The Aggregate Demand for Treasury Debt

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Abstract

Investors value the liquidity and safety of U.S. Treasury bonds. We document this by showing that changes in Treasury supply have large effects on a variety of yield spreads. As a result, Treasury yields are reduced by 72 basis points, on average over the period from 1926-2008. The low yield on Treasuries due to their extreme safety and liquidity suggests that Treasuries in important respects are similar to money. Evidence from quantities supports this idea. When the supply of Treasuries falls, reducing the overall supply of liquid and safe assets, the supply of bank-issued money rises.

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1 Introduction

Money, such as currency or checking accounts, offers a low rate of return relative to other assets. The reasons behind this phenomenon are well understood. Money is (1) a medium of exchange for buying goods and services, (2) of high liquidity, and (3) of extremely high safety in the sense of offering absolute security of nominal repayment. Investors value these attributes of money and drive down the yield on money relative to other assets.

We argue that Treasury bonds have some of the same features as money, namely (2) and (3), and that this drives down the yield on Treasuries relative to assets that do not to the same extent share these features. Figure 1A provides vivid evidence for this assertion. The figure 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 market value of publicly held US government debt to US GDP). The figure reflects a Treasury demand function, akin to a money demand function. When the supply of Treasuries is low, the value that investors assign to the liquidity and safety attributes offered by Treasuries (referred to below as the Treasury convenience yield) is high. As a result the yield on Treasuries is low relative to the yield on the Aaa corporate bonds which offer less liquidity and safety. The opposite applies when the supply of Treasuries is high. We present detailed econometric evidence of the relation reflected in Figure 1 using several alternative yield spread measures and controlling for corporate bond default risk.

The evidence in Figure 1 shows that Treasuries offer unique attributes that are valued by investors, but does not identify the attributes. We further show that Treasuries share features (2) and (3) with money in two ways. First, we examine the yield spread between a pair of assets which are different only in terms of their liquidity, as well as the yield spread between a pair of assets which are different only in terms of their safety. Under the hypothesis that liquidity/safety are priced attributes, the yield spread between these pairs of assets should reflect the equilibrium price of liquidity/safety. We show that changes in Treasury supply affect each of these yield spreads. The results indicate that Treasuries offer liquidity and safety so that changes in the supply of Treasuries separately change the equilibrium price of liquidity and safety. The second type of evidence that Treasuries share (2) and (3) with money relates the quantity of money to the quantity of Treasuries. We show that when the supply of Treasuries falls, the supply of bank-issued money (specifically, M2 minus M1) which offers (2) and (3), rises. We show that the channel underlying this response is that a reduction in the supply of Treasuries increases the prices of liquidity and safety, lowering the yield on bank deposits, and inducing the banking sector to issue more deposits.

These findings suggest that investors value liquidity and safety when pricing assets. We compute that the value investors have paid on average over our main sample from 1926 to 2008 for the liquidity and safety attributes of Treasuries is 72 basis points per year of which 46 basis points is for liquidity and 26 basis points for safety. The government collects seignorage from the liquidity and safety attributes of Treasuries and we compute that the government saves interest costs of 0.25% of GDP per year because of investors' demand for Treasuries. This figure is comparable in magnitude to the traditional notion of seignorage, which stems from the public's willingness to hold fiat money at zero interest. We compute that the latter seignorage is around 0.24% of GDP per year.

In addition to their implications for asset pricing and seignorage, our findings have implications for the demand for money. First, since Treasuries share some of the attributes of money, appropriately constructed "money" aggregates should include the supply of Treasuries. Second, the demand for money stems from demand for liquidity, safety, and a medium-of-exchange. It is likely that there is independent variation in the demand and supply of each of these attributes. For example, during a financial crisis, the demand for liquidity and safety in particular may rise. On the other hand, the extant literature on money demand assumes that money reflects the price of a single attribute. We discuss how to use the yields on Treasuries as well as other safe/liquid assets to recover the underlying demands for the different attributes of money. These findings help shed light on sources of instability in estimates of the money demand function (see Goldfeld and Sichel, 1990).

Finally, our findings imply that Treasury interest rates are not an appropriate benchmark for "riskless" rates. Cost of capital computations using the CAPM should use a higher riskless rate than the Treasury rate – a company with a beta of zero cannot raise funds at the Treasury rate. In addition, our results suggest that the equity premium measured relative to Treasury rates will partly be driven by the liquidity and safety of Treasuries and thus that these Treasury properties are partially responsible for the high equity premium.

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) and Longstaff, Mithal, and Neis (2005)). Duffie and Singleton (1997), Grinblatt (2001), Liu, Longstaff, and Mandell (2004), and Feldhutter and Lando (2005) argue for a significant non-default component in the interest rate swap spread (the spread between the fixed rate in a fixed-for-floating interest rate swap contract and the Treasury rate). Papers in the prior literature use information from the corporate bond market and credit default swaps 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 direct evidence of the existence of a non-default component by documenting that the amount of Treasuries outstanding is a key driver of the non-default component of the corporate bond spread (a similar relation holds for the interest rate swap spread but we do not emphasize that here since swap rates are only available for a fairly short period, starting in 1987).[1]

[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

We are aware of only a few papers in the literature that have noted a correlation between the supply of government debt and interest rate spreads. Cortes (2003) documents a correlation between the US Debt/GDP ratio and swap spreads over a period from 1994 to 2003. Longstaff (2004) documents a correlation between the supply of Treasury debt and the spread between Refcorp bonds and Treasury bonds over a period from 1991 to 2001. 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 much longer sample, provide a theoretical basis to study the relation, use several approaches to rule out that the relation could be driven by time-varying default risk, decompose the Treasury convenience yield into a liquidity and safety component, and show the similarity between money and Treasuries by showing that private sector money supply reacts to Treasury supply.

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 (2010), who examine data from 1952 to 2005 and show that relative supply of long and short Treasuries is related to the slope of the yield curve as well as the excess return on long-term Treasuries over short-term Treasuries. These papers suggest that the demand for Treasury attributes 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 government debt affects the interest rates

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.

[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.

on government bonds. But it is important to note that the effect we identify is on the spread between government interest rates and corporate interest rates. It is possible that Ricardian equivalence fails in a way that government debt has an effect on the general level of interest rates, both corporate and government. Since we focus on spreads, we are unable to isolate such an effect. On the other hand, because 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.

This paper is laid out as follows. The next section lays out a theoretical framework to relate the demand for the attributes offered by Treasuries to the price of Treasuries relative to other assets. The section develops a series of predictions of the theory. We test each of the theoretical predictions in Section 3. In Section 4 we discuss the implications of our findings for a number of important issues in macroeconomics and finance. The paper also includes an appendix providing details on the data construction as well as mathematical derivations.

2 Theoretical Framework

We articulate our theory by modifying a standard representative agent asset-pricing model to include a term whereby agents derive utility directly from holdings of a "convenience" asset. 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,

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

where C_t is the agent's consumption at date t. We introduce utility from holdings of a convenient asset as follows. Suppose that the consumption of C_t is the sum of an endowment of c_t plus "convenience" benefits:

$$C_t = c_t + \nu(\theta_t^A, GDP_t; \xi_t). \tag{2}$$

The benefits are a function of the holdings of convenience assets, θ_t^A. One example which we elaborate on below is that the function $\nu(\cdot)$ captures the notion that holding more Treasury securities reduce costs that would otherwise be incurred by transacting in a less liquid security such as corporate bonds.[3] The argument

[3]To be more precise, we can define $C_t = c_t - cost(\theta_t^A, GDP_t; \xi_t)$, where the function $cost(\cdot)$ reflects costs that will be incurred by holding less liquid securities. By holding more Treasuries, these costs are reduced. This is just a renormalization relative to our defining a benefit function $\nu(\cdot)$ that is increasing in θ_t^A. The important aspect of the modeling is that $dC_t/d\theta_t^A > 0$.

θ_t^A is the market value of the agent's real holdings of convenience assets and include both Treasuries, θ_t^T, and any other private sector assets, θ_t^P, that provide services similar to Treasuries:

$$\theta_t^A = \theta_t^T + k^P \theta_t^P. \tag{3}$$

The constant k^P measures the convenience services provided by the private sector assets relative to Treasuries. The term ξ_t in the convenience function is a preference shock that affects how much utility is derived from convenience assets. An example of such a shock is a "flight-to-quality" as during a financial crisis, where investors may temporarily increase their valuation of convenient assets such as Treasuries.

We assume that the convenience function is homogeneous of degree one in GDP_t and θ_t^A. This captures the idea that liquidity benefits double if both income and convenience assets double. Thus define,

$$v\left(\frac{\theta_t^A}{GDP_t}; \xi_t\right) GDP_t \equiv \nu(\theta_t^A, GDP_t; \xi_t). \tag{4}$$

We assume that the convenience function is increasing in $\frac{\theta_t^A}{GDP_t}$, but the marginal convenience benefit is decreasing in $\frac{\theta_t^A}{GDP_t}$ and has the property $lim_{\frac{\theta_t^A}{GDP_t} \to \infty} v'(\frac{\theta_t^A}{GDP_t}; \xi_t) = 0$. That is, holding more convenience assets reduces the marginal value of an extra unit of convenient assets. Furthermore, this marginal value approaches zero if the agent is holding a large amount of convenient assets.

Let us next consider what underlies our reduced form convenience function $v(\cdot)$. In the monetary economics literature, the convenience of money stems from three attributes: its role as a medium of exchange, its superior liquidity, and its safety in the sense of retaining a certain nominal value. The demand for these attributes drives the low yield on money relative to other assets. While Treasuries do not have the medium of exchange attribute, we argue that they share the liquidity and safety attributes. Papers such as Aiyagari and Gertler (1991), Heaton and Lucas (1996), Vayanos and Vila (1998), and Rocheteau (2009) show how the superior liquidity of an asset will lead investors to pay a higher price for that asset. Under these theories, an increase in the holding of liquid assets will lower the marginal liquidity service provided by any liquid asset. That is, our earlier assumption that the marginal convenience, $v'(\cdot)$, is decreasing in $\frac{\theta_t^A}{GDP_t}$ is a natural outcome of these models. We refer to these theories as describing a liquidity attribute.

The liquidity models we have cited are all heterogeneous agent models rather than homogeneous representative agent models. These models all have two classes of agents where one class trades with the other, incurring transaction costs when such trade involves illiquid assets. In equilibrium, the prices of liquid assets carry a premium over less liquid assets, producing a liquidity function resembling $v(\cdot)$. It is important to keep in mind that while we introduce $v(\cdot)$ in a representative agent model, this reduced form function is motivated by an underlying theoretical model with heterogeneous agents.

A second benefit of Treasuries is that they are widely believed to provide absolute certainty of nominal repayment. Under some theories, this safety attribute can drive a convenience yield that is declining in the supply of safe assets. Suppose that some investors face costs of understanding investment in risky assets, as in the literature on the limited participation of investors in the stock market (Vissing-Jorgensen, 2003). These investors will have a unique demand for riskless assets, driving up the price of riskless assets. The existing literature has shown that participation costs can explain why risk premia on stocks may be high and why interest rates on riskless assets may be low. In addition, in many limited participation models expanding the stock of riskless assets reduces risk premia and raises riskless rates (see Gomes and Michaelides, 2008). Another explanation for safety demand stems from the use of Treasuries as collateral in many financial transactions. Gorton (2010) notes that there is a substantial demand for collateral for purposes of mitigating counterparty risk in derivatives and settlement systems. The collateral in these transactions is required to be extremely safe, thus also driving the demand for a safety attribute. Bansal and Coleman (1996) argue that commercial banks and money market funds use Treasuries to back checkable deposits. Treasuries thus inherit some of the medium-of-exchange convenience of money, lowering the yield on Treasuries. In this explanation, it is again the safety of Treasuries that makes them good backing for checking accounts. We will offer empirical evidence that the safety attribute of Treasuries is one of the drivers of the convenience yield. However, we will not distinguish further on whether the underlying driver of safety demand is due to limited participation, collateral, or the check-backing explanations.

Two points are worth noting. First, since long-term Treasury bonds carry interest rate risk it is unlikely that the explanations offered in the previous paragraph also apply to long-term bonds. For this reason, we refer to this Treasury property as "short-term" safety. In addition, this safety explanation is distinct from that suggested by any of the standard representative agent model explanations of high risk premia in asset markets. This literature has demonstrated how altering the preferences of a representative agent to feature extreme forms of risk aversion can produce low riskless interest rates and high risk premia. However, the quantity of convenient assets is unrelated to asset prices in the representative agent model. One needs a richer model with heterogeneity and/or frictions, along the lines of the literature cited above, to rationalize the quantity effect. The quantity-price relationship is at the heart of our study. Another way to think about how safety demand works is that the relation between price and default risk is very steep near zero-default-risk. Furthermore, the slope of this curve near zero-default-risk decreases in Treasury supply. This latter prediction generates a negative relation between the corporate-Treasury bond spread and Treasury supply.

There are also theories for why safe nominal long-term payoffs may be uniquely valued. Greenwood and Vayanos (2010) suggest that investors such as defined benefit pension funds have a special demand for certain long-term payoffs to back long-term nominal obligations. The same motive may apply to insurance companies that write long-term policies. Chalmers (1998) describes how long-term Treasury bonds are posted as collateral by municipalities to secure their own borrowings. Broadly, this explanation is similar to the preferred habitat hypothesis of the term structure of interest rates (Modigliani and Sutch, 1966), under which investors are hypothesized to prefer certain maturities of bonds. We refer to these theories as a describing a long-term safety attribute.

We can represent these different theoretical rationales for convenience in our specification of $v(\cdot)$. Denote $\theta_t^{T,long}$ as the stock of long-term Treasury bonds, and $\theta_t^{T,short}$ as the stock of short-term Treasuries ($\theta_t^T = \theta_t^{T,long} + \theta_t^{T,short}$). Also define $\theta_t^{P,liq}$ as the stock of non-Treasury liquid assets, $\theta_t^{P,short-safe}$ as the stock of non-Treasury short-term safe assets, and $\theta_t^{P,long-safe}$ as the stock of non-Treasury long-term safe assets. Suppose that total convenience on short-term Treasuries can be written as the sum of two convenience components:

$$v_{T,short}(\cdot) = v_{liq}\left(\frac{\theta_t^T + k^{liq}\theta_t^{P,liq}}{GDP_t}; \xi_t^{liq}\right) + v_{short-safe}\left(\frac{\theta_t^{T,short} + k^{short-safe}\theta_t^{P,short-safe}}{GDP_t}; \xi_t^{short-safe}\right). \tag{5}$$

Similarly, we can specify the convenience on long-term Treasuries as

$$v_{T,long}(\cdot) = v_{liq}\left(\frac{\theta_t^T + k^{liq}\theta_t^{P,liq}}{GDP_t}; \xi_t^{liq}\right) + v_{long-safe}\left(\theta_t^{T,long} + k^{long-safe}\theta_t^{P,long-safe}GDP_t; \xi_t^{long-safe}\right). \tag{6}$$

The constants, k^{liq}, $k^{short-safe}$ and $k^{long-safe}$, measure the convenience that the private sector assets offer relative to Treasuries.

Our specification emphasizes that the safety attributes may differ across short and long-term assets and thus lead to a difference in convenience value in long-term assets relative to short-term assets. In contrast, our specification assumes that both long and short-term Treasuries offer equal liquidity services. The empirical literature has documented the existence of significant liquidity premia on both long-term Treasuries (Krishnamurthy, 2002) and short-term Treasuries (Amihud and Mendelsen, 1991). We are making the somewhat stronger assumption that long and short-term Treasuries are equally liquid (see Fleming, 2003, for more on this point).

2.1 Spreads and Supply

We derive pricing expressions for short and long-term bonds based on these different specifications of convenience. As we describe below, decomposing the convenience in the manner above also yields empirical tests of the existence of priced safety and liquidity attributes. Before describing these tests, let us turn to asset pricing. We initially derive predictions of the convenience yield theory which do not distinguish between the liquidity and safety motives. We then turn to predictions implied by each of these separate motives. In terms of the framework above, our initial set of predictions implicitly assume that both $v_{T,long}$ and $v_{T,short}$ are only functions of θ_t^T (as opposed to functions of both total Treasury supply and short or long-term Treasury supply). This will be the case if long and short Treasury supply moves in parallel (and if the demand shocks are perfectly correlated), or if only a liquidity motive is present. We relax this assumption later.

Denote the price level at date t as Q_t. If the agent buys a zero coupon Treasury bond for a nominal price P_t^T, his real holdings θ_t^A rises by $\frac{P_t^T}{Q_t}$.[4] The first order condition for Treasury bond holdings is then,

$$-\frac{P_t^T}{Q_t}u'(C_t) + \beta E_t\left[\frac{P_{t+1}^T}{Q_{t+1}}u'(C_{t+1})\right] + \frac{P_t^T}{Q_t}v'(\theta_t^A/GDP_t, \xi_t)u'(C_t) = 0 \tag{7}$$

Define the pricing kernel for nominal payoffs as,

$$M_{t+1} = \beta\frac{u'(C_{t+1})}{u'(C_t)}\frac{Q_t}{Q_{t+1}}, \tag{8}$$

so that,

$$P_t^T = E_t[M_{t+1}P_{t+1}^T] + P_t^T v'(\theta_t^A/GDP_t;\xi_t) \quad \Rightarrow \quad P_t^T = \frac{E_t[M_{t+1}P_{t+1}^T]}{1 - v'(\theta_t^A/GDP_t;\xi_t)}. \tag{9}$$

This expression indicates that a positive marginal value of convenience, $v'(\cdot)$, raises the price of Treasuries, P_t^T.

