Liquidity and Financial Intermediation

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Abstract

In this paper, we examine how liquidity premia are affected by the supplies of various types of assets. Specifically, we examine how the supply of government debt affects the real interest rate and the liquidity premium in the economy. More importantly, we examine how the financial sector satisfies the demand for liquidity by transforming illiquid assets into liquid assets, and thereby how the private supply of liquid assets is affected by the supply of government debt. We also show that a rise in uncertainty (i.e., risk premia) hampers the ability of financial institutions to provide liquid assets, and hence may lead to a contraction in the supply of liquid assets in addition to a rise in the liquidity premium. Hence, this paper establishes a close connection between risk premia and liquidity premia. This feature arises naturally out of our model, and as well seems to be a reasonable characterization of current events. The end result is a general equilibrium model that endogenizes the supply of liquid assets and their rate of return. Using quarterly U.S. data from 1950 to 2008, we show that central predictions of the model find strong support in the data.

1 Introduction

Tobin (1963) and Friedman (1969) introduced the idea that short-term nominally riskless securities may provide liquidity services to an economy. This paper develops a model that highlights the special role of such assets in providing liquidity, and endogenizes the supply of these assets by financial intermediaries. In addition to the government supplying bonds that increase the supply of liquid assets in the economy, the financial sector satisfies the demand for liquidity by transforming illiquid private assets into liquid assets. Liquidity premia are affected by the supplies of both types of liquid assets. The end result is a general equilibrium model that endogenizes the supply of liquid assets by the private financial sector and their rate of return. The central question studied in this paper is if such a setup can generate episodes in which concerns of the private sector lead to a simultaneous contraction in the supply of liquid assets and a rise in their yield. We find that the economic channels highlighted in the paper can indeed generate such episodes, which provides a formal setting in which to examine episodes that exhibit the characteristics of a liquidity crises.

This paper builds on the work of Bansal and Coleman (1996), who develop a model that highlights the special role of some assets in providing liquidity. Bansal-Coleman examine the implications of a demand for liquidity in explaining the equity premium and the term premium in government bonds. Their model captures the idea that financial intermediaries face infinite penalties for failing to fulfill their liabilities to depositors. To avoid these penalties, intermediaries back their deposit-liabilities with nominal short term treasury bills; in equilibrium, Treasury-bills provide a non-pecuniary liquidity service that affects their market price and lowers real yields. In this paper, we develop a model in which financial intermediaries (and other private sector entities) can compete with the government to provide highly rated short term securities. Private issuers of these securities earn the liquidity premium and hence have an incentive to issue these securities. The quantity of this issuance, we show, is influenced by the availability of government alternatives and the magnitude of aggregate risks.

To briefly describe the model, we develop a set-up in which households can purchase equity, government debt, and privately-supplied liquid assets (let's call that bank debt). Both government and private debt provide liquidity services, although they are imperfect substitutes. Financial intermediaries issue debt and use the proceeds to purchase equity. In this sense, financial intermediaries transform illiquid assets into liquid assets, although they clearly expose themselves to insolvency in performing such a task. The reward to a financial intermediation is the ability to exploit the liquidity premium by selling liquid assets and purchasing illiquid assets. The cost, as mentioned, is the risk of insolvency. The greater the uncertainty in the economy, the less willing banks are to create liquid assets. In equilibrium, the benefit of liquidity is balanced against the cost of bankruptcy.

The model leads to the following three predictions. (1) A higher supply of government debt leads to a rise in the risk free rate. Essentially, a higher supply of government debt leads to a lower liquidity premium on government debt, which tends to raise its pecuniary return (i.e., the real risk free rate). (2) A higher supply of government debt leads to a lower supply of private debt. The role of financial intermediaries is to produce liquidity. They do this by purchasing illiquid assets and issuing more liquid liabilities. The liquid liabilities of financial intermediaries competes with government debt in providing liquidity. A rise in government debt thus leads to a fall in private debt. (3) A rise in uncertainty leads to a fall in liquidity. A potential cost to financial intermediaries in providing liquidity is the risk they are exposed to by the consequent maturity and risk mismatch between their assets and liabilities. A rise in this uncertainty thus leads to a rise in the cost of providing liquidity, which leads financial intermediaries to providing fewer liquid assets. If one associates such a fall in liquid assets as a liquidity crunch, this is a model in which a rise in uncertainty leads to a liquidity crunch.

