (0.42) increase in $log(Debt/GDP)$ causes the expected excess return for the next year to fall by 80 *bps*.[15] The result is larger than what we find in Table I (33 *bps*). This is not unexpected given the coefficients in Panel A.

In column (4), we add a variable to proxy for the unanticipated change in the $log(Debt/GDP)$ ratio, and hence the convenience yield. Our proxy is the residual from a regression of $log(Debt/GDP)$ one year ahead on the current values of $log(Debt/GDP)$ and of the deficit/GDP ratio (also obtained from Henning Bohn's web page). If the $Debt/GDP$ ratio rises unexpectedly at date $t+1$, then the convenience yield at date $t+1$ falls, and the realized return on corporate bonds over Treasury bonds should rise. The sign on the $log(Debt/GDP)$ innovation accords with this additional prediction of the convenience yield theory, and the variable is statistically significant.

3.5 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.[16]

[15] 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.

[16] 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

The results reported are consistent with those of Table I. Increases in $log(Debt/GDP)$ decrease the CP-Bill yield spread.[17] The effect is statistically significant in all but two of the specifications (the GLS estimations using the EDF control and the $pct-failed$ control).

In Table IV, columns (3) and (4) we use commercial bank 3-month CD rates as an alternative short-term interest rate benchmark. This rate is a bank referenced short-term interest rate, rather than a corporate referenced rate as with commercial paper. Like commercial paper, bank CDs are essentially a buy-and-hold investment, and are thus less liquid than Treasuries. The results presented are again supportive of our convenience yield hypothesis.

The results from the Tables I, II, and III – using long-term bond spreads, the excess return on long-term bonds, and short-term bond spreads – 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 evidence from the finance literature on corporate bond pricing (see, for example, Elton *et al* (2001), Collin-Dufresne, Goldstein, and Martin (2001), Huang and Huang (2001), or Longstaff, Mithal, and Neis (2006)). 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.

3.6 *Baa* Bond Yields

Columns (1) and (2) of Table IV present regressions based on the spread between *Baa* corporate and Treasury bonds, rather than *Aaa* corporate and Treasury bonds. That is, the benchmark here is a lower-grade corporate bond. This is an important comparison because historically the quantity of outstanding *Aaa* bonds has been small, while the quantity of bonds rated *Baa* or better has been significant. For example, data from Lehman Brothers shows that from 1988 to 2004 the stock of outstanding *Aaa* bonds relative to

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". 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."

[17] 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.

GDP averaged 0.5%, while the stock of bonds *Baa* and higher averaged 10.6% of GDP. Thus one may worry that idiosyncratic or compositional factors contaminate the *Aaa* benchmark yield we use. The sample used in the regressions in columns (3) and (4) corresponds to the same time period as that of Table I. The default risk measures come in far more significantly than in earlier regressions, consistent with the fact that the *Baa* rate carries significant default risk. The coefficients on $log(Debt/GDP)$ are large and significant, consistent with the convenience yield hypothesis.

The coefficients in the regressions using *Baa* bonds are roughly double those reported in Table I when using *Aaa* bonds. This result is interesting because it suggests that the *Aaa*-Treasury regressions underestimate the convenience effect of Treasuries. Why might this be so? Since in practice *Aaa* bonds are close to default free, and some of the convenience demand for Treasuries is due to their surety, we posit that the *Aaa* bonds are a convenience substitute for Treasury assets. Thus the *Aaa* bond itself carries a convenience yield.[18] This important result is examined more thoroughly in the next section.

3.7 Quantifying the Convenience Yield

We now estimate the convenience yield on Treasuries. We base these estimates on comparing Treasuries to *Aaa* bonds, as in the regressions in much of this section, and comparing Treasuries to *Baa* bonds, following on our observation that the *Aaa*-Treasury spread underestimates the convenience yield on Treasuries.

The approach is as follows. We have argued that for a sufficiently large value of $Debt/GDP$ the convenience demand of agents is satiated and the convenience yield goes to zero. In this case, any spread between Treasuries and corporate bonds is attributable purely to their differential default risk (plus tax differences). Consider a regression specification based on a function $v'(\cdot)$ which asymptotes to zero as its argument goes to infinity. Note that our previous log-linear specifications involving $log(Debt/GDP)$ does not have this asymptote property. Instead, consider the following exponential specification:

$$S_t = b_0 + b_1 e^{b_2 \times (Debt/GDP)} + c\, Y_t + \epsilon_t. \tag{6}$$

This specification permits a simple decomposition: $b_1 e^{b_2 \times (Debt/GDP)}$ is the convenience yield component of the spread S_t at a given value of $Debt/GDP$. We demean the the controls Y_t in our regressions. Then, b_0 is the component of the spread that is due purely to default, default risk premium, and tax differences.

We estimate equation (6) using GMM with instruments including a constant, $Debt/GDP$, $(Debt/GDP)^2$, and $(Debt/GDP)^3$. Table V reports the results where S_t is the *Aaa*-Treasury spread in columns (1) and (2)

[18] 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.

and *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 with stock market volatility and the slope of the yield curve as controls. The control variables have been demeaned so that b_0 can be interpreted as the asymptote value of the corporate bond spread.

We can evaluate the convenience yield component ($b_1 e^{b_2 \times (Debt/GDP)}$) at the current $Debt/GDP$ ratio of 0.37 to quantify the current convenience yield on the respective spreads. For the *Aaa*-Treasury spread, this expression evaluates to 51 *bps*. For the *Baa*-Treasury spread, the expression evaluates to 100 *bps*. This means that based on the average level of demand for convenience that has prevailed across our sample, the convenience yield on Treasuries relative to *Baa* bonds is 100 *bps*. Relative to *Aaa* bonds, the convenience yield is 51 *bps*, suggesting that *Aaa* bonds themselves have close to 50 *bps* of convenience yield. We call these *average* values because as we have noted, 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.

This range of estimates, from 51 *bps* to 100 *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), using 2001-2002 credit default swap data, 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 their 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*. Feldhutter and Lando (2008), again focusing on detailed estimation of the default component, estimate a convenience yield on Treasuries of close to 60 *bps*.

The values of b_0 in the *Aaa*-Treasury regression is 26 *bps*, while it is between 77 and 92 *bps* for the *Baa*-Treasury regression. These numbers are also consistent with intuition. The default components are relatively larger when the spread is considered relative to *Baa* bonds. 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 7.2) can increase this spread to at most 35 *bps* according to Elton *et al* (2001)'s calculations. Their similar computation for *Baa* bonds puts the spread, including tax component, at 75 *bps*.

4 Decomposing the Convenience Yield

We have so far established that Treasury securities provide a convenience service by showing that variation in Treasury supply causes changes in the yields on Treasury bonds relative to non-Treasury bonds. In this section, we go one level deeper to shed light on who is driving the convenience yield and what aspects of Treasury securities are particularly responsible for convenience. In addition to a qualitative discussion of these questions, we provide a quantitative decomposition of the convenience yield.

4.1 Who Holds Treasury Debt and Why?

Table VI, Panel A 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 VI presents the average fraction of Treasury holdings across these years.[19]

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

Table VI, Panel B shows the composition of each group's bond portfolio (leaving out municipal bond holdings which may largely be driven by tax considerations). This panel is constructed based on Flow of Funds Table L208, L209, L210, and L212.

We offer three motives behind the Treasury holdings, reflected differently across the groups in Table VI. First, a number of observers have noted the superior liquidity of Treasury securities over other assets such as corporate bonds. For example, Chen, Lesmond and Wei (2008) document for 1995 to 2003 that the spread between bid and ask prices on investment grade corporate bonds are close to 50 *bps*. Studying a similar sample period, Longstaff (2004) reports spreads of near 10 *bps* on 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

[19] For simplicity, Table VI omits a few small categories of Treasury owners. The omitted categories are nonfinancial corporate business, nonfarm noncorporate business, government-sponsored enterprises, and brokers and dealers. The total share of Treasuries owned jointly by these groups averages 4.6% with a maximum of 9.4% and a minimum of 0.4%. The most serious failing in this omission is that of brokers and dealers, who often carry long positions in some Treasuries and short positions in other Treasuries, which is reported as a net small position.