Let us next derive pricing expressions for a zero-coupon corporate bond that offers no convenience services. Suppose that the corporate bond may default next period with probability λ_t and in default pays $1 - L_{t+1}$, where L_{t+1} measures the amount of losses suffered in default. If the bond does not default, it is worth P_{t+1}^C. Then, since the bond offers no convenience, its price satisfies

$$P_t^C = \lambda_t E_t[M_{t+1}(1 - L_{t+1})|\text{Default}] + (1 - \lambda_t)E_t[M_{t+1}P_{t+1}^C|\text{No Default}] \tag{10}$$

In our empirical work we estimate the convenience demand $v'(\cdot)$ by relating θ_t^T to different measures of the price difference between P_t^C and P_t^T. There are three price measures we focus on: short-maturity yield spreads between corporate and Treasury bonds, long-maturity yield spreads, and excess returns of corporate bonds over Treasury bonds. We now derive expressions for each of these price measures and compare them. For simplicity, we focus our derivations on zero-coupon bonds and continously compounded yields.

Consider first the case of one period bonds. For such bonds, $P_{t+1}^C = P_{t+1}^T = 1$. Then,

$$e^{-i_t^T} = P_t^T = \frac{E_t[M_{t+1}P_{t+1}^T]}{1 - v'(\theta_t^A/GDP_t;\xi_t)} \approx e^{v'(\theta_t^A/GDP_t;\xi_t)}E_t[M_{t+1}] \tag{11}$$

For the corporate bond, define $\tilde{L}_{t+1}$ as a random variable that is equal to zero if there is no default, and equal to L_{t+1} if there is default. Then,

$$e^{-i_t^C} = P_t^C = E_t[M_{t+1}] - E_t[M_{t+1}]E_t[\tilde{L}_{t+1}] - cov_t[M_{t+1}, \tilde{L}_{t+1}] \approx e^{-\lambda_t E_t[L_{t+1}] - cov_t[M_{t+1}, \tilde{L}_{t+1}]/E_t[M_{t+1}]}E_t[M_{t+1}]$$

We thus have the following prediction:

[4] We deriving pricing expressions for zero-coupon Treasury and corporate bonds. In our empirical work, we examine coupon bonds and assume that the impact of Treasury supply on coupon bond spreads are qualitatively similar.

Prediction 1 *(Impact of Treasury supply on short-term spreads)*

The one-period yield spread between corporate and Treasury bonds is related to the stock of Treasuries as follows:

$$S_{t,1} \equiv i_t^C - i_t^T = v'\left(\frac{\theta_t^T + k^P\theta_t^P}{GDP_t};\xi_t\right) + \lambda_t E_t[L_{t+1}] + cov_t[M_{t+1},\tilde{L}_{t+1}]/E_t[M_{t+1}]. \quad (12)$$

The yield spread reflects the sum of three terms: the convenience yield on Treasuries, the expected default rate on the corporate bond, and a risk premium associated with the covariance between default and the pricing kernel. Assuming that $v''(\cdot) < 0$, $S_{t,1}$ is declining in $\theta_t^T + k^P\theta_t^P$. Consider next the relationship between $S_{t,1}$ and θ_t^T. Project θ_t^P linearly on θ_t^T, so that $\theta_t^P = a_0 + a_1\theta_t^T + error$, where the error is uncorrelated with θ_t^T. Then $\theta_t^T + k^P\theta_t^P = k^P a_0 + (1 + k^P a_1)\theta_t^T + k^P error$. If $1 + k^P a_1 > 0$, then $S_{t,1}$ is declining in θ_t^T. The latter condition will be satisfied if $a_1 > -1/k^P$, i.e. unless the private sector reduces its supply of substitutes by more (in effective terms, $k^P\theta_t^P$) than the increase in the Treasury supply.

We verify the prediction of the convenience model that an increase in θ_t^T causes the yield spread to fall. Our regressions of the yield spread on θ_t^T recover $v'(\cdot)\left(1 + k^P\frac{\partial\theta_t^P}{\partial\theta_t^T}\right)$ rather than $v'(\cdot)$ because of private sector reaction. In order to recover $v'(\cdot)$, we further need knowledge of k^P and $\frac{\partial\theta_t^P}{\partial\theta_t^T}$. We do not explore that in this paper because for most questions of interest, it is more important to know $v'(\cdot)\left(1 + k^P\frac{\partial\theta_t^P}{\partial\theta_t^T}\right)$ rather than $v'(\cdot)$.

Note that it is possible that Treasury supply or private sector supply reacts accommodating to demand shocks (ξ_t) or to increases in corporate default risk. This will bias the relation between spreads and Treasury supply towards finding a positive relation, the opposite of the causal negative relation from Treasury supply to spreads. However, we view it as unlikely that overall Treasury supply reacts substantially to demand shocks or changes in the risk of corporate bonds. The more plausible reaction involves the private sector supply or the government's supply of particular maturities.

Let us next consider multi-period bonds. Define the τ period yields on corporate and Treasury bonds as,

$$i_{t,\tau}^T = -\frac{1}{\tau} ln\ P_t^T \quad \text{and,} \quad i_{t,\tau}^C = -\frac{1}{\tau} ln\ P_t^C. \quad (13)$$

The spread between these bonds is $S_{t,\tau} = i_{t,\tau}^C - i_{t,\tau}^T$.

Consider again the derivation for corporate bonds. Our derivation for multi-period bonds closely follows Duffie and Singleton (1999), reflecting the standard practice in the corporate bond pricing literature. Suppose that the event of default or no-default is non-systematic (i.e. uncorrelated with M_{t+1}). Then, we can drop the conditioning on default/no-default and rewrite (10) as,

$$P_t^C = E_t[M_{t+1}\left(\lambda_t(1 - L_{t+1}) + (1 - \lambda_t)P_{t+1}^C\right)] \quad (14)$$

Assume that we can write the expected present value of the payment in default as,

$$E_t[M_{t+1}(1 - L_{t+1})] = E_t[M_{t+1}P_{t+1}^C](1 - D_t) \quad (15)$$

for a suitable process D_t.[5] This is Duffie and Singleton's "recovery of market value" assumption (RMV). Then,

$$P_t^C = (\lambda_t(1-D_t) + (1-\lambda_t))E_t[M_{t+1}P_{t+1}^C] \approx e^{-\lambda_t D_t} E_t[M_{t+1}P_{t+1}^C]. \tag{16}$$

Note that the term P_{t+1}^C is a function of D_{t+1} and λ_{t+1}, which embody changes in future default expectations such as downgrades. For high-grade corporate bonds, which are the focus our study, almost all of the default-related risk is of this form rather than in terms of the bonds defaulting between t and $t+1$. In our setup, the latter default-related risk may be correlated with M_{t+1} and carry a risk premium. Thus, our restriction that the default event in the next period is non-sytematic is not a substantively important restriction, but does help to simplify our pricing expressions.

Prediction 2 *(Impact of Treasury supply on long-term spreads)*

The yield spread between τ-period corporate and Treasury bonds is related to the stock of Treasuries as follows,

$$S_{t,\tau} = \sum_{j=t}^{t+\tau-1} \frac{1}{\tau} E_t[v'(\theta_j^A/GDP_j;\xi_j)] + \sum_{j=t}^{t+\tau-1} \frac{1}{\tau} E_t[\lambda_j D_j] - \sum_{j=t}^{t+\tau-1} \frac{1}{\tau} cov_t(m_{j+1}, \tilde{R}_{j+1}) \tag{17}$$

where, $m_{j+1} = logM_{j+1}$ (= log $\beta \frac{u'(C_{j+1})}{u'(C_j)} \frac{Q_j}{Q_{j+1}}$), is the log pricing kernel, and $\tilde{R}_{j+1}$ is the one-period excess return of corporate bonds over Treasury bonds. As long as θ_j^A increases with θ_j^T, increases in Treasury supply lower the spread, $S_{t,\tau}$.

The derivation of this spread expression is in the Appendix. The derivation assumes that all relevant variables, including m_t and changes in the corporate and Treasury bond yields, are normally distributed.

The spread reflects three terms: (1) the expected average convenience benefit over the next τ periods; (2) the expected average amount of default; and (3) a risk premium that depends on the covariance between the pricing kernel and the excess return on corporate over Treasury bonds.

Let us pause and compare the short-term and long-term spread expressions. Note that shocks to both θ_t^A/GDP_t and ξ_t have an impact on the short-term spread. The impact of these shocks on the long-term spread depends on the persistence of the shocks. In the data, a flight to quality (liquidity and safety) shock (ξ_t) is short-lived, and should primarily affect short-term spreads. The debt-to-GDP ratio is quite persistent so that shocks to θ_t^A/GDP_t will have a significant impact on both short and long-term spreads. This logic tells us that the convenience yield as embodied in the long-term spread is primarily driven by θ_t^A/GDP_t, while variability in the short-term spread will partly be driven by ξ_t.[6] This is an advantage of using the

[5] Note that in expression (15), the left-hand side expectation is conditioning on default, while the right-hand side expectation is conditioning on no-default. However, given the assumption that the default-event is non-systematic, we can drop the conditioning.

[6] Here is a simple case to formalize these points. Suppose that the convenience yield function is

$$v'(\theta_t^A/GDP_t;\xi_t) = b_0 + b_1 \; log(\theta_t^A/GDP_t) + \; log\xi_t.$$

long-term spread and data on θ_t^A/GDP_t to estimate convenience yields. On the other hand, the corporate bonds we use to construct the short-term spread are close to default free. The corporate bonds used in the long-term spread carry greater default risk. Thus, the results based on the long-term spread are more sensitive to precise controls for default risk.

The last price variable we examine is the excess return of (zero coupon) corporate bonds over Treasury bonds. For Treasury bonds,

$$1 - v'(\theta_t^A/GDP_t;\xi_t) = E_t\left[M_{t+1}\frac{P_{t+1}^T}{P_t^T}\right] \tag{18}$$

We consider the return on a Aaa/Aa index of corporate bonds on which default over the holding period are exceptionally rare. Downgrades are the relevant default-related event. Thus,

$$1 = E_t\left[M_{t+1}\frac{P_{t+1}^C}{P_t^C}\right] \tag{19}$$

Prediction 3 *(Impact of Treasury supply on excess returns)*
The expected excess return of corporate bonds over Treasuries is related to the stock of Treasuries as follows,

$$E_t[M_{t+1}\tilde{R}_{t+1}] = v'(\theta_t^A/GDP_t;\xi_t). \tag{20}$$

We can rewrite this expression as,

$$E_t[\tilde{R}_{t+1}] = \frac{1}{E_t[M_{t+1}]}\Big(v'(\theta_t^A/GDP_t;\xi_t) - cov_t(M_{t+1},\tilde{R}_{t+1})\Big). \tag{21}$$

As long as θ_j^A increases with θ_j^T, an increase in θ_t^T implies a decrease in the expected return on corporate bonds over Treasury bonds.

Let us compare how the excess return regression compares to the yield spread regressions. The advantage of studying returns over yields is that while time-variation in expected default affect yields such variation does not affect expected returns. However, studying returns also has distinct disadvantages. If we take a log-linear approximation, the excess return, $\tilde{R}_{t+1}$ is approximately the change in the long-term yield spread, $-(\tau-1)S_{t+1,\tau-1}+\tau S_{t,\tau}$. We can substitute from the expression for $S_{t,\tau}$ (and $S_{t+1,\tau-1}$) from above, and set

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Here, we have written the demand shock, ξ_t, to enter additively in the convenience yield, and assumed a log convenience yield function, as we do in most of our empirical tests. The short-term spread equally reflects a supply term $b_1\ log(\theta_t^A/GDP_t)$ and a demand term $b_1\ log\xi_t$. Suppose that $log(\theta_t^A/GDP_t)$ is AR(1) with coefficient ρ and that $log\xi_t$ is i.i.d. with mean zero. Then it is easy to verify that the convenience yield component of the long-term spread is,

$$\sum_{j=t}^{t+\tau-1}\frac{1}{\tau}E_t[v'(\theta_j^A/GDP_j;\xi_j)] = b_0 + b_1\ log(\theta_t^A/GDP_t)\left(1+\rho+\rho^2+\ \dots\ +\rho^{\tau-1}\right)\frac{1}{\tau}+\frac{log\xi_t}{\tau}.$$

If we take $\tau = 20$ years (the maturity for the long spread in our study), and $\rho = 0.95$ (consistent with data on the Debt-to-GDP ratio), then the supply coefficient $\left(1+\rho+\rho^2+\ \dots\ +\rho^{\tau-1}\right)\frac{1}{\tau}$ is 0.64, while the demand coefficient $1/\tau$ is 0.05.

$\lambda_t = 0$ (i.e. no defaults on the corporate bonds in the return index, over the next one period) to find $\tilde{R}_{t+1}$:

$$\begin{aligned}\tilde{R}_{t+1} \approx\ & v'(\theta_t^A/GDP_t;\xi_t) - cov_t(m_{t+1},\tilde{R}_{t+1}) \\ & - \sum_{j=t+1}^{t+\tau-1}\Big(E_{t+1}[v'(\theta_j^A/GDP_j;\xi_j)] - E_t[v'(\theta_j^A/GDP_j;\xi_j)]\Big) \\ & - \sum_{j=t+1}^{t+\tau-1}\left(E_{t+1}[\lambda_j D_j] - E_t[\lambda_j D_j]\right) \\ & + \sum_{j=t+1}^{t+\tau-1}\Big(cov_{t+1}(m_{j+1},\tilde{R}_{j+1}) - cov_t(m_{j+1},\tilde{R}_{j+1})\Big)\end{aligned} \tag{22}$$

The first line of this expression is the expected excess return. This expected return reflects the convenience yield as well as the risk premium associated with the variability of corporate-Treasury returns. Changes in θ_t^T will alter the convenience yield, and hence the expected return, in a similar manner as they affect the short-term yield spread. To estimate the convenience yield using excess return regressions, we need to control for any time variation in the risk premium. The long-term spread regressions also require us to control for variation in risk premia, so that in this regard these two price measures have a similar disadvantage. However, the second, third, and fourth lines indicate the disadvantage of studying returns, namely that realized excess returns are affected by news about the convenience benefits on Treasuries, about default and about future risk premia. Realized returns thus could differ dramatically from expected returns, making it statistically difficulty to detect our predicted relation between expected returns and Treasury supply. Given the pros and cons of studying returns versus yields, we present results from both approaches in our empirical work.

2.2 Liquidity and Safety Attributes

We now reintroduce the different liquidity and safety attributes of Treasuries and consider how one can test if these attributes are priced. Following equations (5) and (6), long and short-term assets should be expected to have different convenience yields. To be precise, let us reconsider the short and long-term spread expression. The short-term spread reflects liquidity and short-term safety:

$$\begin{aligned}S_{t,1} = v'_{liq}\left(\frac{\theta_t^T + k^{liq}\theta_t^{P,liq}}{GDP_t};\xi_t^{liq}\right) + v'_{short-safe}\left(\frac{\theta_t^{T,short} + k^{short-safe}\theta_t^{P,short-safe}}{GDP_t};\xi_t^{short-safe}\right) \\ +\lambda_t E_t[L_{t+1}] + cov_t[M_{t+1},\tilde{L}_{t+1}]/E_t[M_{t+1}].\end{aligned} \tag{23}$$

The long-term spread, for large τ, reflects the expected liquidity and long-term safety attributes over the term of the bond:

$$\begin{aligned}S_{t,\tau} =\ & \sum_{j=t}^{t+\tau-1}\frac{1}{\tau}E_t\left[v'_{liq}\left(\frac{\theta_j^T + k^{liq}\theta_j^{P,liq}}{GDP_j};\xi_j^{P,liq}\right) + v'_{long-safe}\left(\frac{\theta_j^{T,long} + k^{long-safe}\theta_j^{P,long-safe}}{GDP_j};\xi_j^{long-safe}\right)\right] \\ & + \sum_{j=t}^{t+\tau-1}\frac{1}{\tau}E_t[\lambda_j D_j] - \sum_{j=t}^{t+\tau-1}\frac{1}{\tau}cov_t(m_{j+1},\tilde{R}_{j+1})\end{aligned} \tag{24}$$

There are a few approaches to test for the existence of separate priced attributes. If we can treat variation in the supply of long and short-term Treasuries as exogenous to other shocks, then a way of identifying the short and long-term safety attributes is to ask whether an increase in $\theta_t^{T,short}$ has a larger effect on the short-term spread than an increase in $\theta_t^{T,long}$ does, and whether an increase in $\theta_t^{T,long}$ has a larger effect on the long-term spread than an increase in $\theta_t^{T,short}$ does. This approach, although not stated in terms of safety attributes, is taken by Greenwood and Vayanos (2010) in their study of government maturity structure and the slope of the yield curve. The difficulty with this approach for our purposes is that it is quite clear that government maturity choices are not exogenous. As described by Greenwood and Vayanos, the Treasury considers the slope of the yield curve and the size of the debt and deficit, among other factors, in determining maturity structure. Greenwood and Vayanos use the Debt-to-GDP ratio as a instrument for maturity structure. We need to find evidence for the existence of two attributes, and with only one instrument, it is not possible to do so.