Using U.S. time series on the supply of government debt and short-term liquid assets produced by the private sector, as well as their corresponding rates of return, we test many of the predictions of the model, including those just mentioned. We find empirical support for all the key predictions of the model: a rise in government debt leads to a rise in the real return to government debt, a rise in government debt leads to a fall in the supply of private debt, and a rise in uncertainty leads to a fall in the supply of private debt. Using unconditional correlations and Vector Auto-regressions (VAR), we document that these findings are quite robust in the data for the extended sample from 1950 to 2008. Some of these empirical dimensions are also featured in earlier research. Krishnamurthy and Vissing-Jorgensen (2008) document a negative correlation between the supply of government debt and the AAA - Treasury spread. Greenwood, Hanson, and Stein (2008) document a negative dependence between the supply of government and private debt across the maturity spectrum as the private sector responds to shifts in the supply of government debt at various maturities.

The model also provides clear insights regarding the recent financial crisis. In Figure 1, we present several key quantities of interest leading up to and including the financial crisis, spanning the first quarter of 2006 to the first quarter of 2009. This period is characterized by a sharp increase in short-term Treasury debt and GDP volatility (a measure of aggregate risk). Consistent with the model's implications, private debt sharply falls during this period; for example, the correlation between short-term government debt and commercial paper is -0.82. The inflation-indexed TIPS (real) yield increases. In sum, the fluctuations observed throughout this period, interpreted as a liquidity crunch, can be accounted for as endogenous outcomes dictated by elevated levels of economic uncertainty and a rise in short-term government debt. That is, the private sector optimally lowered its issuance of short-term highly rated debt in response to higher levels of aggregate risk and a greater supply of liquid assets from the government.

Section 2 presents the model and several examples. In section 3, we discuss the data employed in our empirical exercise. Section 4 presents the VAR methodology and key results. Finally, section 5 concludes.

2 The Model

Consider an endowment economy with households, firms, and financial intermediaries. Households purchase equity, government debt, and privately-supplied liquid assets. Both government and bank debt provide liquidity services, although they are imperfect substitutes. Firms issue equity, which is purchased by households and financial intermediaries. Financial intermediaries issue bank debt and use the proceeds to purchase equity. In this sense financial intermediaries transform illiquid assets into liquid assets, although they clearly expose themselves to insolvency in performing such a task. The reward to a financial intermediary is the ability to exploit the liquidity premium by selling liquid assets and purchasing illiquid assets. The cost, as mentioned, is the risk of insolvency. The greater the uncertainty in the economy, the less willing banks are to create liquid assets. In equilibrium the benefit of liquidity is balanced against the cost of bankruptcy.

Firms in this economy have a very simple decision. They simply receive an endowment y and pay this out as a dividend to their equity holders. They take no other action. The government also performs in a very simple way. Each period they must borrow an amount g by issuing government debt. Any proceeds the government receives is lump-sum rebated back to households. The exogenous state variables in this economy consist of $s = (y, g)$, which is assumed to follow a first-order Markov process.

Households solve the following problem. Households begin a period with holdings of government bonds b, bank debt d, and equity z_h. At the beginning of the period they receive dividends proportional to their equity holdings, they receive the payout on government bonds, they receive a random payout x per unit of bank debt that depends on the ability of banks to fulfill their debt obligations, and as owners of the banks they receive any bank profits Ω. They also receive a lump-sum payout T by the government, which in equilibrium is equal to any funds raised through the issuance of debt. During the period they purchase consumption goods c, and choose new holdings of government bonds b' at price q_b, new bank debt d' at price q_d, and new equity z_h' at price p_z. Purchasing consumption goods incurs a transaction cost $\varphi(c, q_b b', q_d d')$ that depends on consumption, holdings of government debt, and holdings of bank debt. Assume that φ is homogenous of degree one in all three inputs, $\varphi > 0$, $\varphi_1 > 0$, $\varphi_2 < 0$, and that $\varphi_3 < 0$. Households make decisions to maximize expected utility over an infinite horizon, which is comprised of a period utility denoted by $u(c)$ and a constant discount factor β:

$$E\Sigma_{t=0}^{\infty}\beta^t u(c_t). \tag{1}$$

Let V denote the value of household's utility at the optimal program. The dynamic programming formulation of the household's problem can be written as:

$$V(b, d, z_h, y) = max\left\{u(c) + \beta E_s\left[V\left(b', d', z_h', y'\right)\right]\right\} \tag{2}$$

subject to:

$$c + \varphi\left(c, q_b b', q_d d'\right) + q_b b' + q_d d' + p_z(z_h' - z_h) \leq y z_h + b + xd + \Omega + T, \tag{3}$$

where max is with respect to $\{c, b', d', z_h'\}$. The equilibrium conditions, using λ as the multiplier for the flow budget constraint eq. (3), are:

$$\begin{aligned} c + \varphi &= y && (4)\\ u'(c) &= \lambda(1 + \varphi_1) && (5)\\ \lambda q_b(1 + \varphi_2) &= \beta E_s[\lambda'] && (6)\\ \lambda q_d(1 + \varphi_3) &= \beta E_s[\lambda' x'] && (7)\\ \lambda p_z &= \beta E_s[\lambda'(p_z' + y')] && (8) \end{aligned}$$

Note that in equilibrium $q_b b' = g$.