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 in part because of their superior liquidity.

Second, a *regulatory motive* also drives some of the holders of Treasury securities. Kohn (2002) notes that Treasury securities best satisfy the Federal Reserve's portfolio objective of "liquidity, safety, and neutrality in private credit allocation." A similar objective can be ascribed to other governmental holders 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, etc, arises. Thus, an implicit mandate of avoiding investments in private assets may be in the best interests of taxpayers for these governmental entities. Furthermore, municipalities typically find it tax-advantageous to defease an existing debt obligation by pledging safe collateral against the promised payments. For legal reasons, the only collateral that can be used for this purpose are Treasury securities. This regulatory motive also drives some of the state/local government holdings of Treasury securities (Chalmers, 1998).

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*. Vissing-Jorgensen (2003) argues that there are significant costs, both monetary and informational, that may limit household participation in the stock market. The surety demand stems from households seeking to avoid such costs of participating in the stock or corporate bond markets.

"Surety" is different than "risk aversion." To be precise, what we mean by surety is a value investors place on a sure cash-flow above and beyond what would be implied by the pricing kernel. Surety can be distinguished from risk aversion because surety demand has the property that if there is a greater supply of sure assets the price of surety falls, even if the pricing kernel is unchanged. Under risk aversion, the pricing kernel captures risk aversion and Treasury supply is irrelevant for the price of risk.

The surety motive likely applies to some of the foreign private sector's demand for Treasury securities. Desiring to hold assets in US Dollars, some foreign investors choose to hold the dollars in the form of Treasury securities rather than corporate assets. This surety motive may also be important for mutual funds, pension funds, and insurance companies who in targeting a clientele of households who desire surety, buy Treasuries to provide this surety.

These different motives for holding Treasuries are reflected in Table VI. The governmental holders in the top three groups (Federal Reserve Banks, Foreign Official Holdings, State/Local Governments) are likely driven by regulatory motives, and possible also liquidity and surety. The private holders in the next three groups (Banks/Credit Institutions, Households and Mutual Funds, Foreign Private Sector) are likely driven by the liquidity and surety motives, while the long-term investors in the bottom three groups (Federal/State/Local Government Retirement Plans, Private Pensions, Insurance Companies) have no regulatory or liquidity motives and thus care mainly about the surety of Treasuries.

From Table VI, Panel B, it is clear that the groups driven by regulatory motives hold the majority of their bond portfolio in Treasuries, while the long-term investors hold a much smaller fraction of their bond portfolio in Treasuries and furthermore allocate their corporate bond holdings toward long-term bonds.

4.2 Each Group's Contribution to the Convenience Yield

It is commonly thought that reserve accumulation by foreign central banks has had a significant effect on the prices of Treasury bonds. In this section, we appraise this claim. More generally, our analysis sheds light on how significant each of the groups has been in the determination of the total convenience yield on Treasuries.

For simplicity and for statistical reasons, to reduce noise in the estimates, we consolidate the groups into three super-groups and use these as the units of analysis. Group 1 are the governmental holders (Federal Reserve Banks, Foreign Official Holdings, State/Local Governments); Group 2 are private holders who may be driven by both liquidity and surety needs (Banks/Credit Institutions, Households and Mutual Funds, Foreign Private Sector); and, Group 3 are long-term investors (Federal/State/Local Government Retirement, Private Pensions, Insurance Companies). We estimate demand curves for each of these consolidated groups.

We start from a group-level exponential specification relating spreads to the ratio of the group's Treasury holdings relative to GDP:

$$S_t = b_0 + b_1 e^{b_2 \times GroupHoldings/GDP} + cY_t + \epsilon_t^{Group}.$$

Since shocks to the group's Treasury demand will affect both the group's Treasury holdings and (in equilibrium) the spread, we instrument group Treasury holdings using aggregate Treasury supply. Specifically, we estimate the parameters (b_0, b_1, b_2) using GMM based on the moment conditions that ϵ_t^{Group} be uncorrelated with a set of instruments. As instruments we use a constant, Debt/GDP, $(\text{Debt/GDP})^2$, and $(\text{Debt/GDP})^3$. The GMM estimation accounts for first order autocorrelation of the error terms. The estimation results are shown in Table VII.

Figure 3 graphs the estimated demand curves for the regression specification with no default controls. The left-hand panels are based on the Aaa-Treasury spread, while the right-hand panels are based on the Baa-Treasury spread. As we have argued, the full value of Treasury convenience is better captured in the Baa-Treasury spread.

From the figure we see that Group 3 has the most elastic of the demand curves. This group holds only a few Treasuries and is moreover quite price sensitive in demanding Treasuries. This suggests that Group 3 is quantitatively not an important determinant of the convenience yield. A way of making this point precise is to ask what the convenience yield would be if there were only Group 3 holders of Treasuries. We use the demand curve estimates for the *Baa*-Treasury spread to answer this question. From the estimates presented in Table VII, Panel A, column (2), the convenience yield for Group 1 would be $4.04 \times e^{-43.1 \times 0.37}$ if this group held the entire current stock of Treasury debt. This convenience yield evaluates to approximately zero.

Group 2's demand is less elastic than Group 3. Moreover Group 2 is also a more significant holder of Treasuries. Plausibly then, Group 2 plays a bigger part in determining Treasury convenience. If we repeat the convenience yield computation based on Table VII, Panel C, column (2), the convenience yield for Group 2 is $11.34 \times e^{-16.2 \times 0.37}$, which equals 3 *bps*.

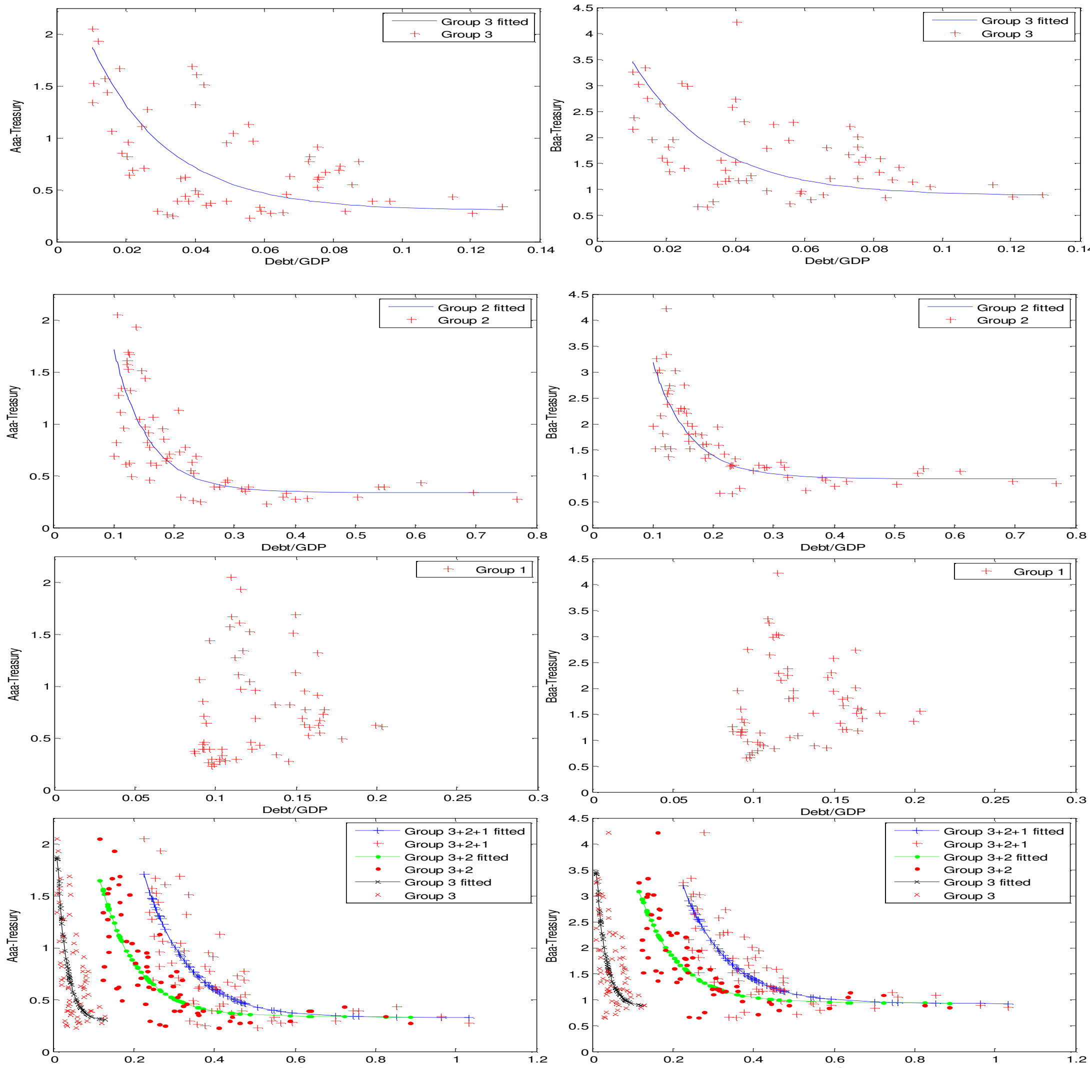
In the bottom panel of Figure 3, the middle curve pictured is the aggregated demand across both groups 2 and 3. For this aggregated demand curve of Group 2+3, our regression estimate from Table VII, Panel B, column (5) gives a convenience yield of $4.73 \times e^{-7.99 \times 0.37}$, which equals 25 *bps*. The reason this number is higher than the sum of the two numbers reported in the previous paragraphs is that we are tracing further up a non-linear demand curve.