We instead take the following approach. We consider pairs of assets which have either equal liquidity and different safety or equal safety and different liquidity. The yield spread between these assets only reflects the price of liquidity or the price of safety. We can then test whether the price of the attribute captured by the yield spread changes with the relevant supply of Treasuries.

Consider first the spread between $P2$ and $P1$ rated commercial paper. The former has a higher default risk than the latter. The assets are short-term but similarly illiquid as we document in the next section. Thus the $P2 - P1$ spread purely reflects the value of short-term safety convenience.

Prediction 4 *(Impact of Treasury supply on price of short-term safety)*
Consider that $P2$ and $P1$ rated commercial paper are equally liquid (i.e. $k_{P2}^{liq} = k_{P1}^{liq}$), but that $k_{P1}^{short-safe} = 1 > k_{P2}^{short-safe}$. Then, the spread between these bond yields is related to the stock of short-term Treasuries as follows:

$$\begin{aligned} S_{t,1}^{P2-P1} &= (k_{P1}^{short-safe} - k_{P2}^{short-safe}) v'_{short-safe}\left(\frac{\theta_t^{T,short} + k^{short-safe}\theta_t^{P,short-safe}}{GDP_t}; \xi_t^{short-safe}\right) \\ &\quad + \lambda_{t,P2} E_t[L_{t+1,P2}] - \lambda_{t,P1} E_t[L_{t+1,P1}] + cov_t[M_{t+1}, \tilde{L}_{t+1,P2} - \tilde{L}_{t+1,P1}]/E_t[M_{t+1}] \end{aligned} \quad (25)$$

If short-term safety is a priced attribute, then increases in the supply of short-term Treasuries will lower $S_{t,1}^{P2-P1}$ (as long as $\theta_t^{T,short} + k^{short-safe}\theta_t^{P,short-safe}$ increases in $\theta_t^{T,short}$).

In terms of the estimation, the P2-P1 spread is directly a function of the supply of short-term convenient assets. We have noted before that there is extensive evidence that both the private sector and the Treasury actively manages the maturity structure of debt. To get around any endogenity issues stemming from this behavior, we use instrumental-variables regressions, using θ_t^T as an instrument for $\theta_t^{T,short}$ (a similar comment applies for testing Prediction 5 and Prediction 8 below).

Next consider a similar prediction but based on the spread between two long-term corporate bonds:

Prediction 5 *(Impact of Treasury supply on price of long-term safety)*
Take two long-term corporate bonds, an Aaa-rated bond and a Baa-rated bond. Consider that these bonds are equally liquid (i.e. $k^{liq}_{Aaa} = k^{liq}_{Baa}$), but that the $k^{long-safe}_{Aaa} > k^{long-safe}_{Baa}$. Then, the spread between these bond yields is related to the stock of long-term Treasuries as follows:

$$\begin{aligned} S^{Baa-Aaa}_{t,\tau} &= (k^{long-safe}_{Aaa} - k^{long-safe}_{Baa}) \sum_{j=t}^{t+\tau-1} \frac{1}{\tau} E_t \left[v'_{long-safe} \left(\frac{\theta^{T,long}_j + k^{long-safe} \theta^{P,long-safe}_j}{GDP_j}; \xi^{long-safe}_j \right) \right] \\ &+ \sum_{j=t}^{t+\tau-1} E_t[\lambda^{Baa}_j D^{Baa}_j - \lambda^{Aaa}_j D^{Aaa}_j] - \sum_{j=t}^{t+\tau-1} \frac{1}{\tau} cov_t(m_{j+1}, \tilde{R}^{Baa-Aaa}_{j+1}). \end{aligned} \tag{26}$$

If long-term safety is a priced attribute, then increases in the supply of long-term Treasuries will lower $S^{Baa-Aaa}_{t,\tau}$ (as long as $\theta^{T,long}_t + k^{long-safe} \theta^{P,long-safe}_t$ increases in $\theta^{T,long}_t$).

A similar comparison, but now getting at the liquidity attribute is through the following.

Prediction 6 *(Impact of Treasury supply on price of liquidity)*
Consider a one-period Treasury bond which offers one unit of liquidity and is default free. Consider also an FDIC insured bank deposit which is default free but only offers $k^{liq} < 1$ units of liquidity. Then, the one-period spread between these bonds is related to the stock of Treasuries as follows:

$$S^{FDIC}_{t,1} = i^{FDIC}_t - i^T_t = (1 - k^{liq}) v'_{liq} \left(\frac{\theta^T_t + k^{liq} \theta^{P,liq}_t}{GDP_t}; \xi^{liq}_t \right). \tag{27}$$

If liquidity is a priced attribute, then increases in the supply of Treasuries will lower $S^{FDIC}_{t,1}$ (as long as $\theta^T_t + k^{liq} \theta^{P,liq}_t$ increases in θ^T_t).

Our last test is for the existence of a long-term safety attribute and focuses on the holdings of agents who for a priori reasons should only be expected to hold Treasuries for the long-term safety attribute. Consider in particular pension funds and insurance companies that have long maturity liabilities and almost no need to hold liquid assets. These investors, as we document, do hold Treasuries. A test for the existence of the long-term safety attribute is therefore as follows:

Prediction 7 *(Holders of long-term safety)*
If changes in θ^T_t change the price of the long-term safety attribute, then it should change the equilibrium holdings of pension funds and insurance companies whose motive to hold Treasuries is driven by the long-term safety attribute.

2.3 Private Sector Substitutes

Private sector substitute assets are assets that carry one or more of the liquidity attribute, the short-term safety attribute, or the long-term safety attribute. We next derive predictions for the behavior of subsitute assets.

A leading substitute asset for Treasuries is money. Insured bank deposits carry the same safety as Treasuries, but some have different liquidity. For example, time-deposits are less liquid than Treasuries, while it is likely that checking accounts and savings accounts are as liquid as Treasuries. However, checking accounts in particular also have a medium-of-exchange attribute, unlike Treasuries, which can drive the yield spread between the interest rates on checking accounts and other assets.

The consideration of money as a convenience substitute asset gives us further predictions of the convenience theory.

Prediction 8 *(Impact of Treasury supply on yield of substitute assets)*
Consider insured bank deposits, which carry an equal amount of the short-term safety attribute as Treasuries and k^{liq} units of liquidity. The one-period spread between a corporate bond with no convenience (liquidity or safety) and the yield on insured bank deposits is related to the stock of Treasuries as follows:

$$\begin{aligned} i_t^C - i_t^{FDIC} \quad &= \quad k^{liq} v'_{liq}\left(\frac{\theta_t^T + k^{liq}\theta_t^{P,liq}}{GDP_t}; \xi_t^{liq}\right) + v'_{short-safe}\left(\frac{\theta_t^{T,short} + k^{short-safe}\theta_t^{P,short-safe}}{GDP_t}; \xi_t^{short-safe}\right) \\ &\quad + \lambda_t E_t[L_{t+1}] + cov_t[M_{t+1}, \tilde{L}_{t+1}]/E_t[M_{t+1}] \end{aligned} \tag{28}$$

If bank deposits are a liquidity and safety substitute for Treasuries, and if liquidity or safety are priced attributes, then increases in the supply of Treasuries will lower $i_t^C - i_t^{FDIC}$ (unless the private sector reduces its supply of substitutes by more in effective terms than the increase in the Treasury supply).[7]

Theory also suggests a relation between the quantities of private-sector substitute assets and Treasuries.

Prediction 9 *(Impact of Treasury supply on supply of substitute assets)*
If the supply of money (specifically bank deposits) is price elastic, then θ_t^{Money} and θ_t^T will be negatively related.

If as in equation (28), a reduction in Treasury supply lowers i_t^{FDIC}, then banks will have an incentive to supply more bank deposits (for example, to make profitable loans at i_t^C). It is worth emphasizing that Prediction 9 is of a completely different nature from our other tests. The other predictions relate bond market spreads to Treasury supply. On the contrary, Prediction 9 relates the *quantity* of substitute convenience assets to Treasury supply.

[7]While we focus on one private-sector substitute, money, the general principal behind this prediction is that the spread between a non-convenient asset and a private sector substitute asset should vary systematically with the supply of Treasuries under the convenience yield theory.

3 Evidence

Details on the data construction for each table as well as the sources for all variables used in our regressions are in the data appendix. The regressions all use data at an annual frequency and for as long a period as is feasible given the variables included in the regression.

3.1 Impact of Treasury Supply on Price Measures

Predictions (1)-(3) state that under the convenience yield hypothesis increases in Treasury supply should reduce short-spreads, long-spreads, and corporate-Treasury excess returns. Tables I and II present regressions confirming these predictions.

The key explanatory variable in the regressions reported in the tables is the log of $Debt/GDP$, where $Debt/GDP$ is the market value of the outstanding stock of US Treasuries divided by US GDP. The measure of government debt corresponds to what is referred to as publicly held debt. It includes debt held by the Federal Reserve, but excludes debt held by other parts of the government such as the Social Security Trust Fund. Our results do not change appreciably if we exclude the holdings of the Federal Reserve. The debt measure is as of the end of the government's fiscal year, i.e. end of June up to and including 1975 and end of September from 1976 on.

The theoretical measure of convenience yield (convenience benefit) is $v'(\theta_t^A/GDP_t)$, where θ_t^A includes both Treasury debt and private sector convenient assets. Predictions (1)-(3) are that the convenience yield is declining in θ_t^A. As we have noted, as long as private sector assets substitute less than one-for-one for changes in Treasury debt, we can verify predictions (1)-(3) by examining the impact of changes in Treasury debt on price measures. The regression coefficient on Treasury debt should be interpreted as reflecting the effect, net of private sector supply response, of a change in Treasury debt on the Treasury convenience yield.

3.1.1 Long-term spreads

In Table I the Treasury debt variable is the logarithm of the Debt-to-GDP ratio, while the dependent variable in each regression is a bond yield spread measured in percentage terms. Panel A and B present results for long-term spreads, namely the spread between long-term Aaa-rated corporate bonds and long-term Treasuries (Panel A) and the spread between long-term Baa-rated corporate bonds and long-term Treasuries (Panel B). We use the log functional form because it provides a good fit and requires estimation of only one parameter. A drawback with the log function is that it does not asymptote to zero as Debt-to-GDP rises. We estimate an alternative functional form with the asymptote property in Section 3.4.

The regressions in Table I are estimated using ordinary least squares (OLS). We report t-statistics adjusting the standard errors assuming an AR(1) error structure. The AR(1) structure is motivated by a standard Box-Jenkins analysis of the autocorrelation function and partial autocorrelation function of the error terms. The first-order autocorrelations are included in the table. Serial correlation is pronounced only in the long-term spread regressions of Panel A. For consistency across columns, we use the AR(1) adjustment in all columns though it makes little difference except in Panel A where t-statistics based on "standard" OLS standard errors (assuming an i.i.d. error term) would be substantially larger than those presented. An alternative to OLS estimation with an AR(1) standard error adjustment would be to use GLS estimation. However, we suspect that $log(Debt/GDP)$ is not a perfect measure of the convenience state variable in the long-term spread regressions, $\sum_{j=t}^{t+\tau-1} \frac{1}{\tau} E_t[v'(\theta_j^A/GDP_j;\xi_j)]$. It is likely that the private sector expectations of this sum involve variables other than the current Debt-to-GDP ratio (notably information about the likely development of the government budget). If so, then Debt-to-GDP is measured with error implying downward bias in the impact of Treasury supply on spreads (under standard assumptions about the measurement error). GLS estimation would be more affected by the measurement error issue. To see this, suppose the error autocorrelation was close to one. Then GLS would effectively transform the data to run a first difference regression. While in levels the variance of $log(Debt/GDP)$ is likely to be large relative to that of the measurement error, in first differences this will not be the case since the high persistence of $log(Debt/GDP)$ means that the volatility of its first difference is low (a formal Monte-Carlo study of this issue is available upon request). These considerations lead us to present OLS regressions with standard errors adjusted for the serial correlation. We emphasize that our OLS regression coefficients are likely to be conservative, understating the impact of Treasury supply on convenience yields.[8]

The coefficient of -0.744 in column (1) of Table I implies that a decrease of one standard deviation in Debt-to-GDP from its mean value of 0.426 to 0.233 increases the convenience yield component of the Aaa-Treasury spread by as much as 0.45% (45 basis points).

Default risk is an important component of the bond spreads. In column (2) and (3) we show that the impact of Treasury supply on the Aaa-Treasury spread is robust to including default controls. Moody's Investors Service (2005) estimates, based on data from 1920 to 2004, 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%. In column (2), we control for default risk using 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.

[8] A standard solution to the bias problem would be an IV approach. If the error term was serially uncorrelated one could use lagged values of log(Debt/GDP) as instrument for log(Debt/GDP). With serially correlated errors one should lag the instrument far enough to avoid correlation between the instrument and the error term. We find that the coefficient on $log(Debt/GDP)$ is larger in IV estimations and keeps increasing as the instrument is lagged further. This suggesting that the measurement error concern is relevant, but that it is unclear how far to lag the instrument and therefore more conservative to report only OLS results.

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 from 1969-2007. The results in column (2) shows that the EDF default measure is informative. Crucially, the coefficient on $log(Debt/GDP)$ remains highly significant and of roughly the same magnitude as in other specifications.[9,10] The EDF measure is only available back to 1969, while we would like a default measure that goes back to 1926. Because the EDF measure is option-pricing based, the key input into the measure is stock return volatility. Thus for the longer sample we use stock return volatility. We measure the weekly returns on the value-weighted S&P index based on daily returns. As the volatility measure for a given year, we compute the standard deviation of the weekly log returns over the year leading up to the end of the government fiscal year (the date of the Debt-to-GDP observation). We annualize this standard deviation by multiplying by the square root of 52. Over the 39 years for which we have both EDF data and stock market volatility estimates, the correlation of these two default measures is 0.75. This provides strong support for the use of stock market volatility as a default control over the full sample. Column (3) presents results using the stock return volatility measure. Volatility is significantly related to the spread, but the coefficient on $log(Debt/GDP)$ is roughly the same as in previous specifications. Furthermore, the economic effects of changes in the default risk measures on the Aaa-Treasury spread are modest compared to the effect of Treasury supply. A one standard deviation increase in the EDF increases the Aaa-Treasury spread by 21 basis points while a one standard deviation increase in stock return volatility increases it by 10 basis points.

The regressions in column (2) and (3) include the slope of the yield curve as a further control. We measure the slope as the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). The slope of the yield curve is a measure of the state of the business cycle. It is known to predict the excess returns on stocks and may also pick up time-varying risk premia on corporate bonds. For example, if

[9] Another issue that arises in interpreting the long-term spread regressions is callability. Duffee (1988) points out that the Moody's Aaa index includes callable corporate bonds. Thus, the Aaa-Treasury 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 yield spreads vary significantly with the level of interest rates. Following this approach, we have investigated adding levels of short and long-term interest rates as explanatory variables and have found that it has no appreciable effects on the coefficient on $log(Debt/GDP)$. We also note that callability does not affect the results on excess bond returns and short-term corporate bond spreads.

[10] A further issue that affects spreads between corporate bonds and Treasuries is that Treasuries are exempt from state taxes, while corporate bonds typically are not. We have run regressions that include a control for the state tax effect on the spread (the product of the average state tax rate and the Aaa yield) and find that our results are largely unchanged. The results are available upon request.

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 measure of variation in the risk premium component of the bond spread, i.e. the term involving $cov_t(\cdot)$ in Prediction 2. We also note that to the extent that corporate default risk is likely to vary with the business cycle, the slope variable can furthermore help control for the default risk in the yield spread.

Turning to the results for the Baa-Treasury spread in Panel B, the coefficient on $log(Debt/GDP)$ in column (5) is considerably higher than the coefficient in column (3) for the Aaa-Treasury spread, and imply that a decrease of one standard deviation in Debt-to-GDP from its mean value of 0.426 to 0.233 increases the convenience yield component of the Baa-Treasury spread by 0.79% (79 basis points). The difference in results between Panel A and B suggests that Aaa bonds offer some convenience services of Treasuries and thus that the Baa-Treasury spread is more appropriate for capturing the full effect of Treasury supply on the Treasury convenience yield. We present further evidence for this interpretation in Table III in section 3.4 below.

3.1.2 Short-term spreads

Panel C and D of Table I are based on short-term bond spreads, with Panel C showing results for the spread between the highest rated commercial paper and Treasury bills, both of 3-month maturity, and Panel D focusing on the spread between lower-grade commercial paper (A2/P2 rated paper) and Treasury bills. The shorter time-period in column (9) is due to yields for lower-grade commercial paper being available only starting in 1974.

Short and long-term spreads may contain different convenience attributes, so we should not expect the coefficients on $log(Debt/GDP)$ to be the same across the different maturities. Nonetheless, the regressions for short-term spreads show that the effect of changes in Treasury supply on short-term spreads are of fairly similar magnitudes as the effect on long-term spreads. Consistent with the results for long-term spreads, the higher coefficients in Panel D than in Panel C is also indicative that the high grade commercial paper in Panel C (like the Aaa-rated long-term bonds in Panel A) has some convenience attributes.

It is important to note that our evidence on the spread between commercial paper and T-Bills is less likely to be affected by issues of omitted expected default or default risk premium controls than the evidence on the Aaa-Treasury spread. This is the case because historical default rates on the highest rated commercial paper (A1/P1) are very low, with literally zero defaults during the period 1972-2000 for which Moodys provide data on commercial paper defaults. This latter observation can also explain why the default controls are statistically not different from zero in the commercial paper regressions in columns (7) and (9). Over a three month period, a highly rated firm may run into financial difficulties and be downgraded, but is unlikely to enter bankruptcy.