Financial intermediaries issue debt in the amount of $q_d d'$ and purchase equity in the amount of $p_z z_b' = q_d d'$. The debt incurs a promise to pay d' in the next period. In the event that the financial intermediary is unable make full payment, it pays out all remaining revenue to the debt holders. The financial intermediary incurs a cost $\gamma p_z z_b'$ for providing its services. The financial intermediary also incurs a bankruptcy cost $p_z \xi z_b'$ that is proportional to its size. It is assumed that the bankruptcy cost is borne directly by the owners/managers of the bank. Profits next period are equal to:

$$\Omega' = (p_z' + y')z_b' - x'd' - \gamma p_z z_b' - \tilde{\xi} p_z z_b'. \tag{9}$$

Given that $p_z z_b' = q_d d'$ it follows that

$$x' = \min\{1, (p_z' + y' - \gamma p_z)q_d/p_z\}. \tag{10}$$

and

$$\tilde{\xi} = \begin{cases} 0 & \text{if } (p_z' + y' - \gamma p_z)q_d/p_z \geq 1 \\ \xi & \text{if } (p_z' + y' - \gamma p_z)q_d/p_z < 1 \end{cases} \tag{11}$$

Note that the gross return on the financial intermediary's investment is equal to $(p_z' + y' - \gamma p_z)/p_z$. The financial intermediary is solvent if this gross return exceeds to gross payout on deposits, which equals $1/q_d$. If this occurs, then $x' = 1$ (all depositors are paid in full) and $\tilde{\xi} = 0$ (no bankruptcy). Otherwise, depositors only receive a fraction of their promised return and owners/managers incur a bankruptcy cost $\tilde{\xi} = \xi$. Note that the probability of default by a financial intermediary does not depend on its size. Given these relations, it follows that profits are given by

$$\Omega' = \begin{cases} (p_z' + y' - p_z/q_d - \gamma p_z)z_b' & \text{if } (p_z' + y' - \gamma p_z)q_d/p_z \geq 1 \\ -\xi p_z z_b' & \text{if } (p_z' + y' - \gamma p_z)q_d/p_z < 1 \end{cases} \tag{12}$$

The equilibrium condition is a zero profit condition: financial intermediaries purchase equity (which does not provide liquidity services) and issue bank debt (which provides liquidity services) up until expected discounted profits equals zero. Define $\omega' = \Omega'/z_b'$ and note that ω'/p_z equals profit per unit of deposits. The zero profit condition can be written as

$$\beta E\left[\frac{u'(c')/(1+\varphi_1')}{u'(c)/(1+\varphi_1)}\frac{\omega'}{p_z}\right] = 0. \tag{13}$$

As financial intermediaries issue more and more debt, the spread between the expected return on their liquid liabilities and their assets falls. This spread cannot fall too far, though, as this is the mechanism by which financial intermediaries are compensated for the risk they absorb. In equilibrium $z_h + z_b = 1$, and bank debt d', or equivalently z_b', is determined to satisfy the bank zero expected profit condition.

Formally, the equilibrium consists of functions $c(s), \lambda(s), q_b(s), q_d(s), p_z(s), z_b'(s)$ that satisfy equations (4)-(8) and (**??**). In lieu of attempting to derive qualitative results for the stochastic model, the approach we take here is to first derive various qualitative results for the deterministic model, and then rely on simulations of a calibrated version of the stochastic model to establish some quantitative results.

2.1 Stationary growth rate with CRRA utility

Consider the model with stationary growth rates in y with constant relative risk aversion (CRRA) utility. Suppose utility is parameterized as:

$$u(c) = \frac{c^{1-\tau}}{1-\tau} \tag{14}$$

Define the following variables:

$$\begin{aligned}
\hat{c} &= c/y, &(15)\\
\hat{b}' &= b'/y, &(16)\\
\hat{d}' &= d'/y, &(17)\\
\hat{g} &= g/y, &(18)\\
\hat{p}_z &= p_z/y, &(19)\\
\hat{\omega} &= \omega/y, &(20)\\
\hat{y}' &= y'/y. &(21)
\end{aligned}$$