The figures for Group 1 are striking. It appears that there is no relation between price and quantity for the governmental institutions. Group 1 holders resemble inelastic buyers of Treasury securities. This is consistent with the evidence from Table VI, Panel B that Group 1 holds the bulk of their portfolio in Treasury securities. These observations suggest the following characterization of Group 1 demand. When a Group 1 holder receives some funds to invest it buys Treasuries with these funds, regardless of price. Thus, for example, a foreign central bank receives a dollar capital inflow and accumulates more dollar reserves. It buys Treasuries with these reserves regardless of the relative price of Treasuries to other U.S. fixed income assets. Note also, from both Table VI and the horizontal axis of the figures, that Group 1 is a large buyer of Treasuries so that the inelastic demand may play a significant role in price determination.

However there is an important point to note about the effects of Group 1's demand on equilibrium. If Group 1 were the only Treasury buyers in the world, then the convenience yield will be zero. That is, if this group has a completely inelastic demand for Treasuries, and this demand is satiated at the current supply of Treasuries, then the marginal value of a Treasury for Group 1 is zero. Thus, Group 1 has an indirect effect on prices. By reducing the supply available to the rest of the groups, it indirectly drives up the convenience yield.

To quantify how big this indirect effect is, consider that Group 1 currently holds 55% of the Treasury debt outstanding. With the demands from all the groups, the aggregate demand curve is the right-most line in the bottom right panel in Figure 3. Without Group 1, the aggregate demand curve would consist of Group 2 and 3 only, as illustrated by the middle line in the same graph. The increase in the convenience yield due to Group 1 can thus be estimated as the vertical distance between these two demand curves, evaluated at $Debt/GDP$ of 0.37. The vertical difference is 50 *bps* (using Table VII, Panel B, column (5) and Panel D,

Figure 3: Demand Curves, by Group



Each panel presents estimates of demand curves for convenience, broken down by groups. The left panels are based on convenience in the *Aaa*-Treasury spread, while the right panels are based on convenience in the *Baa*-Treasury spread. The bottom panels illustrate how the different group demand curves aggregate.

column (5)). This computation shows that the demand of Group 3 is a central driver of the convenience yield.[20]

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 and low US interest rates to the demand for US assets by foreign savers (see also Bernanke (2005)). Our estimates that Group 3 is the largest driver of the convenience yield is consistent with such theories.

4.3 Decomposing the Convenience Yield into Liquidity, Regulatory, and Surety Components

Suppose that the convenience yield function $v(\cdot)$ can be broken into three pieces, each reflecting the three demand motives for holding Treasury assets. Thus, suppose that,

$$v\left(\frac{\theta^T}{GDP}, \frac{\theta^A}{GDP}\right) = v_l\left(\frac{\theta^T}{GDP} + k_l\frac{\theta^A_l}{GDP}\right) + v_s\left(\frac{\theta^T}{GDP} + k_s\frac{\theta^A_s}{GDP}\right) + v_r\left(\frac{\theta^T}{GDP} + k_r\frac{\theta^A_r}{GDP}\right).$$

We have omitted time subscripts on the quantities to save notation.

The evidence offered in the previous section suggests that the governmental holders of Treasuries have inelastic demand curves. Since these holders are largely driven by the regulatory motive, it is likely that the regulatory demand is itself price inelastic. We can think of this as, for regulatory purposes, agents need some quantity of Treasuries, θ^R. Holding less than θ^R leads to large disutility, and holding greater than θ^R provides no incremental benefit. The latter part of this statement is the important one. In practice, Θ^T has probably always exceeded θ^R since the total Treasury holdings of the regulatory holders have always been far less than total Treasury supply. This means that $v_r'(\cdot) = 0$ over the relevant range of Θ^T. Thus,

$$v'\left(\frac{\theta^T}{GDP}, \frac{\theta^A}{GDP}\right) = \overbrace{v_l'\left(\frac{\theta^T}{GDP} + k_l\frac{\theta^A_l}{GDP}\right)}^{\text{Liquidity Component}} + \overbrace{v_s'\left(\frac{\theta^T}{GDP} + k_s\frac{\theta^A_s}{GDP}\right)}^{\text{Surety Component}}. \quad (7)$$

The convenience yield on Treasury assets is only composed of a liquidity and a surety component. The regulatory motive will have an effect on the convenience yield, but as in our arguments regarding Group 1 in the previous section, the effect is indirect.

It is possible to make some headway in decomposing the convenience yield into its liquidity and surety components by using the pricing equations for the alternative assets. Suppose that there exists a surety

[20] The estimations for groups is based on a shorter time period than our earlier exponential estimations. This explains why the convenience yield contributions for Group 2 and 3 of 25 *bps* and for Group 1 of 50 *bps* does not add to the earlier benchmark estimate of a total convenience yield of about 100 bps.

"test" asset for which $k_l = 0$, but $k_s > 0$. Then, the convenience yield on this asset is,

$$k_s v_s' \left(\frac{\theta^T}{GDP} + k_s \frac{\theta_s^A}{GDP} \right) = k_s \times \text{ Surety Component.} \tag{8}$$

Likewise, a test asset providing only liquidity services has convenience yield,[21]

$$k_l v_l' \left(\frac{\theta^T}{GDP} + k_s \frac{\theta_l^A}{GDP} \right) = k_l \times \text{ Liquidity Component.} \tag{9}$$

In practice, it is hard to find an alternative asset that provides only liquidity and no surety. But it is possible to find assets that provide surety but are far less liquid than Treasuries.