3.1.3 Excess returns

Table II presents regressions where the dependent variable is the annual excess return on long-term corporate bonds over long-term Treasury bonds. We use the Ibbotson corporate bond return index. This index gives the total return from holding high grade (Aaa and Aa) corporate bonds with approximately a 20-year maturity over the next month (we use 12 months of returns to compute an annual return). It is important to recognize that Aaa bonds and Aa bonds almost never default over the next month. Moody's Investors Service (2005), using data from 1920 to 2004, reports that the default rate on Aaa bonds over the next year are 0.00% while it is 0.06% on Aa bonds. The default rate over a one month horizon must therefore be close to zero for both Aaa and Aa bonds. 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.

We estimate the return regressions using ordinary least squares. We report t-statistics based on modeling the error as an ARMA(1,1) process. Granger and Morris (1976) show that the sum of an AR(1) process and a white noise process is an ARMA(1,1) process. In our setting, the realized excess return is the sum of the expected excess return and an expectation error. We find that the Aaa-Treasury yield spread has an AR(1) error term and would expect the expected excess return of Aaa-bonds over Treasury bonds to share this component. The expectation error is white noise, assuming expectations are rational. In economic terms, the expectation error captures news about expected convenience yields, default, and default risk premia as shown in equation (22). Cochrane (2008) provides further discussion of the need for ARMA(1,1) processes for return forecasting models. In practice, it turns out that standard errors in the return regressions are similar whether we use OLS with standard errors adjusted assuming ARMA(1,1) error terms or OLS with standard errors that assume i.i.d. error terms. Furthermore, coefficients and standard errors are similar to the OLS results if we estimate the ARMA(1,1) model using maximum-likelihood.

The regression in column (1) includes $log(Debt/GDP)$ as the only explanatory variable. The coefficient estimate of -0.851 is similar to the coefficient estimate in the Aaa-Treasury yield spread regression in column (1) of Table 1. This is not surprising since the bonds underlying the returns in Table II are long-term bonds. Thus the coefficient on $log(Debt/GDP)$ in Table II reflects the one period convenience on holding long-term bonds. The fact that our Aaa-Treasury yield spread result is robust to analyzing returns alleviates concerns that the effect of Treasury supply on the Aaa-Treasury yield spread could be reflecting a correlation between Treasury supply and expected default on the Aaa bonds. This is the case since expected excess returns, unlike yield spreads, should not vary systematically with changes in expected default as these affect both expected cash flows and today's price. The effect of Treasury supply on excess returns is, however, not statistically significant. This is likely due to the fact that most of the variation in excess returns is due to news (expectational errors); the standard deviation of annual excess returns is 3.72 percent while the standard deviation of the Aaa-Treasury yield spread is 45 basis points. To help isolate the effect of Treasury supply on expected excess returns, the results in columns (2) includes a "credit hedge" for changes in default risk (a major component of the expectational error). The credit hedge is the contemporaneous return on junk bonds relative to Baa bonds (obtained from Ibbotson). Including this hedge helps to reduce the noise in realized returns that is unrelated to the convenience yield and thereby improves the power in the regressions. For example, if credit risk rises between t and $t+1$, then corporate bonds will deliver a low return over this period. The return on junk bonds relative to Baa bonds will also be low during this period and can serve to hedge out this change in credit risk. The R^2 in the regression column (2) is much higher than that of column (1). When including the credit hedge, the effect of Treasury supply on excess returns is statistically significant (and larger in magnitude). Column (3) adds an additional hedge, the excess return of long-term Treasuries over Treasury bills, in order to capture news about shifts in the yield curve which could affect excess returns of corporate bonds over Treasuries in case of any duration mismatch. We furthermore include the yield curve slope to capture time-varying default risk premia. Adding these two controls do not appreciably change the effect of Treasury supply.

3.2 Evidence for the Existence of Priced Liquidity and Safety Attributes

We next move to testing Predictions (4)-(7) that the convenience yield on Treasuries is a reflection of two priced attributes: liquidity and safety. We consider pairs of assets with different liquidity but similar safety or with different safety but similar liquidity. Table III and IV present the results.

The first two columns of Table III present evidence for the existence of a unique demand for long-term safe assets leading to a positive convenience price of the long-term safety attribute. The dependent variable is the spread between Baa and Aaa corporate bonds. Baa bonds carry more default risk than Aaa bonds but are similarly illiquid. Chen, Lesmond and Wei (2008) study corporate bond liquidity in a large sample of corporate bonds over the period 1995 to 2003 and report that the spread between bid and ask prices on Aaa corporate bonds averaged 52 *bps* while they averaged 58 *bps* on the Baa corporate bonds. These spreads compare to near 10 *bp* for Treasury bonds (Longstaff, 2004). Thus any convenience yield as measured in the Baa-Aaa spread can only reflect the price of the long-term safety attribute, as opposed to a liquidity effect. Column (1) shows that an increase in Treasury supply leads to a decrease in the Baa-Aaa spread, confirming the existence of a priced long-term safety attribute driven by Treasury supply. Theory suggests that the supply of long-term safe assets rather than the total supply of Treasuries should drive the price of long-term safety. In column (2), we presents results using the supply of long-term Treasury debt, measured as the supply of Treasuries with greater than 10 years maturity divided by GDP. Since the maturity structure of government debt is likely to be endogenous, we instrument the long-term supply by powers of $(Debt/GDP)$.

The first-stage of the instrumental variables regression is not reported for brevity, but shows a significant relation between the total debt and the measure of long-term debt. The coefficient of -0.310 means that a one standard deviation decrease in the supply of long term Treasuries (as a ratio to GDP) from its mean value of 0.078 to 0.021 raises the price of long-term safety by 41 basis points.

Column (3) and (4) present evidence for the existence of a priced short-term safety attribute driven by Treasury supply. The dependent variable is the spread between three month A2/P2 rated and A1/P1 rated commercial paper. As noted earlier, over a three month period, based on data from 1972 to 2000, Moody's Investors Service (2000) estimates that the default probability on A2/P2 paper is 0.02%, while it is 0% for A1/P1 paper. Thus there is a (small) difference in the safety of these short-term assets. As for liquidity, there is little secondary market trading activity in commercial paper of any rating. Covitz and Downing (2007) based on data from 1998 to 2003 report that most of the commercial paper activity is in terms of new issuance. Secondary market transactions account for less than 2% of the new issuance activity on any day. Using trading volume as a proxy for liquidity and EDF as a proxy for credit risk, Covitz and Downing find that, in the cross-section of commercial paper, liquidity differences explain very little of the variation in rates. Thus, any convenience yield as measured in the P2-P1 spread reflects the price of the short-term safety attribute. In column (3) we use total Treasury supply while column (4) presents an IV regression, where the supply measure is of Treasuries with maturity less than 1 year divided by GDP. The results in both column (3) and (4) confirm the existence of a significant price of short-term safety. The coefficient of -1.453 in column (4) means that a one standard deviation decrease in the supply of short-term Treasuries (as a ratio to GDP) from its mean value of 0.124 to 0.104 raises the price of short-term safety by 26 basis points.

The last two columns present evidence for the existence of a priced liquidity attribute of Treasuries, comparing assets with similar safety but different liquidity. The dependent variable in column (5) is the spread between the interest rate customers receive on 6 month FDIC-insured CDs and 6 month Treasury bills. We start the CD series in 1984, corresponding to the phasing out of Regulation Q (see Gilbert, 1986). Given FDIC insurance, any convenience yield documented via Treasury supply affecting this spread can only reflect a liquidity attribute. The supply variable in the regression is the total supply of Treasuries, since all Treasuries carry the liquidity attribute. The impact of Treasury supply on the CD-Treasury spread confirms the existence of a significant price of liquidity over the 1984-2008 period. To obtain evidence going back further, column (6) uses data on the spread between the average interest rate paid on time and savings deposits and Treasury bill rates. Since interest rate ceilings set by Regulation Q were binding at various points during the period from 1966 until their phase-out in the mid 1980s (see again Gilbert, 1986), we focus on data from 1934 – the first year of FDIC insurance – to 1965 (we do not have CD rate data from this earlier period). The interest rate on time and savings deposits is less ideal than the CD rate because FDIC insurance does not apply to large deposits, so the interest rate on time and savings deposits reflect a mix of insured accounts and non-insured accounts. The FDIC reports that insurance applied to approximately 75% of all deposits at commercial banks over the period from 1934 to 1965 (Federal Deposit Insurance Corporation: The First Fifty Years, a History of the FDIC, 1933-1983 (Washington: FDIC, 1984)). As a result, there is a slight difference in the safety of the average time and savings deposit and of Treasuries. In addition, the time and savings deposits are an amalgam of deposits with different maturities, making it more difficult to maturity match the series to Treasuries. We match it to 6-month Treasuries. Subject to these qualifiers, the evidence in column (6) of an impact of Treasury supply on the interest rate spread between time and savings deposits and Treasuries provides further support that investors value liquidity with Treasury supply driving the price of liquidity.[11]

We can gauge the magnitude of the liquidity effect in two different ways. First, note that the deposits in column (6) include very short-term savings accounts which are quite liquid. That is the spread in column (6) reflects the difference between a very liquid Treasury and a liquid bank account, so that the spread reflects an underestimate of how much Treasury yields are reduced by the liquidity attribute of Treasuries. The spread in column (5) is a more pure read on the liquidity impact on Treasury yields, although the sample is quite short. The coefficient of -1.904 means that a one standard deviation decrease in the supply of Treasuries (as a ratio to GDP) from its mean value of 0.426 to 0.233 raises the price of liquidity by 115 basis points. A second estimate of the impact of Treasury supply on the price of liquidity comes from the regression in Table I, column (7), which is the high-grade CP spread regression from 1969 to 2007. We have noted that data from 1972 on indicates that there has never been a default on high grade CP. The coefficient on the default controls in that regression are also small and statistically not different from zero. Using this spread as a measure of liquidity, we find that a one standard deviation decrease in the supply of Treasuries (as ratios to GDP) from its mean value of 0.426 to 0.233 raises the price of liquidity by 61 basis points.

Prediction 7 offers another way to demonstrate the existence of a priced long-term safety attribute. As reported in Table VII, private and government pension funds and insurance companies together hold 11% of the total stock of Treasuries, on average from 1945-2008. These Treasury holdings are on average 26% of these groups' portfolio allocation to long-term bond investments. It is likely that these groups holdings' of Treasuries is only driven by their demand for the long-term safety attribute. Since they are long-term investors, these groups are unlikely to have any liquidity demand. If changes in the price of Treasury convenience cause these groups to change their holdings of Treasuries, this is indirect evidence that part of the changing price of convenience is a change in the price of long-term safety. The regression should be

[11] Note that it is possible that bank deposit accounts have a medium-of-exchange attribute that is not shared by Treasury bills. Even in this case, the coefficient on the Treasury supply variable in the regressions is only evidence of a priced liquidity attribute, since variation in Treasury supply should not be expected to affect the price of the medium-of-exchange attribute.

read as the estimate of an inverse demand-curve. We regress the Baa-Aaa spread, as a measure of the price of long-term safety, on the ratio of the groups' Treasury holdings to GDP. Since the demand shocks to the groups' Treasury holdings affect both the spread and its Treasury holdings a standard endogeneity issue is present, and the regression is therefore estimated by instrumental variables, using powers of $Debt/GDP$ as instruments. The results are in Table IV. The coefficient on log holdings is statistically significant at the 10% level. The regression coefficient is -0.372 implies that a 50 basis point decrease in the spread is associated with a 20 percent increase in the groups' Treasury holdings relative to GDP. This shows that these agents substantially increase their holdings of Treasuries when the (long-term safety) convenience yield on Treasuries decreases, consistent with Prediction 7.

3.3 Evidence on Money

The results in Table III suggest that Aaa rated bonds and A1/P1 rated commercial paper share some of the safety attributes of Treasuries. In this section we also show that time and savings deposits share some of the safety and/or liquidity convenience of Treasuries. Specifically, we test Prediction 8 (that the supply of Treasuries negatively affects the yield spread between non-convenient assets and time and savings deposits) and Prediction 9 (that the supply of Treasuries negatively affects the supply of time and savings deposits).

The evidence validating Prediction 9 is particularly compelling for our convenience yield theory. All of the other tests of the theory involve relations between Treasury supply and bond market spreads. There may be lingering doubts that there is some common part of these spreads that for reasons other than our theory (e.g. insufficient default controls) is correlated with Treasury supply. The evidence for Prediction 9 is of a completely different nature and relates the *quantity* of substitute convenience assets to Treasury supply.

As one can see in Figure 2, the evidence in favor of Prediction 9 is striking. The vertical axis in Figure 2A is the quantity of small-denomination (and thus FDIC insured) time and savings deposits, measured as M2 minus M1, all divided by GDP.[12] This money aggregate is graphed versus the $Debt/GDP$ ratio based on annual observations from 1934 to 2008. The figure reveals a clear substitution pattern, consistent with Prediction 9. When there are less Treasuries outstanding, the banking sector increases the supply of bank deposits.[13] The non-M1M2 money aggregate shares the safety and liquidity attributes of Treasuries. The fact that a decrease in Treasury supply generates an increase in non-M1M2 therefore provides evidence that

[12]We exclude Treasury holdings of retail money market funds from M2 since we want to focus on substitutes for Treasuries in this part of the analysis.

[13]There are a few other papers which have documented related substitution patterns. 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 over a sample from 1945 to 1978. Greenwood, Hanson, and Stein show a negative relation between the maturity structure (long versus short) of corporate bonds and government bonds over a sample from 1963 to 2005.

Treasury supply drives the equilibrium price of safety and liquidity.

We exclude M1 (currency and checking accounts) in this analysis because it has the medium-of-exchange attribute, unlike Treasuries. Currency outstanding is also directly controlled by the government, and therefore we may not expect the supply of such currency to be price elastic. The same applies to checking accounts since banks must hold reserves against checking accounts and the supply of bank reserves is largely determined by the Federal Reserve. Thus, it is cleanest to exclude M1 and focus on assets under the private sector's control that only offer safety and liquidity convenience.

Table V presents these results in regression form. In Panel A we regress measures of money on Debt/GDP. In addition to the non-M1M2 measure, we also consider non-M1M3. The latter measure includes small and large time and savings deposits, repos and Eurodollars.[14] The M3 measure is available beginning in 1959. All of the measures reveal a significant negative correlation between money and Treasury supply. The coefficient in column (3) of -0.621 indicates that when Treasury supply falls by \$1, the banking sector responds by supplying \$0.62 of deposits. In Panel B, we elaborate on the mechanism underlying the banking sector response, showing that the change in the private sector supply is induced by price changes. In column (4), we regress the spread between Baa rated bonds and the interest rate paid on the non-M1M2 bank deposits on $log(Debt/GDP)$, with controls. This regression indicates that a decrease in Treasury supply reduces the interest rate on bank deposits relative to the Baa bond rate, consistent with Prediction 8. The channel here is that the price of short-term safety/liquidity rises when Treasury supply declines, causing the interest rate on bank deposits, which carry safety/liquidity attributes, to fall. In column (5), we then regress the supply of bank deposits, measured as $log(\text{non-}M1M2/GDP)$, on the fitted spread response. Column (5) is thus the second stage of an IV regression where we regress the supply of bank deposits on the spread between Baa rated bonds and non-M1M2, instrumented by total Treasury supply. The decrease in the bank deposit rate induces the banking sector to supply more deposits. The regressions in Panel B exclude the Regulation Q period of 1966 to 1983.

We have noted that the money evidence is particularly compelling for our convenience yield theory because Prediction 9 is of a different nature than our other tests, and the relation as depicted in Figure 2 is so striking. The money evidence is also interesting because it highlights that the effects suggested in Figure 1 are not merely about the pricing of Treasury bonds, but are more broadly about assets that offer liquidity and safety services. Liquidity and safety are attributes that are priced in the asset market. Moreover, as we discuss further in Section 4.2, this evidence is relevant for the larger literature in monetary economics on the liquidity effects of money.

[14] We exclude both retail and institutional money funds' holdings of Treasuries.

3.4 Quantifying the convenience yield

We next turn to quantifying the level of the convenience yield. Results from the log-specification pin down the derivative of the convenience yield with respect to Treasury supply, but do not pin down the level of the convenience yield as a function of Treasury supply. Theory suggests that the value of convenience should go to zero given sufficient convenience assets. Imposing this asymptote property allows us quantify the level of the convenience yield, since the convenience yield at some θ_t^T given an estimated relation between spreads and Treasury supply of $f(\theta^T/GDP)$ is simply $f(\theta_t^T/GDP_t) - f(\infty)$ (i.e. the distance between the predicted spread and the estimated asymptote).

The log function does not have the asymptote property.[15] Table VI reports results in which we model the convenience yield with a function that is piecewise linear in Treasury supply, $b_1 \max[b_2 - Debt/GDP, 0]$. Visually, the piecewise linear function appears to be a good fit of the relation as depicted in Figure 1. Indeed, the R^2s for the piecewise linear function rise somewhat relative to the log function. Regressions are estimated by non-linear least squares. As in Table I, the standard errors are adjusted assuming the error term is AR(1).