Suppose the exogenous variables $\hat{s} = (\hat{y}, \hat{g})$ follow a first-order Markov process. For ease of notation, define

$$\hat{\varphi} = \varphi(\hat{c}, q_b\hat{b}', q_d\hat{d}'),$$

and

$$\hat{\varphi}_i = \varphi_i(\hat{c}, q_b\hat{b}', q_d\hat{d}').$$

It can easily be shown that the transformed variables must satisfy the following equilibrium conditions:

$$\begin{aligned}
\hat{c} + \hat{\varphi} &= 1 &(22)\\
q_b(1+\hat{\varphi}_2) &= \beta E_s\left[\left(\frac{\hat{c}'}{\hat{c}}\hat{y}'\right)^{-\tau}\frac{1+\hat{\varphi}_1}{1+\hat{\varphi}_1'}\right] &(23)
\end{aligned}$$

$$
\begin{aligned}
q_d(1+\hat{\varphi}_3) &= \beta E_s\left[\left(\frac{\hat{c}'}{\hat{c}}\hat{y}'\right)^{-\tau}\frac{1+\hat{\varphi}_1}{1+\hat{\varphi}_1'}x'\right] && (24)\\
\hat{p}_z &= \beta E_s\left[\left(\frac{\hat{c}'}{\hat{c}}\hat{y}'\right)^{-\tau}\frac{1+\hat{\varphi}_1}{1+\hat{\varphi}_1'}(\hat{p}_z'+1)(\hat{y}')\right] && (25)\\
x' &= \min\left\{1,\left(\frac{\hat{p}_z'+1}{\hat{p}_z}\hat{y}'-\gamma\right)q_d\right\} && (26)\\
\frac{\hat{\omega}'}{\hat{p}_z} &= \begin{cases}\left(\frac{\hat{p}_z'+1}{\hat{p}_z}\hat{y}'-\frac{1}{q_d}-\gamma\right) & \text{if } \left(\frac{\hat{p}_z'+1}{\hat{p}_z}\hat{y}'-\gamma\right)q_d\geq 1\\ -\xi & \text{if } \left(\frac{\hat{p}_z'+1}{\hat{p}_z}\hat{y}'-\gamma\right)q_d< 1\end{cases} && (27)\\
0 &= \beta E_s\left[\left(\frac{\hat{c}'}{\hat{c}}\hat{y}'\right)^{-\tau}\frac{1+\hat{\varphi}_1}{1+\hat{\varphi}_1'}\frac{\omega'}{\hat{p}_z}\right] && (28)\\
& && (29)
\end{aligned}
$$

2.2 A Deterministic Example

Consider the behavior of this model in the absence of uncertainty, constant $(\hat{y},\hat{g})$, and with a Cobb-Douglas transaction cost function:

$$\varphi(c,q_b b',q_d d')=\bar{\varphi}c^{\alpha_1}(q_b b')^{\alpha_2}(q_d d')^{\alpha_3}, \tag{30}$$

with $\bar{\varphi}>0$, $\alpha_1+\alpha_2+\alpha_3=1$, $\alpha_1>1$, $\alpha_2<0$, and $\alpha_3<0$. The absence of uncertainty leads to the following equilibrium conditions:

$$
\begin{aligned}
\hat{c}+\hat{\varphi} &= 1 && (31)\\
q_b(1+\hat{\varphi}_2) &= \beta\hat{y}^{-\tau} && (32)\\
q_d(1+\hat{\varphi}_3) &= \beta\hat{y}^{-\tau} && (33)\\
\hat{p}_z &= \beta\hat{y}^{1-\tau}(\hat{p}_z+1) && (34)\\
0 &= \beta\hat{y}^{-\tau}\left(\frac{\hat{p}_z+1}{\hat{p}_z}\hat{y}-\frac{1}{q_d}-\gamma\right) && (35)
\end{aligned}
$$

Eq. (34) can be used to solve for $\hat{p}_z$ as

$$\hat{p}_z=\frac{\beta\hat{y}^{1-\tau}}{1-\beta\hat{y}^{1-\tau}}. \tag{36}$$

Eqs. (35) and (36) can be used to solve for q_d as

$$q_d=\frac{\beta\hat{y}^{-\tau}}{1-\beta\hat{y}^{-\tau}\gamma}. \tag{37}$$

Combining eqs. (33) and (37), write

$$\hat{\varphi}_3 = -\beta \hat{y}^{-\tau} \gamma. \tag{38}$$

Eq. (38) can be used to solve for $q_d \hat{d}'/\hat{c}$ as a function of $q_b \hat{b}'/\hat{c}$. Indeed, using the Cobb-Douglas form of the transaction cost function, this relation is given by

$$\frac{q_d \hat{d}'}{\hat{c}} = \left(\frac{-\beta \hat{y}^{-\tau} \gamma}{\alpha_3 \bar{\varphi}} \right)^{\frac{1}{\alpha_3 - 1}} \left(\frac{q_b \hat{b}'}{\hat{c}} \right)^{\frac{-\alpha_2}{\alpha_3 - 1}}. \tag{39}$$