One such asset is a *Aaa* bond. Moody's estimates based on data from 1920 to 1999 that the default rate on *Aaa* rated bonds over a 10 year period is around 1%, while for *Baa* bonds this default rate is 8% (see Moody's Historical Default Rates of Corporate Bond Issuers, 1920-1999). Thus *Aaa* bonds are an order of magnitude safer than *Baa* bonds; if there is a special value placed on the surety of debt securities it will be reflected in the relative pricing of these bonds. Consider, for example, the case of mutual funds that target investors who value surety. Some such funds explicitly state in their prospectus that they only invest in *Aaa* rated corporate or government securities. For such a fund, both *Aaa* bonds and Treasuries satisfy the surety mandate. Moreover, as both *Aaa* and *Baa* rated corporate bonds are similarly illiquid, their spread is not driven by liquidity differences. Chen, Lesmond and Wei (2008) study corporate bond liquidity in a large sample of corporate bonds over the period 1995 to 2003 and report the spread between bid and ask prices on *Aaa* corporate bonds average 52 *bps* while they average 58 *bps* on the *Baa* corporate bonds. These spreads compare to near 10 *bp* for Treasury bonds (Longstaff, 2004). Thus the convenience yield measured in the $Baa - Aaa$ spread mainly contains surety convenience.

In Section 3.7 we find that the convenience yield from the *Baa*-Treasury spread at the current Debt/GDP ratio of 0.37 is 100 *bps*. From the *Aaa*-Treasury spread we find that the convenience yield is 51 *bps*. Thus, the difference of 49 *bps* is the convenience yield on *Aaa* bonds relative to *Baa* bonds. We can also do this computation by estimating the exponential demand function of (6) using the $Baa - Aaa$ spread along with default controls. This estimation gives $b_0 = 0.64(5.47)$, $b_1 = 1.77(2.81)$ and $b_2 = -3.37(2.29)$. Evaluating the convenience yield based on these number gives 51 *bps*.

Thus, around 50 *bps* is our estimate of the surety convenience on *Aaa* bonds. Equation (8) shows that if the surety on *Aaa* bonds is a fraction k_s of the surety of Treasuries, then the surety component of Treasury convenience is $50/k_s$ *bps*. In practice k_s is probably less than one, but considering that the default rates on *Aaa* bonds are only 1%, the value of k_s is plausibly close to one. Then, a lower bound on the surety component of Treasuries is 50 *bps*. An upper bound on the liquidity component of Treasuries is the residual convenience yield of 50 *bps*.

[21] A test asset providing only regulatory services has a convenience yield of zero since $v_r'(\cdot) = 0$.

The above computations break the spread down purely into a surety and liquidity component. We now compute the indirect effect that regulatory demand has on the surety and liquidity components. Suppose that all of the regulatory demand stems from Group 1, and moreover that all of Group 1's holdings are driven by regulatory demand. With the regulatory demand from Group 1, the aggregate demand curve is the top line in the bottom panel of Figure 3. Without Group 1, the aggregate demand curve would consist of Group 2 and 3 only, as illustrated by the middle line in the bottom panel of Figure 3. As described above, the increase in the convenience yield due to Group 1 can thus be estimated as the vertical distance between these two demand curves, evaluated at $Debt/GDP$ of 0.37. Using the left graph for Aaa-Treasury the vertical difference is 30 bps, while the vertical difference is 50 bps based on the right graph for Baa-Treasury. This computation shows that the demand of Group 3 drives up the convenience yield on Treasury bonds (relative to Baa bonds) by 50 bps. Of these 50 bps, $50-30 = 20$ bps is due to an increase in the $Baa-Aaa$ spread and thus due to Group 3 driving up the surety component of the convenience yield, with the remaining 30 bps due to an increase in the liquidity component of the convenience yield.

5 Alternative Asset Supplies

This section discusses three potential convenience substitutes for Treasuries: corporate bonds, agency bonds, and mortgage-backed securities. We argue that only high-grade corporate bonds and agency bonds carry some of the liquidity features of Treasuries and document that the supplies of these convenience substitutes are small over most of our sample period. The lack of large amounts of private sector substitutes for Treasuries helps explain the large documented convenience yield on Treasuries.

5.1 Corporate Bonds

We have shown that the $Baa-Aaa$ spread rises when the $Debt/GDP$ ratio falls, suggesting that Aaa bonds are a convenience substitute for Treasuries. McDonald (1983) and Greenwood, Hanson, and Stein (2008) document that the supply of corporate bonds is negatively related to the supply of Treasury securities. McDonald shows a negative relation between the aggregate amount of corporate debt outstanding and the aggregate amount of government debt. Greenwood, Hanson, and Stein show a negative relation between the maturity structure (long versus short) of the corporate bonds and the government bonds. Both of these results suggest that the corporate sector attempts to manufacture assets to "fill in the gaps" created by variations in government debt issues. It seems possible that this correlation is being driven by substitutability in the convenience provided by corporate and Treasury assets.

If Aaa rated bonds have convenience properties, do Aa rated bonds do as well? At what level of default risk does the convenience value disappear? In principal this question can be answered following the steps we have taken with *Aaa* bonds. We can construct the yield spread between *Aa* or *A* rated bonds and *Baa* bonds and regress the spread on the $Debt/GDP$ ratio with controls. However, we do not have a long time series of data for each grade of bonds to answer this question. Instead we refer to results by Longstaff, Mithal and Neis (2006). These authors study the pricing of corporate bonds relative to Treasury bonds, using information from the credit-default swap market to pin down default probabilities. As with most papers in the literature, their paper finds that there is a substantial non-default component in the corporate bond spreads. Interestingly they find that the non-default component is lowest for the highest grade bonds (*Aaa* and *Aa*), and is higher and roughly constant for ratings of A and below. This finding suggests that the surety value is significant only for *Aaa* and *Aa* rated bonds, and provides support for using the *Baa* bond yield as a no-convenience yield benchmark.

5.2 Agency Bonds

Agency bonds, because they are implicitly guaranteed by the Federal Government, carry very low default risk and therefore some of the surety of Treasuries. We know from Table VI, Panel B that foreign central banks hold a small fraction of Agency bonds, so that they may carry some of the regulatory features of Treasuries. Agency bonds also carry low capital requirements for banks and can be used as collateral at the discount window, implying a regulatory demand from banks. On the other hand, as Longstaff (2004) points out, Agency bonds are not as liquid as Treasuries suggesting that they will not be able to fully substitute for Treasury securities.

In columns (3) and (4) of Table VIII, we present regressions where the dependent variable is the spread between *Baa* bonds and long-term Agency bonds issued by the Federal National Mortgage Association (FNMA). We focus on FNMA bonds as opposed to another government agency since data on these bonds are available for a long period of time and since there tends to be a number of bond issues outstanding in a given year. We use the following approach to construct a time series of FNMA yields. For a given year, we focus on (1) bonds whose prices are between 90 and 110, (2) bonds that are non-callable, and (3) bonds that have maturity of approximately 10 years. We average the yields on FNMA bonds that satisfy these criteria. The price criterion is important because there are tax effects that can have significant impact on bonds whose prices are far from par. For some years, especially the early part of the sample, there are either none or only one or two FNMA bonds of this maturity. In these years we use the closest shorter maturity, averaging yields for bonds with (say) approximately 8 year maturity. The average maturity across years is 8.6 years for the FNMA series. The sources for yields are the New York Times and the Bank and Quotation Record. We use Moody's manuals to confirm that the bonds used are all non-callable. Our FNMA-Treasury spread series is available from 1958 to 2004 with the exception of 1978.

The regressions based on FNMA bonds also include the spread between the 20 year and 10 year Treasury yield as a control because the *Baa* bonds have a maturity of 20 years or above compared to the approximately 10 year maturity of the FNMA bonds. The regressions suggest that supply plays a significant role in explain the Agency spread. We thus conclude that Agency bonds are also a convenience substitute for Treasuries. The convenience yield on these bonds likely stems from their surety and their use in satisfying regulatory mandates, and to a smaller extent their liquidity.