The term $b_1 \max[b_2 - Debt/GDP, 0]$ is the convenience yield on long-term Treasury debt as a function of the Debt-to-GDP ratio. Consider the estimates from column (4) for the Baa-Treasury spread. We can evaluate the convenience yield function at historical values of the Debt-to-GDP ratio from 1926 to 2008, and average these numbers to come up with the average value of the convenience yield over our sample. This computation gives 72 basis points. The Baa-Treasury spread reflects both long-term safety and liquidity. We have argued that the Baa-Aaa spread is only driven by long-term safety, while the Aaa-Treasury spreads are primarily driven by liquidity given the low default rate on Aaa bonds. To provide a sense of the relative magnitudes of the safety and liquidity convenience components, we make the simplifying assumption that the Aaa-Treasury spread only reflects liquidity, while the Baa-Aaa spread only reflects safety. Based on the Aaa-Treasury estimates of column (2), the average liquidity convenience is 46 basis points. This number should be interpreted as an upper bound for liquidity convenience, since the Aaa-Treasury spread does contain some safety convenience as well (since Aaa bonds are not quite as safe as Treasuries). Further, subtracting 46 from 72, gives us that safety convenience is worth 26 basis points on average (a lower bound since Aaas do carry some default risk).

In the piecewise linear regressions, the constant term b_0 is the average default component of the spread, since the EDF, volatility and slope controls in the regressions are demeaned. Consider column (4) for the Baa-Treasury spread. This regression indicates that b_0 is 1.199, which is within the range of estimates from

[15] We can imagine estimating a function $\max(-log\ Debt/GDP, 0)$, which does have the asymptote property. Since the Debt-to-GDP ratio exceeds one in only two data points during the 1940s, the coefficient estimate in this case will be virtually the same as the one we report. However, this function implicitly assumes that the asymptote is reached when the Debt-to-GDP ratio is one, when there no a priori reason to make such an assumption.

the corporate bond price literature of the default component of Baa bonds (see Elton *et al* (2001) and Longstaff, Mithal and Neis (2006)).

Finally, the estimates of b_2 of the piecewise linear specification provides an estimate of how large Debt-to-GDP needs to be before the demand for convenience is fully saturated. The regressions for both the Aaa-Treasury spread and the Baa-Treasury spread indicate that this limit is around 0.55. It is interesting to note that the latest CBO projection of the Debt/GDP ratio for 2010 puts the ratio at 0.603, indicating that if historical relationships prevail, the convenience yield is likely to fall to zero in the near future.

There is an important caveat in interpreting the piecewise linear estimates. The estimates of b_0 and b_2 are heavily affected by observations in the right tail of Figure 1 (i.e. high Debt-to-GDP ratios). These high ratios only occur during the 1940s and 1950s, so the parameter estimates are influenced by the idiosyncrasies of the war period. In an effort to help finance the war debt at low interest rates, the Federal Reserve committed to purchase long-term Treasury bonds at a floor below prevailing market prices, thereby inducing long-term Treasury rates to be lower than market forces would have otherwise dictated. As events played out, the Federal Reserve did not in fact accumulate much long-term Treasuries, but even so, the commitment to a floor should be expected to affect prices. As a result, our estimates of b_0 are biased upwards – implying that our above estimate of an average Treasury convenience yield of 72 basis points is conservative – and estimates of b_2 biased downwards. The Federal Reserve intervened much more strongly in the Treasury bill market. Policy at the time effectively allowed commercial banks to carry Treasury bills as interest bearing reserves. In addition, beginning in 1943, the Federal Reserve directly purchased a large share of newly issued Treasury bills, while long-term bonds were held by a variety of investors. The Federal Reserve directly held 72% of total Treasury bills outstanding in 1944. See Wicker (1969) for further details on all of these points. We present piecewise linear regressions for the long-term spreads, subject to the caveat noted above, but we do not present results for the short-term spreads on grounds that they are likely largely uninformative about convenience yields. We also note, as can be seen from columns (2), (4), (7), and (9) in Table I, that our main results about the impact of Treasury supply on yields hold for subsamples that do not include the war period.

4 Implications

We have shown that: (1) Changes in Treasury supply drives the convenience yield on Treasuries; (2) Both safety and liquidity drive the convenience yield; (3) Money offers safety and liquidity convenience and is thus a Treasury substitute; and (4) The average Treasury convenience yield is large. In this section, we discuss implications of our findings for a number of important issues in finance and macroeconomics.

4.1 Seignorage from Treasury Bonds

Investors purchase Treasury securities despite the fact that these securities offer a low return because they convey convenience benefits. In this section, we evaluate how much seignorage the government collects from being able to finance the US federal debt with securities that offer convenience benefits.

The historical average Debt-to-GDP ratio is 0.426. At this Debt-to-GDP, the convenience yield from the Baa-Treasury piecewise linear specification in column (4) of Table VI evaluates to 59 basis points. Multiplying these numbers together gives seignorage of 0.251% of GDP. Here is another seignorage computation. If we evaluate the convenience yield at each of the Debt-to-GDP ratios in our sample, multiplying by that Debt-to-GDP ratio, and then averaging, we find that average seignorage is 0.238% of GDP. These computations are only for long-term convenience and therefore ignore the dependence of convenience on maturity and hence how seignorage depends on the maturity structure of debt.

To put these numbers in perspective, consider the seignorage that the government derives from households' willingness to hold fiat money at no interest. The monetary base at the end of 2007, prior to the Federal Reserve's quantitative easing experiment, was $848 Billion, corresponding to 6% of GDP. Suppose the federal government had to repurchase the monetary base by issuing Treasury bills and that these Treasury bills had a 4% nominal yield. Then the annual interest expense of this additional debt would be $4 \times 0.06 = 0.24\%$ of GDP per year.

Together, these calculations suggest that the total benefit from the convenience yield on Treasuries is large and that the seignorage to the government from being able to finance the current level of debt with securities that have a convenience yield is of the same order of magnitude as the seignorage resulting from the public's willingness to hold fiat money at no interest.

4.2 Implications for Money Demand Relations

The factors that drive the demand for Treasuries also drive the demand for money. Figure 2 is fairly compelling evidence for this point. The exercise in this paper has been to examine liquidity and safety demands as they are reflected in the prices of Treasury securities relative to other securities. It is useful to revisit the literature on money demand relations from the vantage of our study as it may shed light on some of the sources of the instability in money demand on which many authors have commented (see Goldfeld and Sichel, 1990).

The convenience yield on money, say as reflected by the spread between the interest rate on checking accounts and corporate bond interest rates, is the sum of the convenience yields due to three underlying attributes. The demand for money stems from demand for liquidity, short-term safety, and a medium-of-exchange. Denote the money spread as S_t^M. Then analogous to Treasuries, we can express S_t^M as

$$S_t^M = k^{M,liq} v'_{liq}(\theta_t^{A,liq}/GDP_t; \xi_t^{liq}) + k^{M,short-safe} v'_{short-safe}(\theta_t^{A,short-safe}/GDP_t; \xi_t^{short-safe}) + k^{M,X} v'_X(\theta_t^X/GDP_t, \xi_t^X) \quad (29)$$

where "X" stands for medium of exchange.

The literature estimating money demand most commonly estimates a relation between the spread, S_t^M, and measures of monetary aggregates such as M1, M2, or broader aggregates of short-term bank liabilities. From equation (29), it is clear that the supply of Treasuries, both long and short, should be integrated into monetary aggregates. The supply of Treasuries drives the prices of liquidity and short-term safety and therefore drives part of the overall convenience yield on money. Ignoring variation in the supply of Treasuries can lead to instability in the estimated money demand relations.

Many authors report increased stability when estimating a money demand function that weighs the sub-components of money (currency, deposits, money-market accounts, etc.) by the convenience provided by the sub-component (see for example Rotemberg, Driscoll, and Poterba, 1995). This approach follows the work of Barnett (1980). Our suggestion to include Treasuries, with some weight, in money aggregates is similar to these approaches and may likewise improve the stability of money demand estimates. However, it is worth emphasizing that Barnett's approach assumes that money contains the price of a single attribute, when it seems likely from our study that money contains the prices of multiple attributes. Thus, different aggregates of Treasuries (short-term and total), with varying weights, should be used to construct separate liquidity and short-term safety aggregates. It seems possible that there is a stable demand for each of the underlying attributes, but this is missed given the aggregation that is done in the literature.

The prices of liquidity and short-term safety are reflected in both S_t^M and in the spreads of "non-money" instruments such as the CP-Bills spread or the P2-P1 spread. That is, there is information in these other spreads that is relevant for estimating the demand for the underlying attributes of money and hence for estimating money demand. As far as we are aware, there are no papers in the money demand literature that utilize the information contained in these other spreads. In Section 3.4 we estimate the convenience yield on long-term Treasuries due separately to their liquidity and long-term safety by examining both the Baa-Aaa spread as well as the Aaa-Treasury spread. A similar approach, using the short term CP-Bills and P2-P1 spreads, could be applied to estimating money demand.

To examine the demand for money in a similar manner as we have examined the demand for Treasuries, the roadmap would be as follows. First, construct aggregates for the different attributes of money. To do so, the key information that is needed is the weights (ks) on different supply aggregates. There are two possible ways to recover the ks. One can use a-priori information to come up with ks. For example, we have argued that insured bank deposits and Treasury bills should have the same weight in the short-safety aggregate because both are default free. Alternatively, it is possible to recover some ks from regressions. For example, from equation (27) we can see that k^{liq} of bank deposits can be recovered from the regression coefficient on Treasury supply, when regressing $S_{t,1}^{FDIC}$ on Treasury supply. This approach needs to be broadened and also applied to evaluate the ks for the medium-of-exchange attribute. The second step is to estimate the demand for the different attributes (i.e. the functions $v'_{liq}(\cdot), v'_{short-safe}(\cdot)$ and $v'_X(\cdot)$). This can be done using a demand system. For example, the P2-P1 spread largely contains the price of the short-term safety attribute, and hence the demand for short-term safety can be estimated using the P2-P1 spread. Likewise, the A1/P1 CP-Bill spread largely contains the price of the liquidity attribute. The spread between T-bill rates and checking deposit rates contains some mix of the price of liquidity and the medium of exchange attribute. These three prices can be used in a demand system, also using the information of the relevant supply aggregate, to separately recover the demand for each attribute of money ($v'_{liq}(\cdot), v'_{short-safe}(\cdot)$ and $v'_X(\cdot)$). Aggregating the three estimated convenience demand relations gives us a money demand function.

4.3 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 price of a one-period Treasury is $P_t^T = \frac{E_t[M_{t+1}]}{1-v'(\theta_t^A/GDP_t;\xi_t)}$ (or interest rate of $i_t^T \approx -ln\ E_t[M_{t+1}] - v'(\cdot)$). The Treasury interest rate is lower than the "true" riskless interest rate. 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.[16]

Our riskless rate finding has many implications for applications in finance. It implies that cost of capital computations using the CAPM should use a higher riskless rate than the Treasury rate – a company with a beta of zero cannot raise funds at the Treasury rate. The finding also has 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 convenience 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. The literature has found that the high spread between corporate bond rates and Treasury rates, and the

[16] 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 the rate on interest rate swaps.

high equity premium, measured as the average excess stock market return over Treasury bill rates, are hard to reconcile based on standard factors. Accounting for a true riskless rate that is higher than the Treasury rate can go some way towards reconciling these findings. We find that true riskless rates should be about 72 basis points higher than Treasury rates. In addition, the literature has documented patterns of unexplained comovement in spreads across debt instruments. 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. The spreads examined in these studies are measured relative to Treasuries. Variation in the Treasury convenience yield is one possible explanation for the comovement phenomena.

4.4 Effect of Foreign Official Demand on Treasury Yields

Table VII reports on who are the main holders of Treasuries and what fraction of overall bond holdings Treasuries constitute for each group. We have commented earlier on the holdings of banks as well as the holdings of the long-term investors (pension funds and insurance companies). In 2008, foreign official holders own the largest share of Treasury debt at 37% of total Treasury supply. These holdings have steadily risen over the post-war period from almost zero in 1945. The recent large holdings have been a data point in a debate on the effects of global imbalances on interest rates (see, for example, Bernanke (2005), Caballero, Farhi, and Gourinchas (2006), Caballero and Krishnamurthy (2009), and Jagannathan, Kapoor and Schaumburg (2009).)

We evaluate the quantitative effect of foreign official demand on Treasury interest rates by asking how much the convenience yield will fall if the foreign official holders were to sell their holdings, thus effectively increasing the supply of Treasuries available to other Treasury holders. For this computation, we need to know the elasticity of the holdings of foreign official holders to the convenience yield. We estimate the inverse demand curve in a similar manner as for the long-term investors of Table IV. The results are quite different, however. The coefficient on the log holdings of this group, when regressing the Baa-Treasury spread on the log of the group's holdings to GDP and instrumenting using the log of total Treasury debt to GDP as in Table IV, is 15.2 with a t-statistic of 0.39. The result indicates that there is no relationship between the foreign official investors' holdings of Treasuries and the convenience yield (i.e. foreign official demand is completely inelastic). We can also get a sense of this by looking at Panel B of Table VII. Foreign official holders hold the bulk of their bond market portfolio in Treasury securities. It appears that when 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.

Suppose therefore that the holdings of foreign official holders at time t, θ_t^{FOH}/GDP_t, does not depend on the convenience yield S_t. Here S_t denotes the convenience yield on long-term Treasuries. Denote the demand function from all groups excluding foreign official holders by $D_{not-FOH}(S_t)$. Then the market clearing condition is,

$$D_{not-FOH}(S_t) + \theta_t^{FOH}/GDP_t = \theta_t^T/GDP_t,$$

giving a convenience yield of,

$$S_t = D^{-1}_{not-FOH}\left(\frac{\theta_t^T - \theta_t^{FOH}}{GDP_t}\right).$$

To compute the effect of the sale of all foreign official holdings of Treasuries on Treasury yields (relative to yields on non-convenient assets), we need to compute the difference between $D^{-1}_{not-FOH}\left(\frac{\theta_t^T}{GDP_t}\right)$ and $D^{-1}_{not-FOH}\left(\frac{\theta_t^T-\theta_t^{FOH}}{GDP_t}\right)$. In empirical work, we regress spreads on θ_t^T/GDP_t to recover a convenience yield function $f(\theta_t^T/GDP_t)$. Because foreign official demand is inelastic, $D^{-1}_{not-FOH}(\cdot)$ is simply $f(\theta_t^T/GDP_t)$ shifted left by θ_t^{FOH}/GDP_t. Therefore, $D^{-1}_{not-FOH}\left(\frac{\theta_t^T}{GDP_t}\right)$ minus $D^{-1}_{not-FOH}\left(\frac{\theta_t^T-\theta_t^{FOH}}{GDP_t}\right)$ equals $f\left(\frac{\theta_t^T+\theta_t^{FOH}}{GDP_t}\right)$ minus $f\left(\theta_t^T/GDP_t\right)$.

At the historical average Debt-to-GDP ratio of 0.426, a sale of this magnitude (37% of Treasury supply) will have a large effect on Treasury yields. We evaluate the estimated convenience yield function at holdings of 0.426 and $0.584 = 0.426 \times 1.37$, both as a ratio to GDP. Based on the piecewise linear specification for the Baa-Treasury spread (Table VI, column 4), the effect will be to raise long-term Treasury yields by 59 basis points relative to the Baa corporate bond yield. Based on the log specification for the Baa-Treasury spread (Table I, column 5), the effect is to raise long-term Treasury yields by 41 basis points. The effect on short-term yields, based on the CPP2-Bill specification (Table I, column 9) is to raise Treasury yields by 60 basis points. All of these computations are relative to corporate bond rates. Our computations do not include any possible effect of foreign sales on the level of all interest rates.[17]

5 Conclusion

Investors value the liquidity and safety attributes of Treasuries. We document this by showing that changes in Treasury supply have large effects on a variety of yield spreads. Evaluated based on the Baa-Treasury

[17]We report the impact of a sale at the historical average Debt-to-GDP ratio and using our estimated average convenience demand function. The numbers should thus be interpreted not as the short-run impact of a sale but as an average impact evaluated at "normal" supply and demand conditions. Current Treasury supply is higher than average, with the current CBO projection of the Debt-to-GDP ratio for 2010 at 0.603. Our estimates, based on historical experience, implies that at this high supply of Treasuries the convenience yield is zero, which suggests that sales of Treasury bonds will have no short-run impact on yield spreads. However, there are two reasons this computation is inaccurate. First, the recent crisis has reflected a flight-to-quality (demand) shock that has driven up the convenience yield and effectively increased b_2 in the piecewise linear specification. Second, the deterioration in the credit quality and liquidity of private sector assets implies that the supply of non-Treasury convenient assets has declined. This makes it difficult to assess the short-run impact of a large Treasury sale. We instead report the "long-run" impact at average supply and demand conditions.

spread (for long-term bonds), a one standard deviation reduction in Treasury supply (starting from mean supply) lowers Treasury yields by 79 basis points relative to corporate bond yields. The effects based on the CPP2-Bills spread (for short-term bonds) is of a roughly similar magnitude.

By studying pairs of assets with similar liquidity but different safety (higher and lower grade corporate bonds and commercial paper) or with similar safety but different liquidity (FDIC insured CDs and Treasury bills) we document that changes in Treasury supply drive both the equilibrium price of safety and the equilibrium price of liquidity. This implies that Treasuries carry both a safety and liquidity attribute. Using a piecewise linear specification, we estimate that the average convenience yield on long-term Treasuries over the period 1926-2008 is 72 basis points, of which 46 basis points is driven by the liquidity of Treasuries and 26 basis points by the safety of Treasuries.