5.3 Mortgages

Another plausible Treasury substitute is agency- and GSE-backed mortgage pools (mortgage backed securities or MBS). These securities are backed by a combination of the government and the housing stock. However, note that these securities do not connote the same surety as Treasuries or agency debt. Their cash-flows depend on prepayment and default by households and therefore their valuation depends on the appropriate modeling of prepayment and default risk. As explained in Gabaix, Krishnamurthy, and Vigneron (2007), the typical buyers of MBS are sophisticated investors who have developed an expertise in prepayment modeling.[22] Moreover, other than a small segment of the MBS universe, most MBS are as illiquid as corporate bonds. Finally, it is unclear that they satisfy the regulatory demand of the governmental investors.

In columns (5) and (6) of Table VIII, we present regressions where the dependent variable is the spread between *Baa* bonds and the 30-year FHA secondary market rate (obtained from FRED, with data available from 1964 to 1999). We are unable to find a significant role for supply in any of the *Baa*-Mortgage specifications.[23] While it is possible that the lack of correlation is due to small-sample/data issues, the fact that we find a role for supply in most of the other regressions suggests that it is more plausible that the MBS are not a convenience substitute for Treasuries.

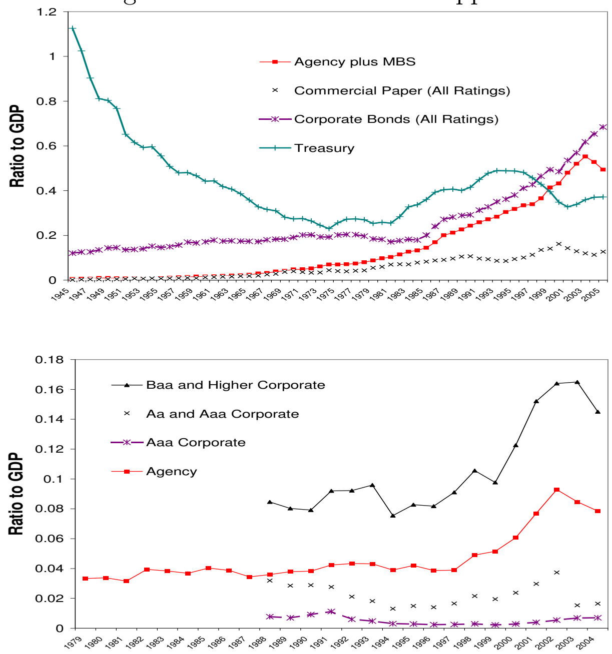
5.4 Supplies

Figure 4 pictures the evolution of potential alternative asset supplies over a long sample. The top panel graphs the Treasury/GDP ratio ("+" marks) that has been the focus of our study. The data used in the top panel are from the Flow of Funds accounts. For consistency with the other data series used in the figure, the Treasury Debt series also uses data from the Flow of Funds accounts.

[22] In contrast, while some Agency, *Aaa*, and Treasury debt is callable, the call options are straight calls that are easily valued. Moreover, these bonds are often not callable for a substantial period of their lives.

[23] Our results are encouraging for the potential effectiveness of the Fed's Term Securities Lending Facility (TSLF) which was initiated during the subprime crisis. In the TSLF, the Fed repos out Treasuries in exchange for MBS. Since MBS are not convenience assets while Treasuries are, the operation increases the total supply of convenience assets, and importantly, the supply of liquid assets. Like an open market operation in which the central bank provides liquidity in the form of bank reserves, the TSLF provides liquidity in the form of Treasury securities. The theoretical literature on financial crises (e.g., Caballero and Krishnamurthy, 2008) suggests that the central bank can play an important role in providing liquidity during a financial crisis.

Figure 4: Alternative Asset Supplies



The figure presents the evolution of asset supplies, measured as stock oustanding relative to GDP. The top panel pictures data from the Flow of Funds of the Federal Reserve and covers a sample from 1945 to 2005 (annual). The supplies are measured in book value terms. The bottom panel pictures data from Lehman Brothers and covers a sample from 1979 (or 1988) to 2004. The supplies are measured at market values.

We also graph the total stock of Agency plus Agency-backed MBS, relative to GDP (square marks). The Flow of Funds does not allow us to view each of these items separately, while following on our previous analysis it is primarily the Agency debt that should be of interest. Nevertheless, it is clear from this graph that prior to 1980 even the total is small compared to Treasuries/GDP. The bottom panel uses data for a more recent period from Lehman Brothers, for which we can observe Agency supply separately (square marks). Here we see that Agency/GDP is less than 0.04 until about 2000. This compares to Treasury/GDP ratios in the range of $0.30 - 0.50$.

The graphs also picture the stock of corporate debt outstanding. From the Flow of Funds (top panel), we picture the total stock of corporate debt relative to GDP ("*" mark/dashed line). These amounts are substantial and comparable to the stock of Treasuries in many years. However, these numbers include all ratings categories including non-investment grade debt (i.e. ratings below *Baa*), while we have presented evidence that only the *Aaa* and possibly *Aa* bonds have convenience attributes. The Lehman data in the bottom panel breaks down the supplies by ratings categories. *Aaa* corporate (the bottom line) is a very small number, totaling less than 0.01 of GDP. If we include *Aa* bonds, the total rises closer to 0.03 of GDP, which is still small relative to Treasury supply.

The top panel also graphs short-term corporate debt (i.e. commercial paper, indicated with "x" marks), which tends to uniformly encompass higher rated corporate debt. The average value of the stock of commercial paper outstanding relative to GDP from the graph is 0.055.

Overall, it is clear from these graphs that the alternative asset supplies have only amounted to between 0.05 to 0.10 of GDP. Most of the increase in alternative asset supplies are in the last 10 years over which there has been a countervailing trend on the demand side as foreign central banks have stockpiled Treasuries. Moreover, since we have previously shown that the aggregate demand curve for convenience is downward-sloping we know that over most of the sample there have not been enough Agency bonds and *Aaa*/*Aa* bonds to satiate convenience demand. To close this section, we offer some thoughts on why this has not been the case.

It is well understood that liquidity has a coordination element. If everyone trades Treasuries because they are thought to be liquid, then Treasuries will in fact be liquid. From this standpoint, if the convenience yield on Treasuries is due to their superior liquidity, we can understand why the private sector has been unable to manufacture liquidity substitutes. Of course, one can always ask why the coordination equilibrium does not shift to a private alternative. Here, the best we can say is: apparently it has not. It is worth adding that we can ask the same question about fiat money: Why has the private sector not manufactured monetary assets to drive the convenience yield on fiat money to zero?

We have also shown that *Aaa* corporate bonds and Agency bonds carry a convenience value relative to *Baa* bonds, arguing that this likely stems from their surety. Why have alternative private sector asset supplies not increased to drive this surety value to zero? One answer is that issuing a *Aaa* or *Aa* rated corporate bond requires the private sector to undertake real investment projects that are relatively sure. To the extent that such investments are technologically limited, there can be in practice only a limited quantities of surety substitutes. The recent subprime crisis offers two pertinent lessons here. First, we can interpret the impetus for financially engineered *Aaa* bonds as stemming from investors' demand for surety convenience. Second, as it is now apparent that many of these engineered bonds were not in fact *Aaa*, it is also apparent that it is difficult to create a truly sure asset.

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. In this section, we discuss implications of our findings for a number of important issues in finance and macroeconomics.

6.1 Value of Treasury Convenience to Investors

Investors purchase Treasury securities despite the fact that these securities offer a low return because they convey convenience benefits. In this section we quantify the total annual value that investors place on the convenience benefits of Treasuries. 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.

Recall that in Section 2.1 we assume that the representative investor receives utility from,

$$c_t - v(\theta_t^T/GDP_t, 1)GDP_t.$$

Take two levels of debt $\theta_t^{0,T}$ and $\theta_t^{1,T}$, with $\theta_t^{1,T} > \theta_t^{0,T}$. The investor will pay, in consumption terms,

$$\Delta c_t = \left(v(\theta_t^{1,T}/GDP_t, 1) - v(\theta_t^{0,T}/GDP_t, 1) \right) GDP_t$$

to enjoy the benefits of holding the higher level of Treasury securities. In our regressions with the exponential specification, we estimate,

$$v'(\theta_t^T/GDP_t) = \frac{\partial v\left(\theta_t^T/GDP_t, 1\right)}{\partial \theta_t^T/GDP_t} = b_1 e^{b_2 \times \theta_t^T/GDP_t}.$$

Integrating we find that,

$$\frac{\Delta c_t}{GDP_t} = \frac{b_1}{b_2}\left(e^{b_2 \times \theta_t^{1,T}/GDP_t} - e^{b_2 \times \theta_t^{0,T}/GDP_t} \right).$$

Table IX presents the results based on both the *Baa*-Treasury estimate as well at the *Aaa*-Treasury estimate. The second number in the third column is 0.42%. The interpretation of this number is that investors will pay 0.42% of GDP every year in order to enjoy the benefits of having a Treasury/GDP ratio of 0.10.

These computations are probably a lower bound. The exponential function has the property that $v'(0) = b_1$ so that the marginal utility of having an additional Treasury, starting from holding zero Treasuries, is bounded. But since the regulatory demand for Treasuries is inelastic, the marginal utility is likely to be quite high at low levels which can have large quantitative effects on our computations.

Ignoring the regulatory demand, we can follow on our previous decomposition of the convenience yield into a surety and liquidity component and decompose the 0.42% value into a liquidity value of 0.29% (from the *Aaa*-Treasury spread) and a surety value of 0.13% (i.e. $0.42 - 0.29$).

Of particular interest is the value investors place on the current stock of Treasuries. The Debt/GDP ratio is currently about 0.37. The value investors put on this amount of aggregate convenience is 0.60% (liquidity) and 0.35% (surety) of GDP per year. With US GDP for 2005 at $12.5 Trillion, this corresponds to $75 and $44 Billion in benefits for the year 2005. 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 $75 billion ($44 billion) real perpetuity at a real discount rate of 2%, the stock value of the benefit is $3.74 trillion ($2.20 trillion).

6.2 Value of Treasury Convenience to Taxpayers

Because investors value the convenience features of Treasuries, the US Treasury is able to sell Treasury bonds at a premium. 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 100 *bps* (from Section 3.7), the yield on Treasuries would be about 100 *bps* higher if Treasuries did not provide convenience benefits. That would imply increased interest expenses to the Treasury of $1\% \times 0.37 = 0.37\%$ 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 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 of the same order of magnitude as the annual benefit to taxpayers resulting from the public's willingness to hold money at no interest.

6.3 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 *Baa* corporate bonds. Indeed, our exponential specification implies that only around 26 *bps* of the yield spread between *Baa* 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 surety features of Treasuries.

Therefore, investors who do not place much value on these features of Treasuries would be better off buying *Baa* 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 *Baa* corporate bonds and earned an extra 1.0% in annual return, then the person could enjoy an annual real consumption of $47,967 per year in retirement, a 29% increase over the annual consumption in the first scenario.

6.4 Implications for Interest Rate Swap Spreads

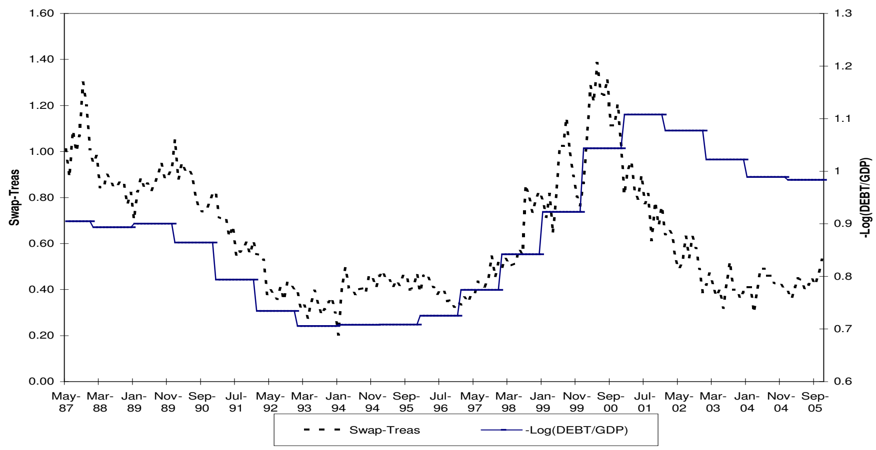
The literature on interest rate swaps has prominently raised the possibility that there may be a convenience yield on Treasury securities (see Duffie and Singleton (1997), Grinblatt (2001), He (2001), Liu, Longstaff, and Mandell (2004), Li (2004), and Feldhutter and Lando (2005)).

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 (2008), studying a sample from 1996 to 2005, find that the default component of swap spreads averages around 11 *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 Dollar swap spread is the difference between the fixed rate in a 10-year fixed-for-floating interest rate

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.

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 10 *bp* 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.

6.5 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 10 *bps* 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 (2007) show that corporate bond spreads and mortgage backed spreads comove. Variation in the Treasury convenience yield is one possible explanation for the comovement phenomena.

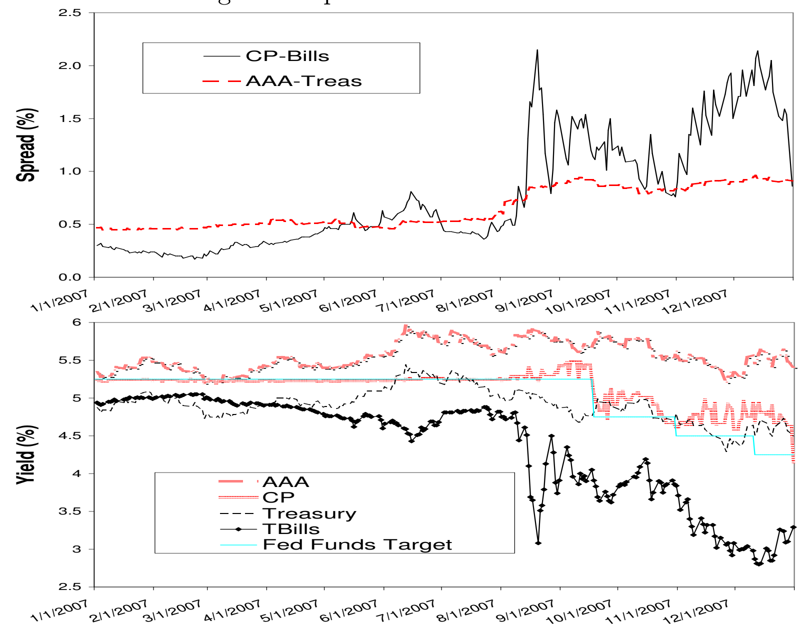
6.6 Demand Shock: Flight to Liquidity

If Treasuries are indeed special, it is likely that there is variation in the demand for Treasury convenience over time. A leading example of a demand shift is a financial crisis in which there is a flight-to-Treasury-liquidity. Below we focus on the period around the subprime mortgage crisis in 2007.

Figure 6 (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).

There are two pieces of evidence from the figure suggesting that this episode reflects an increased demand for Treasury convenience. First, consider the bottom panel of the figure which 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. Indeed, the commercial paper rate more closely tracks the Federal Funds target rate than does the Treasury Bill rate. Second, in order for the pattern of relatively flat commercial paper yields and dramatically lower Treasury

Figure 6: 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. Also pictured is the Federal Funds target rate.