The low yields on Treasuries due to their extreme safety and liquidity imply that Treasuries in important respects are similar to money. Evidence from quantities provide further support for this idea – the private sector expands money supply (bank deposits) when the government reduces Treasury supply. While we focus on money as a key substitute for Treasuries, our evidence suggests that other assets such as Aaa rated corporate bonds and A1/P1 rated commercial paper carry some (but not all) of the convenience of Treasuries.

Our results have immediate implications for asset pricing by showing that theoretical models need to incorporate priced liquidity and safety attributes in order to be empirically succeesful in understanding asset prices. We emphasize further implications of our findings for tax payers (Treasury seignorage), money demand, the riskless rate, and the potential impact of a sale of Treasuries by foreign central banks.

References

[1] Aiyagari, S.R., and Gertler, M., 1991. Asset returns with transactions costs and uninsured individual risk. *Journal of Monetary Economics 27*, 311331.

[2] Amihud, Y., Mendelson, H., 1991. Liquidity, maturity, and the yields on U.S. Treasury securities. Journal of Finance 46, 31-53.

[3] Bernanke, Ben, 2005, The Global Saving Glut and the U.S. Current Account Deficit, Sandridge Lecture, Virginia Association of Economics, Richmond, Virginia, Federal Reserve Board.

[4] Bansal, Ravi, and John Wilbur Coleman II, 1996, A Monetary Explanation of the Equity Premium, Term Premium, and Risk-free Rate Puzzles, *Journal of Political Economy* 104(6), 11351171.

[5] Barnett, William (1980), Economic monetary aggregates: An application of index number and aggregation theory, *Journal of Econometrics*, 14: 11-48.

[6] Barro, Robert J., 1974, Are government bonds net wealth?, *Journal of Political Economy* 82, 1095-1117.

[7] Barro, Robert J., 1987, Government Spending, Interest Rates, Prices, and Budget Deficits in the United Kingdom, 1701-1918, *Journal of Monetary Economics* 20(2), 221-247.

[8] Bohn, Henning, 1998, The Behavior of U.S. Public Debt and Deficits, *Quarterly Journal of Economics* 113(3), 949-963.

[9] Boudoukh, Jacob, Matthew Richardson, Richard Stanton, and Robert Whitelaw, 1997, Pricing mortgage-backed securities in a multifactor interest rate environment: A multivariate density estimation approach, *Review of Financial Studies* 10, 405-446.

[10] Caballero, Ricardo, Emmanuel Farhi, and Pierre-Olivier Gourinchas, 2006, An Equilibrium Model of Global Imbalances and Low Interest Rates, Working Paper, MIT.

[11] Caballero, Ricardo, and Arvind Krishnamurthy, 2009, Global Imbalances and Financial Fragility, *American Economic Review*, 99(2), pages 584-88,

[12] Chalmers, John M, 1998, Default risk cannot explain the Muni puzzle: evidence from municipal bonds that are secured by U.S. treasury obligations, *Review of Financial Studies* 11, 281-308.

[13] Chava, Sudheer and Robert A. Jarrow, 2004, Bankruptcy prediction with industry effects, *Review of Finance* 8, 537569.

[14] Chen, Long, David Lesmond and Jason Wei, 2007, Corporate Yield Spreads and Bond Liquidity, *Journal of Finance* 61(1).

[15] Cochrane, John, 2008, Comments on "Bond Supply and Excess Bond Returns by Robin Greenwood and Dimitri Vayanos.

[16] Collin-Dufresne, Pierre, Robert Goldstein, and J. Spencer Martin, 2001, The Determinants of Credit Spread Changes, *The Journal of Finance*, 66, 2177-2207.

[17] Cortes, Fabio, 2003, Understanding and modelling swap spreads, Bank of England Quarterly Bulletin, Winter 2003.

[18] Covitz, Dan, and Chris Downing, 2007, Liquidity or credit risk? The determinants of very short-term corporate yield spreads, Journal of Finance 62, 2303-2328

[19] Duffee, Greg, 1998, The relation between Treasury yields and corporate bond yield spreads, *Journal of Finance* 53, 2225-2242.

[20] Duffie, Darrell and Kenneth J. Singleton (1997). An Econometric Model of the Term Structure of Interest Rate Swap Yields. *Journal of Finance* 52, 1287-1321.

[21] Duffie, Darrell and Kenneth J. Singleton (1999). Modeling Term Structures of Defaultable Bonds . *The Review of Financial Studies* 12(4), 687-720.

[22] Elmendorf, Douglas W., and N. Gregory Mankiw, 1999, Government Debt. In John B. Taylor and Michael Woodford (eds.), Handbook of Macroeconomics, Amsterdam: Elsevier Science, Chapter 25.

[23] Elton, E., M. Gruber, D. Agrawal, and C. Mann., 2001, Explaining the Rate Spread on Corporate Bonds, *Journal of Finance* 56, 247-277.

[24] Evans, P., 1987, Do budget deficits raise nominal interest rates? Evidence from six countries, *Journal of Monetary Economics* 20(2), 281-300.

[25] Feldhutter, Peter and David Lando, 2008, Decomposing swap spreads, *Journal of Financial Economics* 88(2), 375-405.

[26] Fleming, Michael, 2003, Measuring Treasury Market Liquidity, *Federal Reserve Bank of New York Economic Policy Review*, 9(3), 83-108.

[27] Friedman, Benjamin and Kenneth Kuttner, 1998 Indicator Properties of the PaperBill Spread: Lessons from Recent Experience, *Review of Economics and Statistics.*

[28] Gilbert, R. Alton, 1986, Requiem for Regulation Q: What it Did and Why it Passed Away, *Federal Reserve Bank of St. Louis Review* 68(2) 2237.

[29] Gabaix, Xavier, Arvind Krishnamurthy and Olivier Vigneron, 2007, Limits of Arbitrage: Theory and Evidence from the MBS market, *Journal of Finance* 62(2), 557-595.

[30] Goldfeld, Stephen M. and Daniel E. Sichel, 1990, The demand for money, In: Benjamin M. Friedman and Frank H. Hahn, Editor(s), Handbook of Monetary Economics, Elsevier, 1990, Volume 1, Pages 299-356

[31] Gomes, Francisco and Alexander Michaelides, 2008, Asset Pricing with Limited Risk Sharing and Heterogeneous Agents, *Review of Financial Studies* 21(1), 415-448.

[32] Gorton, Gary, 2010, Slapped by the Invisible Hand: The Panic of 2007, Oxford University Press; 2010.

[33] Granger, C. W. J. and M. J. Morris, 1976, Time Series Modelling and Interpretation, *Journal of the Royal Statistical Society. Series A (General)* 139 (2), 246-257.

[34] Greenwood, Robin, and Dimitri Vayanos, 2010a, Bond Supply and Excess Bond Returns, Working Paper, Harvard Business School.

[35] Greenwood, Robin, and Dimitri Vayanos, 2010b, Price Pressure in the Government Bond Market, *American Economic Review, Papers and Proceedings*, forthcoming.

[36] Greenwood, Robin, Sam Hanson and Jeremy Stein, 2009, A Gap Filling Theory of Corporate Debt Maturity Choice, *Journal of Finance*, forthcoming.

[37] Grinblatt, M. (2001). An Analytical Solution for Interest Rate Swap Spreads. *International Review of Finance* 2(3), 113-149.

[38] Heaton, John and Deborah Lucas, 1996, Evaluating the Effects of Incomplete Markets on Risk Sharing and Asset Pricing, *Journal of Political Economy 104*, 443-487.

[39] Homer, S., *A History of Interest Rates, Second Edition*, (New Brunswick: Rutgers University Press, 1977).

[40] Hull, John, Mirela Predescu and Alan White, 2004, "The Relationship Between Credit Default Swap Spreads, Bond Yields, and Credit Rating Announcements," *Journal of Banking and Finance*, 28, 2789-2811.

[41] Jagannathan, Ravi, Mitch Kapoor and Ernst Schaumburg, 2009, Why we are in a recession? The Financial Crisis is the symptom not the disease, working paper, Northwestern University.

[42] Krishnamurthy, A. (2002). The bond/old-bond spread. *Journal of Finan- cial Economics* 66, 463-506.

[43] Laubach, T., 2007, New Evidence on the Interest Rate Effects of Budget Deficits and Debt, Board of Governors of the Federal Reserve System, Working Paper.

[44] Liu, J., F. A. Longstaff, and R. E. Mandell (2004). The Market Price of Credit Risk: An Empirical Analysis of Interest Rate Swap Spreads. forthcoming, *Journal of Business*.

[45] Longstaff, F., 2004 The Flight-To-Liquidity Premium in U.S. Treasury Bond Prices, *Journal of Business*, 77, 511-526.

[46] Longstaff, F., S. Mithal and E. Neis, 2006, Corporate Yields Spreads: Default Risk or Liquidity? New Evidence from the Credit-Default Swap Market, forthcoming, *Journal of Finance*.

[47] Lucas, Robert E., Jr, 2000, Inflation and Welfare, *Econometrica*, 68(2), pp. 247-274.

[48] McDonald, Robert, 1983, Government debt and private leverage: An extension of the Miller Theorem, *Journal of Public Economics* 22(3): 303-325.

[49] Merton, R., 1974, "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates," *Journal of Finance*, 29, 449470.

[50] Modigliani, F. and R. Sutch, 1966, Innovations in Interest-Rate Policy, *American Economic Review*, 56, 178-197.

[51] Moody's Investors Service (2000), "Commercial Paper Defaults and Rating Transitions, 1972-2000", New York.

[52] Moody's Investors Service (2005), "Default and Recovery Rates of Corporate Bond Issuers, 1920-2004", New York.

[53] Plosser, Charles, 1987, Fiscal policy and the term structure, *Journal of Monetary Economics* 20(2),343-367.

[54] Reinhart, Vincent and Brian P. Sack, 2000, The Economic Consequences of Disappearing Government Debt, *Brookings Papers on Economic Activity*, 163-220.

[55] Rocheteau, Guillaume, 2009, A Monetary Approach to Asset Liquidity, Working Paper, University of California-Irvine.

[56] Rotemberg, Julio J., John C. Driscoll, and James M. Poterba, 1995, Money, Output, and Prices: Evidence from a New Monetary Aggregate, *Journal of Business and Economic Statistics* 13, pp 67-83.

[57] Sidrauski, Miguel, 1967, " Rational Choice and Patterns of Growth in a Monetary Economy," *American Economic Review*, 57(2), pp. 534-544.

[58] Sundaresan, S., and Zhenyu Wang, 2006, Y2K Options and Liquidity Premium in Treasury Bond Markets, working paper, Columbia University.

[59] Vayanos, Dimitri and Jean-Luc Vila, 1999, Equilibrium Interest Rate and Liquidity Premium With Transaction Costs, *Economic Theory 13*, 509-539

[60] Vissing-Jorgensen, Annette, 2003, Perspectives on Behavioral Finance: Does "Irrationality" Disappear with Wealth? Evidence from Expectations and Actions, NBER Macroeconomics Annual 2003.

[61] Wicker, Elmus, 1969, World War II Policy of Fixing a Pattern of Interest Rates, *Journal of Finance*, 24(3), 447-458.

A Derivation for Prediction 2

We rewrite (9), using the approximation that $1 - v'(\cdot) \approx e^{-v'(\cdot)}$, so that the return from t to $t+1$ on holding Treasury bonds satisfies,

$$1 = e^{v'(\theta_t^A/GDP_t;\xi_t)} E_t[M_{t+1} P_{t+1}^T / P_t^T] = E_t[M_{t+1} e^{-(\tau-1)i_{t+1,\tau-1}^T + \tau i_{t,\tau}^T + v'(\theta_t^A/GDP_t;\xi_t)}]. \tag{30}$$

Likewise, for corporate bonds, rewriting (16), we find,

$$1 = e^{-\lambda_t D_t} E_t[M_{t+1} P_{t+1}^C / P_t^C] = E_t[M_{t+1} e^{-(\tau-1)i_{t+1,\tau-1}^C + \tau i_{t,\tau}^C - \lambda_t D_t}]. \tag{31}$$

The excess return on corporate bonds over Treasury bonds is,

$$\tilde{R}_{t+1} = \frac{P_{t+1}^C}{P_t^C} - \frac{P_{t+1}^T}{P_t^T} \approx -(\tau - 1) S_{t+1,\tau-1} + \tau S_{t,\tau}.$$

We log-linearize to make the approximation. We make the following computations to arrive at an expression for the spread $S_{t,\tau}$. We assume that M_{t+1} is lognormally distributed (where $m \equiv ln\ M$) and that all interest rates are normally distributed. Then, it is straightforward to rewrite (30) as,

$$1 = e^{v'(\theta_t^A/GDP_t;\xi_t) + E_t[m_{t+1}] + 1/2 var_t[m_{t+1}] - (\tau-1)E_t[i_{t+1,\tau-1}^T] + \tau i_{t,\tau}^T + \frac{1}{2}(\tau-1)^2 var_t(i_{t+1,\tau-1}^T) - cov_t(m_{t+1}, (\tau-1)i_{t+1,\tau-1}^T - \tau i_{t,\tau}^T)},$$

and rewrite (31) as,

$$1 = e^{-\lambda_t D_t + E[m_{t+1}] + 1/2 var[m_{t+1}] - (\tau-1)E_t[i_{t+1,\tau-1}^C] + \tau i_{t,\tau}^C + \frac{1}{2}(\tau-1)^2 var_t(i_{t+1,\tau-1}^C) - cov(m_{t+1}, (\tau-1)i_{t+1,\tau-1}^C - \tau i_{t,\tau}^C)}.$$

We take logs and subtract these last two equations. We assume that the terms involving $var_t(i_{t+1,\tau-1}^T)$ and $var_t(i_{t+1,\tau-1}^C)$ are approximately the same. That is, innovations in both corporate and Treasury rates have the same variance. Then,

$$0 = \frac{1}{\tau}(v'(\theta_t^A/GDP_t;\xi_t) + \lambda_t D_t) + \frac{\tau-1}{\tau} E_t[S_{t+1,\tau-1}] - S_{t,\tau} + \frac{1}{\tau} cov_t(m_{t+1}, (\tau-1)S_{t+1,\tau-1} - \tau S_{t,\tau}),$$

or,

$$S_{t,\tau} = \frac{1}{\tau}(v'(\theta_t^A/GDP_t;\xi_t) + \lambda_t D_t) + \frac{\tau-1}{\tau} E_t[S_{t+1,\tau-1}] - \frac{1}{\tau} cov_t(m_{t+1}, \tilde{R}_{t+1}).$$

Solving this equation recursively for $S_{t,\tau}$ we find the expression in the text.

B Data

Table I:

Aaa-Treasury yield spread: The percentage spread between Moody's Aaa-rated long maturity corporate bond yield and the yield on long maturity Treasury bonds. The Moody's Aaa index is constructed from a sample of long maturity ($\geq$ 20 years) industrial and utility bonds (industrial only from 2002 onward), available from 1919-2008. The yield on long maturity Treasury bonds is the average yield on long-term government bonds, available from 1919 - 1999. The Treasury bonds included are due or callable after 8 years for 1919-1925, 12 years for 1926-1941, 15 years for 1941-1951, 12 years for 1952, and 10 years for 1953-1999. We use the yield on 20-year maturity Treasury bonds for 2000 - 2008. All three data series are from the Federal Reserve's FRED database (series AAA, LTGOVTBD, and GS20), with the exception that the long-term Treasury yield data for 1919-1924 are from Banking and Monetary Statistics, 1914-1941, Table 128. We use annual observations, sampled in July of the year up to (and including) 1975 and in October of each year after that.

Baa-Treasury yield spread: The percentage spread between Moody's Baa-rated long maturity corporate bond yield and the yield on long maturity Treasury bonds. The Moody's Baa index is constructed from a sample of long maturity ($\geq$ 20 years) industrial and utility bonds (industrial only from 2002 onward), available from 1919-2008. The Baa data series is also from the FRED database (series BAA). We use annual observations, sampled in July of the year up to (and including) 1975 and in October of the year after that.

CP-Bills yield spread: The percentage yield spread between commercial paper and Treasury bills. For 1971-2008 the commercial paper yield is from the FRED database. For 1971-1996 it is the series CP3M (the average of offering rates on 3-month commercial paper placed by several leading dealers for firms whose bond rating is AA or equivalent) and for 1997-2008 the series CPN3M (the 3-Month AA nonfinancial commercial paper rate). Prior to 1971 we use the commercial paper series for prime commercial paper, 4-6 month maturity, from Banking and Monetary Statistics (Table 12.5 for 1941-1970 and Table 120 for 1920-1940). The Treasury bill yield is for 3-month Treasury bills from 1971-2008 (from FRED, series TB3MS), 6-month Treasury bills for 1959-1970 (from FRED, series TB6MS), and 3-6 month Treasury bills for 1920-1958 from the NBER Macro History database (series M13029b for 1931-1958 and series m13029a for 1920-1930). We use annual observations, sampled in July of the year up to (and including) 1975 and in October of each year after that.

CPP2-Bills yield spread: The percentage yield spread between lower-grade commercial paper and Treasury bills. Calculated as the sum of the CP-bills yield spread described above (i.e. high-grade commercial paper minus Treasury bills) and the yield spread between 30-day A2/P2 nonfinancial commercial paper and 30-day AA nonfinancial commercial paper, with data for 1974-1997 obtained from Bloomberg and data from

1998-2007 obtained from the Federal Reserve. [18]

Debt/GDP: The supply of Treasuries scaled by GDP, at market value. Calculated as (Debt/GDP with Debt at face value)*(Total market value of Treasuries/Total face value of Treasuries).

The Debt/GDP series (with debt at face value) is from Henning Bohn's web page for years 1919-2003. The debt measure includes debt held by the Federal Reserve, but excludes debt held by other parts of the government such as the Social Security Trust Fund. Debt is for the end of the government's fiscal year, i.e. end of June up to and including 1975 and end of September from 1976 on. GDP is for the calendar year in which the government fiscal year started (fiscal year t starts in calendar year t-1), with GDP data used from 1929 on and GNP data used prior to that. We extend Bohn's series up to 2008 using Treasury data from Flow of Funds Table L.209 and GDP data from NIPA Table 1.1.5. For 2004-2008 we use GDP for the four quarters leading up to the date of the fiscal year end.

The CRSP Monthly US Treasury Database is used to calculate the factor for translating face values to market values (Total market value of Treasuries/Total face value of Treasuries). This data base starts in 1926. Prior to 1949 the amounts outstanding are missing for a lot of the Treasuries. From 1949 onward, at least 97% of Treasuries in the database have values for both amounts outstanding and price, thus allowing us to calculate the ratio of market value to face value for the U.S. Treasury market as a whole. We multiply Bohn's Debt/GDP series by the CRSP ratio of Treasury market to face value to get a series for the market value of Treasury Debt/GDP. Over the period 1949-2008 the correlation between Debt/GDP at face value and Debt/GDP at market value is 0.992 and the means and standard deviations of the two series are very similar. Prior to 1949, one can still calculate the ratio of Treasury market to face value for the set bonds in the CRSP data base for which the data are available. This set is somewhat skewed towards better coverage of long maturities. We get similar results whether we use Debt/GDP at face value and Debt/GDP at market value in the pre-1949 period. We report the results which use the market Debt/GDP series.

Prior to 1919 the CRSP data base is not available and we therefore do not make the market value adjustment. In general, over the 1926-2008 period our results throughout the paper are very similar whether the market value adjustment is made or not.

Volatility: Annualized standard deviation of weekly log stock returns on the S&P500 index. We calculate weekly returns on the value-weighted S&P index based on daily returns obtain from CRSP. As the volatility measure for a given year, we compute the standard deviation of the weekly log returns over the year leading up to the end of the government's fiscal year. We annualize the standard deviation of weekly log returns by multiplying by the square root of 52.

EDF: Expected default frequency for corporate bonds. The data are obtained from Moody's-KMV. We use the median EDF reported by Moody's-KMV for large firms (defined as firms with book value of

[18] We thank Michael Fleming at the Federal Reserve for help obtaining this data.

assets > $300 million in current dollars). The EDF measure is available from 1969 to 2007. We use annual observations, sampled in July of the year up to (and including) 1975 and in October of each year after that.

Slope: Slope of the Treasury yield curve measured as the spread between the 10-year Treasury yield and the 3-month Treasury yield. The interest rate on Treasuries with 10 year maturity is from FRED from 1953 to 2005 (series GS10). Prior to 1953 we use series m13033a (1926-1941) and m13033b (1942-1952) from the NBER Macro History Database, with both these series referring to the yield on long-term Treasuries. The interest rate on Treasuries with 3 month maturity is from FRED from 1934 to 2008 (series TB3MS) and from the NBER Macro History database prior to that (series m13029a for 1926-1933, referring to 3-6 month Treasuries). We use annual observations, sampled in July of the year up to (and including) 1975 and in October of each year after that.

In all tables, volatility, EDF and slope variables are demeaned.

Table II:

Excess return of corporate bonds over Treasuries: The one-year percentage excess return on long term corporate bonds over long term government bonds. Both return series are from Ibbotson's Stocks, Bonds, Bills & Inflation Yearbook and begin in 1926 and end in 2003. The Ibbotson corporate bond index is based on the total return from holding high grade (Aaa and Aa) corporate bonds with approximately 20-year maturity. If a bond is downgraded during a particular month, Ibbotson includes its return for that month in the computation of the index return before removing the bond from future portfolios. The Ibbotson long term government bond index covers a one-bond (one Treasury issue) portfolio with a term of approximately 20 years and a coupon rate close to the current level of the yield curve. Returns are annual from July to the next June for 1926 to 1975 and annual from October to the next September from 1976 on.

Excess return of corporate junk bonds over corporate Baa-rated bonds: The one-year percentage excess return on corporate bonds rated below Baa over corporate bonds rated Baa. Both series are obtained directly from Ibbotson Associates (now part of Morningstar) and are available from 1926-1989. From 1990 to 2003 we use data obtained from Lehman Brothers, specifically their Intermediate U.S. High Yield minus their Baa Corporate. Returns are annual from July to the next June for 1926 to 1975 and annual from October to the next September from 1976 on.

Duration hedge: The one-year percentage excess return on long-term government bonds over short-term government bonds. The long-term government bond series is from Ibbotson (described above). The short-term government bond series is the return on 90-day Treasury bills from the CRSP US Treasury and Inflation database. Returns are annual from July to the next June for 1926 to 1975 and annual from October to the next September from 1976 on.

Debt/GDP, slope: As for Table I.

Table III, Panel A:

Baa-Aaa yield spread: The percentage yield spread between the Moody's Baa-rated long maturity bond yield and Moody's Aaa-rated long maturity bond yield. Both series are described under Table 1 above. We use annual observations, sampled in July of the year up to (and including) 1975 and in October of each year after that.

A2/P2-A1/P1 yield spread: The yield spread between 30-day A2/P2 nonfinancial commercial paper and 30-day AA nonfinancial commercial paper, with data for 1974-1997 obtained from Bloomberg and data from 1998-2007 obtained from the Federal Reserve. We use annual observations, sampled in July of the year up to (and including) 1975 and in October of each year after that.

(Debt>10 year maturity)/GDP: The ratio of Treasury debt with more than 10 year remaining maturity to GDP. From 1949-2008 the amount of Treasury debt is at market value and calculated using the CRSP Monthly US Treasury Database. From 1926-1948 the amount of Treasury debt is at face value and obtained from Banking and Monetary Statistics 1914-1941 Table 147 and Banking and Monetary Statistics 1941-1970 Table 13.5 D.

(Debt$\leq$ 1 year maturity)/GDP: The ratio of Treasury debt with a year or less of remaining maturity to GDP. From 1949-2008 the amount of Treasury debt is at market value and calculated using the CRSP Monthly US Treasury Database (we only use this series in column (2) which is based on data from 1974 onward).

Debt/GDP, volatility, slope: As for Table I.

Table III, Panel B:

(FDIC insured CDs)-Bills yield spread: The percentage yield spread between the yield on 6-month certificates of deposit and Treasury bills. The CD yields are the national average rates obtainable by depositors on small-denomination (and thus FDIC insured) CDs of 6 month maturity, where small-denomination means the account-opening minimum. The rates are from Bank Rate Monitor and are obtained from the New York Times for 1984-1997 and from Bloomberg for 1998-2008. The Treasury bill yield used is the yield on 6-month bills obtained from FRED (series TB6MS). Yields are annual, as of the end of September.

(Time & Savings Accounts)-Bills yield spread: The percentage yield spread between time and savings accounts and Treasury bills. We estimate the yield on time and savings accounts using data from FDIC Historical Statistics on Banking, Table CB06 and CB15. Specifically, we divide the total annual interest on deposits in domestic offices by the sum of savings and time deposits in domestic offices (using averages of beginning and end of year values for the deposits). The FDIC series is available from 1935 onward. We compare this yield series to the yield on 6-month Treasuries, with data obtained from FRED (series TB6MS) from 1959 on and from the NBER Macro History database prior to that (series m13029b for 1931-1958 and series m13029a for 1926-1930, both referring to 3-6 month Treasuries). Since the yield on time and savings accounts is an annual average, we use the annual calendar year average of 6-month monthly Treasury bill rates for comparison.

Slope: Slope of the Treasury yield curve measured as the spread between the 10-year Treasury yield and the 6-month Treasury yield. The interest rate on Treasuries with 10 year maturity is from FRED from 1953 to 2005 (series GS10). Prior to 1953 we use series m13033a (1926-1941) and m13033b (1942-1952) from the NBER Macro History Database, with both these series referring to the yield on long-term Treasuries. The interest rate on Treasuries with 6 month maturity is from FRED from 1959 to 2008 (series TB6MS) and from the NBER Macro History database prior to that (series m13029b, referring to 3-6 month Treasuries). The slope variable in column (5) is based on October values to match the timing of the left-hand side variable. The slope variable in column (6) is (annual calendar year average of 10-year monthly yields)-(annual calendar year average of 6-month monthly yields), in order to match the timing of the dependent variable which is a calendar year average.

Debt/GDP: As for Table I.

Table IV:

Debt held by pension funds and insurance companies: Treasury holdings of pension funds and insurance companies, from Flow of Funds Accounts of the United States, Table L. 209, groups Property-casualty insurance companies, Life insurance companies, Private pension funds, State and local government retirement funds, and Federal government retirement funds. To match the timing of Debt/GDP, the Treasury holdings of pension funds and insurance companies are as of end of June up to 1975 and as of end of September from 1976 on, with the exception that for 1945-1951 only end of year holdings are available.

Baa-Aaa yield spread: As for Table III, Panel A.

Debt/GDP, volatility, slope: As for Table 1.

Table V, Panel A:

(non-M1 M2)/GDP, (non-M2 M3)/GDP, (non-M1 M3)/GDP: We start our money supply series in 1934 since this is the first year of FDIC insurance. Money supply data from 1934-1958 are from Friedman and Schwartz (1970), Table 1. Subsequent money supply data are from Federal Reserve Statistical Release H.6. M1 refers to currency, traveler's checks, demand deposits, and other checkable deposits. M2 refers to M1 plus savings deposits (including MMDAs), small-denomination time deposits and retail money market funds. M3 refers to M2 plus large time deposits, repos, Eurodollars, and institutional money market funds. M3 data are available only for 1959-2005. We refer to M2 minus M1 as non-M1 M2, to M3 minus M2 as non-M2 M3 and to M3 minus M1 as non-M1 M3.

In our measure of non-M1 M2 we exclude Treasury holdings of retail money market funds (thus focusing on savings deposits, including MMDAs, small-denomination time deposits and non-Treasury retail money market fund holdings). This is done because we are interested in studying the part of money which is not Treasuries. Similarly, we exclude Treasury holdings of institutional money market funds from non-M2 M3 which thus consists of large time deposits, repos, Eurodollars, and non-Treasury institutional money market fund holdings. Our series for non-M1 M3 then consists of savings deposits, including MMDAs, small-denomination time deposits, non-Treasury retail money market fund holdings, large time deposits, repos, Eurodollars, and non-Treasury institutional money market fund holdings. To estimate Treasury holdings of retail money market funds and of institutional money market funds, we obtain holdings of money market funds from Flow of Funds Table L. 121. We assume that retail and institutional money market funds have the same ratio of Treasury holdings to total fund holdings.

Money data are as of end of June up to and including 1975 and end of September from 1976 on. From 1948 on GDP data used to define ratios of money to GDP are sums of quarterly GDP for the four quarters leading up to the date of the money data used, with quarterly GDP data from NIPA Table 1.1.5. For 1929-1947 we use annual GDP data from NIPA Table 1.1.5 and prior to 1929 we use GDP data from Louis D. Johnston and Samuel H. Williamson, What Was the U.S. GDP Then? MeasuringWorth, 2008. URL: http://www.measuringworth.org/usgdp/.

Debt/GDP: As for Table I.

Year: A time trend.

Table V, Panel B:

Baa-(non-M1M2) yield spread: Percentage yield spread between the Moody's Baa-rated long maturity bond yield and the yield on non-M1 M2. For the Baa yield, we use annual observations, sampled in July of the year up to (and including) 1975 and in October of each year after that. We estimate the yield on non-M1 M2 as the yield on time $ savings accounts from Table III, Panel B.

Debt/GDP: As for Table I.

Volatility: As for Table I, with the exception that we here use the standard deviation of the weekly log returns over the calendar year (as opposed to the government fiscal year), in order to match the timing of the non-M1 M2 yield which is a calendar year average.

Slope: As for Table I, with the exception that we here use calendar year averages: (annual calendar year average of 10-year monthly yields)-(annual calendar year average of 3-month monthly yields), in order to match the timing of the non-M1 M2 yield which is a calendar year average.

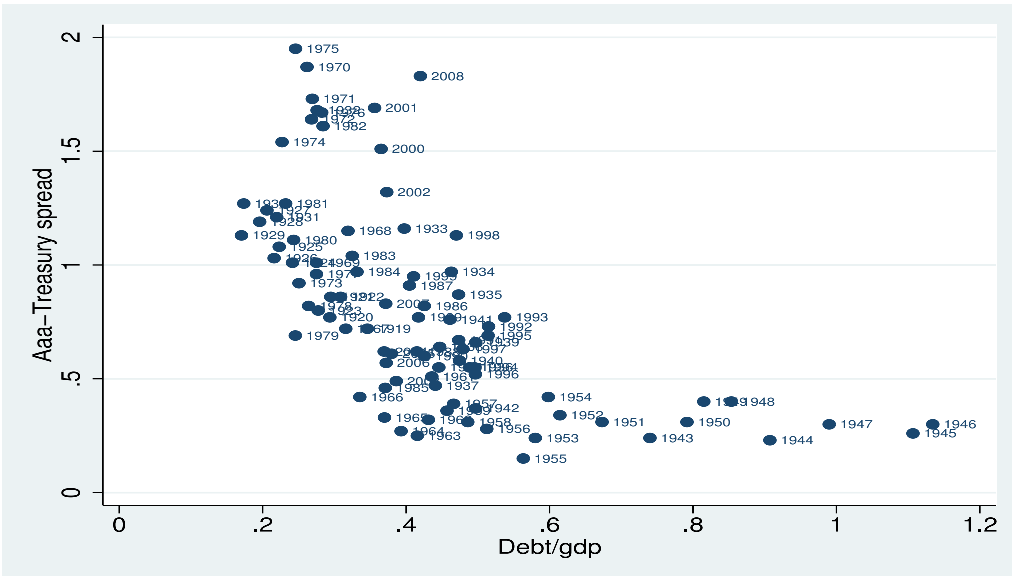
Table VI: Same data as Table I.

Table VII:

The data in this table are all from Flow of Funds Accounts of the United States and are end of year, from 1945-2008. Treasury holdings are from Table L. 209 and Table L. 107, holdings of agency- and GSE-backed securities are from Table L. 210 and L. 107, holdings of corporate bonds are from Table L. 212 (we denote these long-term corporate bonds in the table to distinguish them from commercial paper), and holdings of commercial paper are from Table L. 208 (we denote these short-term corporate bonds in the table).

Figure 1: Corporate Bond Spread and Government Debt

A. Scatter plot



B. Time series plot

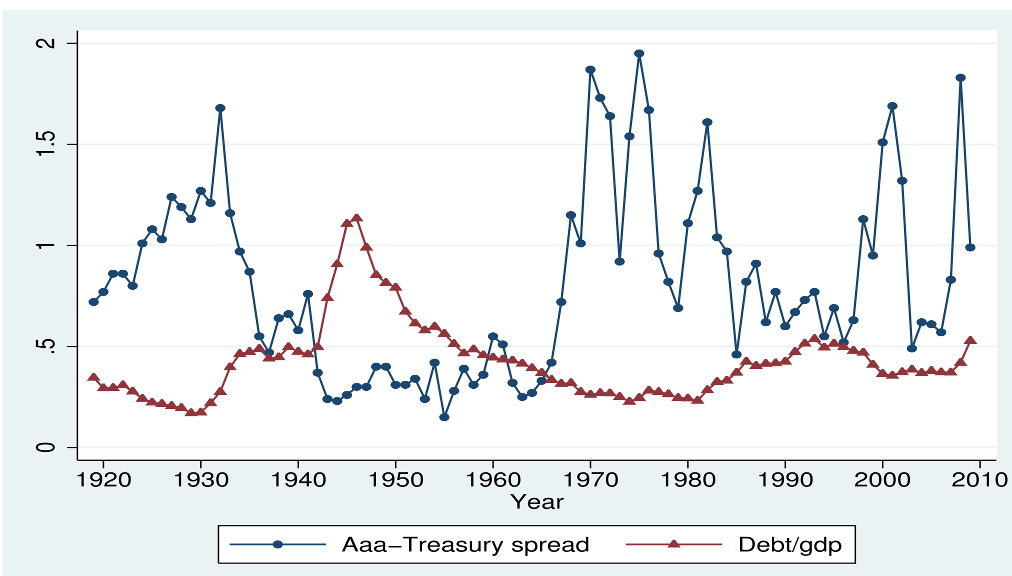
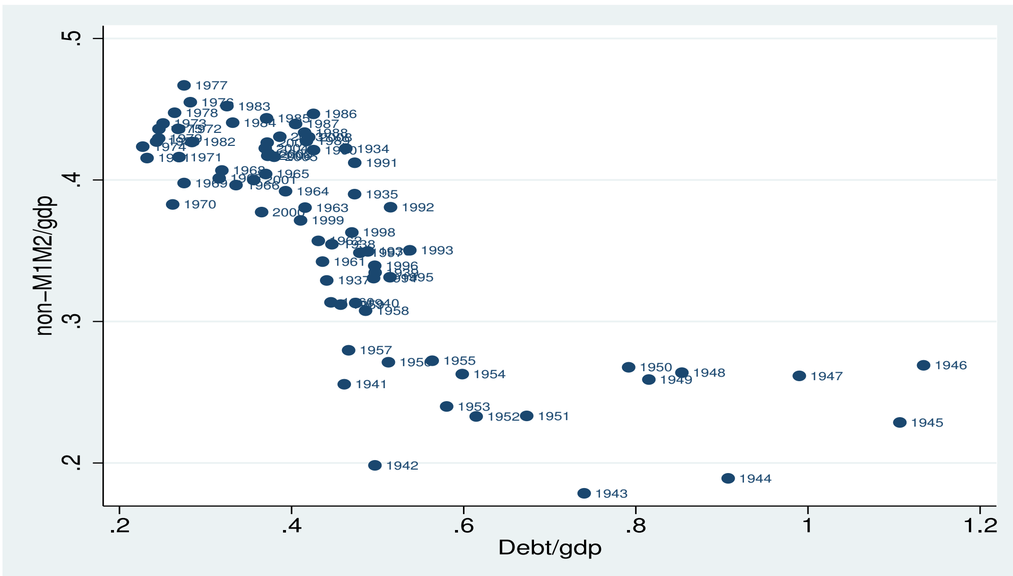


Figure 1A plots the Aaa-Treasury corporate bond spread (y-axis) against the Debt-to-GDP ratio (x-axis) while Figure 1B is a time-series graph of the same two time series. Both figures are based on annual observations from 1919 to 2008. The corporate bond spread is the difference between the percentage yield on Moody's *Aaa* long maturity bond index and the percentage yield on long maturity Treasury bonds.