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.[24]

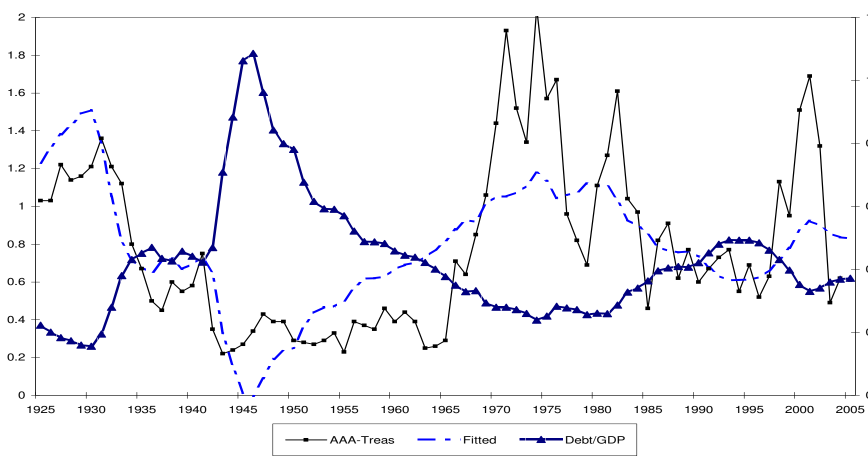
[24] These observations also suggest that our study of supply effects is better served by focusing on long-term spreads. The long-term spread reflects the expected demand shocks over the entire life of the long-term bond. This expected demand is

7 Robustness

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

7.1 Regressions, by Subsample

Figure 7: 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.

As noted earlier, demand conditions are likely to have varied over time, in contrast to our assumption of a stable demand curve.. To get a sense of the low frequency variation in demand, Figure 7 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.

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.

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. Such steepening is also consistent with the observation that in the period after 1971, foreign central banks have been large and inelastic demanders of Treasury bonds. 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 XI 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.

7.2 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 (2) 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 (2) 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.[25]

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.[26]

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

[25] 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).

[26] 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.

and local taxes paid to adjusted gross income less deficit.[27]

The results are reported in the first two columns of Table X. 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.

7.3 Level of Interest Rates and Callability

Table X 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. Thus, the bond yield spread may reflect an interest rate 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 a long-term nominal rate (the *Aaa* rate), as well as the short-term real Federal Funds 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.

7.4 Excluding Fed Holdings

In previous regressions, the stock of debt excludes government holdings in the Social Security Trust Fund but includes Federal Reserve Banks' holdings. We have also investigated excluding the Federal Reserve Banks' holdings when constructing the stock of Treasury debt measure. The results are not reported, but are almost identical to previous results.

[27] 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.

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 1.8*bps* (Table I, Panel B, column (2)) and 4.4*bps* (Table V, column (4)). We suggest that the demand for convenience stems from the surety of Treasuries, the superior trading liquidity of Treasuries, and their use in satisfying regulatory mandates. We estimate the convenience yield at the current level of Treasury debt outstanding to be around 100 *bps*, of which 50 *bps* is liquidity convenience and 50 *bps* is surety convenience.. Our estimates also imply that the value of the liquidity provided by the current level of Treasuries is around 0.95% of GDP per year.

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A Multi-period Bonds

This appendix derives expressions for pricing multi-period zero-coupon corporate and Treasury bonds, when the Treasury bonds offer convenience services. The derivation follows from the utility function given in Section 2.1. We define the stochastic discount factor at date t for a (real) cash-flow at date $s \geq t$ as,

$$M_{t,s} = \beta^{s-t} \frac{u'(C_s)}{u'(C_t)}.$$

Suppose that the agent holds θ_t^T T-period nominal zero-coupon Treasury bonds at date t with price P_t^T. Then, the first order condition for the agent's holding of θ_t^T gives,

$$P_t^T = E_t[M_{t,T} \frac{1}{1+\pi_{t,T}}] + \sum_{s=t}^{T-1} E_t \left[M_{t,s} v'(\theta_s^T / GDP_s) \right].$$

The first term on the right-hand side is the present value of a nominal payment of one at date T ($\pi_{t,T}$ is realized inflation from date t to date T). The second-term is the present value of the stream of convenience benefits from holding one more unit of a Treasury from date t to date T.

For a corporate bond with nominal payment of $1 - d_T$, where d_T is the fraction of default on the bond, the price is,

$$P_t^C = E_t[M_{t,T} \frac{1}{1+\pi_{t,T}} (1 - d_T)].$$

Approximating the spread in yields between these bonds as,

$$\begin{aligned} i_t^C - i_t^T &\approx \frac{P_t^T - P_t^C}{T} \\ &= \frac{1}{T} E_t[M_{t,T} \frac{1}{1+\pi_{t,T}}] E_t[d_T] + \frac{1}{T} cov_t[M_{T,s} \frac{1}{1+\pi_{t,T}}, d_T] + \sum_{s=t}^{T-1} E_t \left[M_{t,s} v'(\theta_s^T / GDP_s) \right] \end{aligned}$$

This spread has a default term, a default risk-premium term and a convenience yield term. If we assume that θ_s^T / GDP_s captures most of the predictability of $M_{t,s} v'(\theta_s^T / GDP_s)$ then we can define another function,

$$\mu'(\theta_t^T / GDP_t) = \sum_{s=t}^{T-1} E_t \left[M_{t,s} v'(\theta_s^T / GDP_s) \right].$$

We estimate the function $\mu'(\cdot)$ in our empirical work.

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 book value of Treasury debt outstanding, 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

	(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 annual percentage excess return on long term corporate bonds over long term government bonds. 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, realized innovations to stock market volatility and the Baa-Aaa spread, the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*), and the realized returns on long term government bonds over short term bonds (*durationhedge*). In Panel B, independent variables are based on the book value of Treasury debt outstanding, US GDP, and yield curve slope. The additional independent variable is the realized innovation to log (Debt/GDP). All regressions include a constant. The error is modeled as an ARMA(1,1).

	Panel A: Excess Returns and Yield Spread			
	(1)	(2)	(3)	(4)
$Aaa - Treasury$	1.26 (1.73)	1.82 (2.38)	2.13 (2.72)	1.30 (1.65)
volatility innovation		-34.8 (4.48)	-35.1 (4.76)	
$Baa - Aaa$ innovation				-0.21(0.32)
slope			0.75 (2.97)	
durationhedge			-0.14 (4.49)	
R^2	0.05	0.19	0.34	0.05
N	79	79	79	79
	Panel B: Excess Returns and Treasury Supply			
$log(Debt/GDP)$	-0.96 (1.42)	-1.58 (1.83)	-1.91 (2.30)	-1.75 (2.17)
volatility innovation		-34.9 (4.28)	-35.7 (4.47)	-42.4 (5.40)
slope			0.86 (3.35)	0.55 (1.75)
durationhedge			-0.13 (4.33)	-0.14 (4.80)
$log(Debt/GDP)$ innovation				9.12 (2.50)
R^2	0.01	0.15	0.30	0.33
N	79	79	79	79

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 book value of Treasury debt outstanding, 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

	1920 - 2005			1969 - 2005	1926 - 2005		1963 - 2003
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$log(Debt/GDP)$	-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

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$log(Debt/GDP)$	-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

Alternative Bond Benchmarks

The dependent variable varies across specification and is a spread between a non-Treasury benchmark and similar maturity Treasury yield, both measured in percentage units. We present results for long-term spreads (*Baa*) and a short-term spread (bank CD rate). Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, the volatility default risk control as well as a control for the slope of the yield curve. *t*-statistics based on Newey-West robust standard errors in parentheses. Data are annual. Sample period varies across the specifications.

	Baa-Treasury		**Bank CD-TBills**	
	(1)	(2)	(3)	(4)
$log(Debt/GDP)$	-1.38 (5.68)	-1.38 (7.76)	-1.25 (2.89)	-0.98 (2.33)
volatility		9.77(6.57)		4.57 (0.74)
slope		0.24(3.75)		-0.12 (1.33)
R^2	0.37	0.73	0.22	0.28
N	80	80	42	42

Table V

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 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. The regressions are estimated using GMM. *t*-statistics are based on autocorrelation and heteroskedasticity robust standard errors. Data are annual, beginning in 1925 and ending in 2005.