Figure 2: Money and Government Debt

A. Scatter plot



B. Time series plot

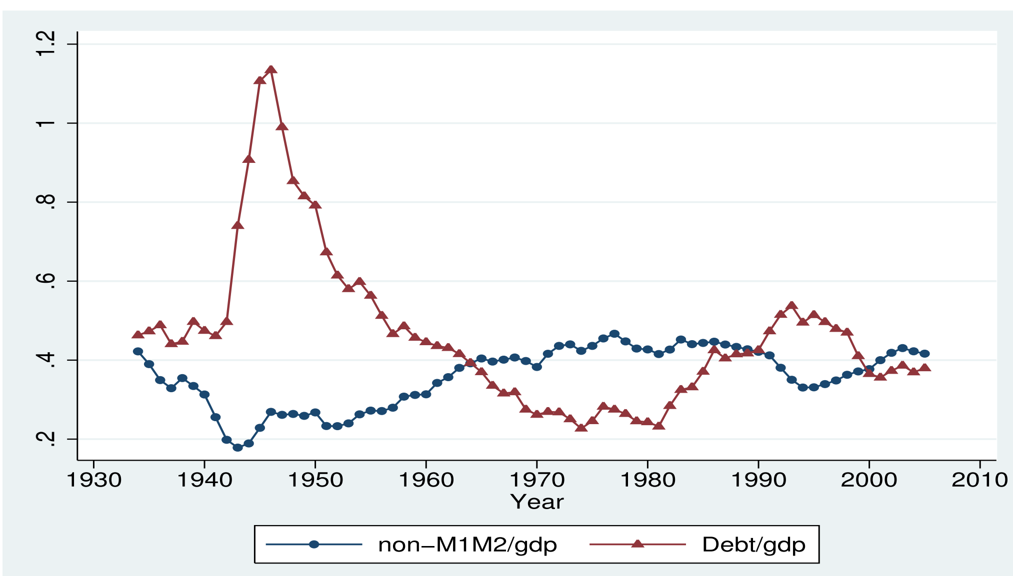


Figure 2A plots the quantity of small time and savings deposits, measured as M2 minus M1 minus Treasury holdings of retail money market funds divided by GDP, against the Debt-to-GDP ratio while Figure 2B is a time-series graph of the same two time series. Both figures are based on annual observations from 1934 to 2008.

Table I

Impact of Treasury Supply on Bond Spreads: Log Specification

The dependent variables are short and long-term yield spreads between corporate and Treasury bonds, both measured in percentage units. Independent variables are the log of the ratio of the market value of Treasury debt outstanding to US GDP, and controls for the default risk and risk premium on corporate bonds. EDF is the expected default frequency for corporate bonds. Volatility is the annualized standard deviation of weekly log stock returns on the S&P500 index. Slope is the slope of the Treasury yield curve measured as the spread between the 10-year Treasury yield and the 3-month Treasury yield. The data appendix provides the precise definitions of all variables. EDF, volatility, and slope controls are demeaned. Regressions are estimated by ordinary least squares. The standard errors are adjusted assuming errors are AR(1). We use the Box-Jenkins methodology for identifying the error structure. ρ denotes the first order autocorrelation of the error terms. t-statistics in brackets.

	Panel A: Aaa-Treasury			**Panel B: Baa-Treasury**		**Panel C: CP-Bills**			**Panel D: CPP2-Bills**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Period	1919-2008	1969-2007	1926-2008	1969-2007	1926-2008	1920-2008	1969-2007	1926-2008	1974-2007
$log(Debt/GDP)$	-0.744	-0.910	-0.797	-1.752	-1.304	-0.728	-1.006	-0.550	-1.919
	[-4.32]	[-3.35]	[-5.06]	[-5.98]	[-7.54]	[-4.37]	[-2.21]	[-3.52]	[-3.86]
EDF		0.953		1.206			0.024		0.086
		[3.57]		[3.71]			[0.05]		[0.16]
$Volatility$			1.294		6.364			1.947	
			[1.90]		[6.88]			[2.33]	
$Slope$		0.045	0.080	0.175	0.309		-0.123	-0.085	-0.105
		[1.05]	[1.86]	[2.04]	[4.64]		[-1.30]	[-1.42]	[-1.13]
$Intercept$	0.111	0.052	0.078	0.208	0.737	0.095	-0.269	0.229	-0.813
	[0.62]	[0.18]	[0.49]	[0.66]	[4.34]	[0.56]	[-0.55]	[1.49]	[-1.58]
R^2	0.447	0.623	0.568	0.669	0.690	0.224	0.211	0.259	0.282
ρ	0.572	0.402	0.528	0.066	0.012	0.183	-0.023	0.018	0.122
N	90	39	83	39	83	89	39	83	34

Table II

Impact of Treasury Supply on 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 Ibbotson, beginning in 1926 and ending in 2003. Controls include the annual percentage excess return on corporate junk bonds over corporate Baa-rated bonds (*CreditHedge*), the spread between the 10-year Treasury yield and the 3-month Treasury yield (*Slope*), and the excess return on long term government bonds over short term government bonds (*DurationHedge*). The data appendix provides the precise definitions of all variables. Regressions are estimated by ordinary least squares. The standard errors are adjusted assuming errors are ARMA(1,1). t-statistics in brackets.

	(1)	(2)	(3)
$log(Debt/GDP)$	-0.851	-1.696	-1.826
	[-1.29]	[-2.21]	[-1.83]
$CreditHedge$		0.160	0.121
		[2.89]	[2.22]
$Slope$			0.678
			[1.64]
$DurationHedge$			-0.117
			[-2.56]
$Intercept$	-0.301	-1.245	-1.127
	[-0.46]	[-1.60]	[-1.13]
R^2	0.009	0.100	0.162
N	78	78	78

Table III

Impact of Treasury Supply on the Price of Safety and the Price of Liquidity

The dependent variables are: The spread between Baa-rated corporate bonds and Aaa-rated bonds (column (1) and (2)), the spread between A2/P2-rated and A1/P1-rated commercial paper (column (3) and (4)), the spread between the interest rate on FDIC insured 6 month CDs and 6-month Treasury bills (column (5)), and the spread between the average interest rate paid by banks on time and savings deposits and 6-month Treasury bills (column (6)). Independent variables are the log of the ratio of the market value of Treasury debt outstanding to US GDP, the log of the ratio of the market value of Treasury debt with remaining maturity greater than 10 years to US GDP, the log of the ratio of the market value of Treasury debt with remaining maturity less than 1 year to US GDP, the annualized standard deviation of weekly log stock returns on the S&P500 index ($Volatility$), and the slope of the Treasury yield curve measured as the spread between the 10-year Treasury yield and the 3-month Treasury yield in column (1)-(4) and as the spread between the 10-year Treasury yield and the 6-month Treasury yield in column (5)-(6). The data appendix provides the precise definitions of all variables. Regressions are estimated by ordinary least squares or instrumental variables (2SLS), where we use instruments $Debt/GDP$, $(Debt/GDP)^2$, and $(Debt/GDP)^3$, as indicated. The standard errors are adjusted assuming errors are AR(1) or i.i.d. as indicated. We use the Box-Jenkins methodology for identifying the error structure. t-statistics in brackets.

	Panel A: Price of Safety				**Panel B: Price of Liquidity**	
	Assets with similar liquidity and different safety:				Assets with similar safety and different liquidity:	
	$S^{Baa-Aaa}$		S^{P2-P1}		$S^{FDIC\ insured\ CDs\text{-}Bills}$	$S^{Time\ \&\ Savings\ Accounts\text{-}Bills}$
	(1)	(2)	(3)	(4)	(5)	(6)
Period	1926-2008	1926-2008	1974-2007	1974-2007	1984-2008	1935-1965
$log(Debt/GDP)$	-0.506		-0.879		-1.904	-0.639
	[-3.42]		[-4.47]		[-1.83]	[-2.37]
log(Debt > 10 year mat/GDP), instr. by		-0.310				
(Debt/GDP), (Debt/GDP)^2, (Debt/GDP)^3		[-2.40]				
log(Debt ≤ 1 year mat/GDP) instr. by				-1.453		
(Debt/GDP), Debt/GDP)^2, (Debt/GDP)^3				[-2.94]		
$Volatility$	5.070	6.311	0.321	0.029		
	[6.53]	[6.66]	[0.38]	[0.03]		
Slope	0.229	0.209	0.014	0.054	0.137	1.013
	[4.15]	[3.24]	[0.40]	[1.14]	[1.32]	[8.48]
$Constant$	0.660	0.241	-0.500	-2.662	-1.500	-0.070
	[4.52]	[0.648]	[-2.45]	[-2.56]	[-1.63]	[-0.41]
N	83	83	34	34	25	31
R^2	0.600		0.486		0.271	0.720
Estimation method	OLS	IV	OLS	IV	OLS	OLS
Error term	AR(1)	AR(1)	AR(1)	AR(1)	i.i.d.	i.i.d.

Table IV

Demand Curve Estimate of Long-term Holders

The dependent variable is the spread between Baa bonds and Aaa bonds. The independent variables are the log of the ratio of the Treasury holdings of public and private pension funds and insurance companies to GDP ($log(Debt_{GROUP}/GDP)$), the annualized standard deviation of weekly log stock returns on the S&P500 index ($Volatility$), and the slope of the Treasury yield curve measured as the spread between the 10-year Treasury yield and the 6-month Treasury yield (*Slope*). The data appendix provides the precise definitions of all variables. The estimation is by instrumental variables (2SLS), where we use instruments $Debt/GDP$, $(Debt/GDP)^2$, and $(Debt/GDP)^3$. Standard errors are adjusted assuming an AR(2) error structure. t-statistics in brackets.

Period	$log(Debt_{GROUP}/GDP)$	$Volatility$	*Slope*	$Constant$	N
1945-2008	-0.372 [-1.95]	3.484 [2.56]	0.207 [3.35]	-0.266 [-0.44]	64

Table V

Response of Money to Treasury Supply, 1934-2008

Panel A presents reduced form regressions between measures of money and Treasury supply. The money measures include small time and savings deposits and non-Treasury retail money market fund holdings (non-M1 M2, minus retail money market fund Treasury holdings) and small and large time and savings deposits, non-Treasury retail and institutional money market fund holdings, repos and Eurodollars (non-M1 M3, minus retail and institutional money market fund Treasury holdings). Panel B presents structural instrumental variables estimates of the supply response of the banking system. In the first stage, the spread between Baa bond yields and the interest rate on non-M1 M2 is regressed on $log(Debt/GDP)$ and controls. In the second stage, $log(non-M1M2/GDP)$ is regressed on the fitted values of the spread and controls. The data appendix provides the precise definitions of all variables. The regressions in Panel B exclude the Regulation Q period of 1966-1983. Errors are adjusted assuming serial correlation of either AR(2) or AR(1), as indicated. We use the Box-Jenkins methodology to identify the error structure. t-statistics in brackets.

	Panel A: Reduced Form			**Panel B: Structural Form**			
	(1)	(2)	(3)		(4)		(5)
				1st Stage of IV		**2nd Stage of IV**	
Dep. Var.	non-M1 M2/GDP	non-M1 M2/GDP	non-M1 M3/GDP	$S^{Baa-(non-M1M2)}$		$log(non-M1M2/GDP)$	
Period	1926-2008	1959-2005	1959-2005		1935-1965, 1984-2008		1935-1965, 1984-2008
$Debt/GDP$	-0.305	-0.352	-0.553	$Log(Debt/gdp)$	-1.587	$S^{Baa-nonM1M2}$	0.394
	[-5.52]	[-4.16]	[-3.34]		[-2.10]		[2.29]
$Year$		0.001	0.007	$Volatility$	7.942	$Volatility$	-2.717
		[1.86]	[5.99]		[2.81]		[-1.47]
				$Slope$	0.440	$Slope$	-0.140
					[2.27]		[-1.37]
$Intercept$	0.502	-1.467	-12.161	$Intercept$	2.279	$Intercept$	-2.439
	[18.26]	[-1.38]	[-5.69]		[3.94]		[-4.13]
R^2	0.601	0.534	0.802				
N	75	47	47		56		56
Estimation method	OLS	OLS	OLS		OLS		IV
Standard errors	AR(2)	AR(2)	AR(2)		AR(1)		AR(1)

Table VI

Impact of Treasury Supply on Bond Spreads: Piecewise Linear Specification

This table estimates a piecewise linear specification for the relation between Treasury supply and bond spread. The function estimated is $b_0 + b_1 \times max[b_2 - Debt/GDP, 0]$. The dependent variables are long-term yield spreads between corporate and Treasury bonds, measured in percentage units. Independent variables are the log of the ratio of the market value of Treasury debt outstanding to US GDP, and controls for the default risk and risk premium on corporate bonds. Volatility is the annualized standard deviation of weekly log stock returns on the S&P500 index. Slope is the slope of the Treasury yield curve measured as the spread between the 10-year Treasury yield and the 3-month Treasury yield. The data appendix provides the precise definitions of all variables. Volatility and slope are demeaned. Regressions are estimated by non-linear least squares. The standard errors are adjusted assuming errors are AR(1). We use the Box-Jenkins methodology for identifying the error structure. t-statistics in brackets.

	Panel A: Aaa-Treasury		**Panel B: Baa-Treasury**	
	(1)	(2)	(3)	(4)
Period	1919-2008	1926-2008	1919-2008	1926-2008
b_0	0.319	0.346	1.019	1.199
	[1.80]	[2.51]	[1.94]	[7.29]
b_1	2.579	3.060	4.310	4.941
	[4.02]	[5.07]	[2.64]	[6.75]
b_2	0.585	0.549	0.625	0.545
	[6.96]	[9.56]	[4.22]	[12.92]
$Volatility$		1.189		6.236
		[1.90]		[7.05]
$Slope$		0.095		0.330
		[2.38]		[5.03]
R^2	0.477	0.612	0.290	0.704
N	90	83	90	83

Table VII

Debt Holdings, by Group

Panel A of this table presents statistics on the fraction of Treasury securities held by various groups. Panel B presents the bond portfolio composition of each of the groups, broken down into Treasury, Agency, and short and long-term corporate bonds. The data are from the Flow of Funds Accounts of the Federal Reserve, and are annual (end of year) from 1945 to 2008. Mutual funds include closed-end funds and exchange traded funds.

Group	**Panel A: Who Holds Treasury Debt?**				
	Mean	Std. Dev.	1945	1975	2008
Federal Reserve Banks	0.138	0.040	0.097	0.199	0.075
Foreign Official Holdings	0.113	0.088	0.010	0.141	0.367
State/Local Governments	0.088	0.042	0.022	0.064	0.076
Banks/Credit Institutions	0.201	0.116	0.416	0.222	0.017
Households and Mutual Funds	0.260	0.051	0.265	0.263	0.169
Foreign Private Sector	0.042	0.049	0.000	0.010	0.140
Fedrl/State/Local Govt. Ret.	0.035	0.022	0.006	0.006	0.045
Private Pensions	0.028	0.020	0.008	0.029	0.029
Insurance Companies	0.048	0.023	0.093	0.022	0.025

	Panel B: Bond Market Portfolio Composition			
	Treasury	Agency	Long-term Corporate	Short-term Corporate
Federal Reserve Banks	0.983	0.017	0.000	0.001
Foreign Official Holdings	0.948	0.052	0.000	0.000
State/Local Governments	0.720	0.217	0.029	0.034
Banks/Credit Institutions	0.526	0.312	0.141	0.020
Households and Mutual Funds	0.563	0.095	0.223	0.118
Foreign Private Sector	0.240	0.084	0.479	0.197
Fedrl/State/Local Govt. Ret.	0.387	0.108	0.487	0.018
Private Pensions	0.233	0.142	0.583	0.042
Insurance Companies	0.172	0.078	0.726	0.024