	$Aaa - Treasury$		$Baa - Treasury$	
	(1)	(2)	(3)	(4)
b_0	0.25 (5.06)	0.26 (5.27)	0.77 (6.97)	0.92 (10.21)
b_1	3.25 (3.72)	3.72 (3.88)	4.76 (3.50)	5.27 (4.89)
b_2	-4.95 (5.32)	-5.36 (6.32)	-3.77 (3.63)	-4.49 (6.11)
volatility		0.62 (0.80)		9.41 (6.69)
slope		0.09 (2.13)		0.28 (4.35)
R^2	0.55	0.59	0.38	0.75
N	80	80	80	80

Table VI

Debt Holdings, by Group

Panel A of 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 funds and exchange traded funds. Panel B presents the bond portfolio composition of each of the groups, broken down into Treasury, Agency, and short and long-term corporate bonds. Small holdings of 1% or less are sometimes reported as zero in the Flow of Funds.

Group	**Panel A: Who holds Treasury Debt?**				
	Mean	Std. Dev.	1945	1975	2005
Federal Reserve Banks	0.14	0.04	0.1	0.21	.16
Foreign Official Holdings	0.1	0.07	0.01	0.15	.29
State/Local Governments	0.09	0.04	0.02	0.07	.10
Banks/Credit Institutions	0.21	0.11	0.42	0.21	.03
Households and Mutual Funds	0.27	0.05	0.26	0.26	.16
Foreign Private Sector	0.04	0.05	0	0.01	.17
Fedrl/State/Local Govt. Ret.	0.03	0.02	0.01	0.01	.03
Private Pensions	0.03	0.02	0.01	0.03	.02
Insurance Companies	0.05	0.02	0.09	0.02	.03

	Panel B: Bond Market Portfolio Composition			
	Treasury	Agency	Long-term Corporate	Short-term Corporate
Federal Reserve Banks	0.98	0.02	0	0
Foreign Official Holdings	0.96	0.04	0	0
State/Local Governments	0.74	0.21	0.02	0.03
Banks/Credit Institutions	0.55	0.3	0.13	0.02
Households and Mutual Funds	0.58	0.08	0.22	0.12
Foreign Private Sector	0.24	0.08	0.48	0.2
Fedrl/State/Local Govt. Ret.	0.39	0.1	0.49	0.02
Private Pensions	0.23	0.13	0.59	0.04
Insurance Companies	0.18	0.07	0.72	0.03

Table VII

Group Demand Curves

We estimate demand curves for Group 2, Group 3, Groups 3+2, and Groups 3+2+1 of the following form:

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

where, S_t in columns (1), (2), and (5) 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. S_t in columns (3), (4), and (6) is the corporate spread using the Moody's *Aaa* 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. The demand curves are estimated using GMM using $Debt/GDP$, $(Debt/GDP)^2$, and $(Debt/GDP)^3$ as instruments. t-statistics are based on autocorrelation and heteroskedasticity robust standard errors. Each regression has 60 annual data points, beginning in 1945 and ending in 2005.

	Panel A: Group 3				**Panel B: Group 3+2**	
	Baa-Treas		**Aaa-Treas**		**Baa-Treas**	**Aaa-Treas**
	(1)	(2)	(3)	(4)	(5)	(6)
b_0	0.87 (14.22)	0.70 (4.09)	0.3 (7.14)	0.25 (3.67)	0.92 (12.09)	0.32 (8.97)
b_1	4.04 (3.47)	2.95 (6.65)	2.51 (4.03)	2.50 (4.86)	4.73 (3.61)	4.62 (2.38)
b_2	-43.14 (3.59)	-26.51 (3.65)	-44.88 (3.47)	-41.29 (3.53)	-7.99 (4.93)	-10.72 (4.18)
volatility		24.53 (5.80)		-0.09 (0.01)	15.96 (3.54)	-0.06(0.01)
slope		0.34 (3.87)		0.20 (3.91)	0.18 (2.72)	0.08 (1.62)

	Panel C: Group 2				**Panel D: Group 3+2+1**	
	Baa-Treas		**Aaa-Treas**		**Baa-Treas**	**Aaa-Treas**
	(1)	(2)	(3)	(4)	(5)	(6)
b_0	0.94 (21.60)	0.93(15.17)	0.34(13.41)	0.33(10.66)	0.87 (10.26)	0.31 (7.65)
b_1	11.34(2.04)	6.87(2.29)	7.53(1.68)	7.53(1.41)	8.71 (3.03)	10.42 (1.84)
b_2	-16.24(4.65)	-12.62(4.11)	-17.02(3.96)	-16.90(3.28)	-6.63 (5.50)	-8.9 (0.44)
volatility		12.89(2.40)		0.06(0.01)	18.59 (4.41)	0.44 (0.08)
slope		0.13(1.94)		0.04(0.80)	0.22 (4.00)	0.11 (2.48)

Table VIII

Alternative Assets

The dependent variable varies across specification. We consider the spread between the Moody's *Baa* long maturity bond yield and Moody's *Aaa* long maturity bond yield, both measured in percentage units; the *Baa* to FNMA Agency spread; and the *Baa* to Mortgage spread. Independent variables are based on the book value of Treasury debt outstanding, US GDP, the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*), stock market volatility, and in columns (3) and (4), the spread between the 20 year Treasury yield and the 10 year Treasury yield (*long slope*). All regressions include a constant. OLS regressions in Panel A report *t*-statistics based on Newey-West robust standard errors in parentheses. GLS regressions are presented in Panel B, based on AR(1) residuals. Data are annual, with varying start date and ending in 2004 or 2005.

Panel A: OLS

	Baa-Aaa		Baa-Agency		Baa-Mortgage	
	(1)	(2)	(3)	(4)	(5)	(6)
$log(Debt/GDP)$	-0.69 (3.52)	-0.57 (4.44)	-0.92 (2.37)	-0.55 (2.15)	0.08 (0.20)	-0.09 (0.21)
volatility		8.81 (8.09)		16.99 (3.87)		7.85 (1.31)
slope		0.19 (3.60)		0.30 (3.76)		0.20 (3.25)
long slope			1.21 (5.09)	0.64 (3.06)		
R^2	0.16	0.65	0.39	0.68	0.001	0.29
N	87	80	46	46	36	36

Panel B: GLS

	Baa-Aaa		Baa-Agency		Baa-Mortgage	
	(1)	(2)	(3)	(4)	(5)	(6)
$log(Debt/GDP)$	-0.64 (1.92)	-0.58 (4.26)	-0.97 (2.36)	-0.53 (1.88)	0.15 (0.36)	-0.06 (0.16)
volatility		8.11 (6.29)		17.05 (3.78)		6.74 (1.19)
slope		0.18 (3.68)		0.32 (6.03)		0.19 (2.83)
long slope			1.20 (5.17)	0.64 (3.65)		
R^2	0.04	0.58	0.40	0.76	0.004	0.25
ρ	0.74	0.12	-0.02	-0.26	0.19	0.08
N	86	79	44	44	35	35

Table IX

Value of Convenience

This table presents estimates of the value of 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 for both the *Baa*-Treasury and *Aaa*-Treasury estimates.

Treasuries/GDP	0	0.1	0.2	0.3	0.37	0.5	1	3
Convenience value based on:								
Aaa-Treasury	0 %	0.29	0.46	0.56	0.60	0.65	0.69	0.69
Baa-Treasury	0 %	0.42	0.70	0.87	0.95	1.05	1.16	1.17

Table X

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 book value of Treasury debt outstanding, 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 (5.41)	-1.25 (5.44)	-0.63 (5.53)
$taxrate \times Aaa$	0.37 (1.33)	0.08 (0.26)			
$volatility$		2.35 (2.81)	10.0 (2.19)	10.0 (2.21)	1.81 (2.08)
$slope$		0.05 (1.08)	0.07 (1.56)	0.07 (1.59)	0.02 (0.49)
Ex-post Real			0.001 (0.04)		
Ex-ante Real				-0.004 (0.20)	
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 XI

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)	(2)	(3)
	Excluding 1942-1951	Excluding 1925-1941	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