Here we can see that a rise in $q_b \hat{b}'/c$ leads to a fall in $q_d \hat{d}'/\hat{c}$. That is, a rise in government debt as a fraction of consumption leads to a fall in private debt as a fraction of consumption. Essentially, a rise in government debt reduces the transaction-service return of private debt, which is thus met by a reduction in the amount of private debt.

Re-write eq. (31) as

$$\hat{c} \left(1 + \varphi \left(1, \frac{q_b \hat{b}'}{\hat{c}}, \frac{q_d \hat{d}'}{\hat{c}} \right) \right) = 1. \tag{40}$$

Use eq. (39), and the functional form of φ, to write this as

$$\hat{c} \left(1 + \bar{\varphi} \left(\frac{-\beta \hat{y}^{-\tau} \gamma}{\alpha_3 \bar{\varphi}} \right)^{\frac{\alpha_3}{\alpha_3 - 1}} \left(\frac{q_b \hat{b}'}{\hat{c}} \right)^{\frac{-\alpha_2}{\alpha_3 - 1}} \right) = 1. \tag{41}$$

Note that the left side of this equation is a strictly-increasing function of $\hat{c}$, and that there exists a solution $\hat{c}$ such that $0 < c < 1$. Given $\hat{y}$ and $q_b \hat{b}' = \hat{g}$, eq. (41) thus determines $\hat{c}$. With $\hat{c}$ determined, $q_d \hat{d}'$ is determined by eq. (39) (which determines $\hat{d}'$, as q_d is already determined). Using results already obtained, q_b can be written as

$$q_b = \frac{\beta \hat{y}^{-\tau}}{1 + \alpha_2 \bar{\varphi} \left(\frac{-\beta \hat{y}^{-\tau} \gamma}{\alpha_3 \bar{\varphi}} \right)^{\frac{\alpha_3}{\alpha_3 - 1}} \left(\frac{q_b \hat{b}'}{\hat{c}} \right)^{\frac{\alpha_1}{\alpha_3 - 1}}}. \tag{42}$$

These results determine the entire equilibrium.

Let's now derive some qualitative results. First, note that a rise in $q_b \hat{b}'$ leads to a rise in $q_b \hat{b}'/\hat{c}$: if not, then the left side of eq. (41) will exceed 1 following the rise in $q_b \hat{b}'$, which is a contradiction. Also, as already mentioned, a rise in $q_b \hat{b}'/\hat{c}$ leads to a fall in $q_d \hat{d}'/\hat{c}$. Hence, a rise in government debt will lead to a rise in government debt relative to GDP and a fall in bank debt relative to GDP. Note that a rise in $q_b \hat{b}'/\hat{c}$ will not affect q_d, as q_d is given by the zero profit condition for banks, which is unaffected by $q_b\hat{b}'/\hat{c}$. However, a rise in $q_b\hat{b}'/\hat{c}$ will affect q_b. Per above, a rise in $q_b\hat{b}'$ leads to a fall in q_b. Essentially, a rise in government debt reduces the transaction-service return to government debt, hence leading to a rise in the pecuniary return to government debt. Consequently, a rise in $q_b\hat{b}'$ leads to a fall in the spread between interest rates on d' and b'. To summarize, a rise in government debt will lead to: (1) a fall in bank debt relative to GDP, (2) a rise in the yield in government debt, and (3) and fall in the spread between the yield on bank debt and government debt.

2.3 Computing the Equilibrium

To solve this model, the following functional forms were chosen. Utility is chosen to be CRRA:

$$u(c) = \frac{c^{1-\tau}}{1-\tau}. \tag{43}$$

The transaction cost function is chosen to be:

$$\varphi(c, q_b b', q_d d') = \bar{\varphi} c^{\alpha_1} (q_b b')^{\alpha_2} (q_d d')^{\alpha_3}. \tag{44}$$

Also, the stochastic process for $\hat{y}$ and $\hat{g}$ is assumed to follow a vector autoregressive process:

$$\begin{pmatrix} \hat{y}' \\ \hat{g}' \end{pmatrix} = \Pi \begin{pmatrix} \hat{y} \\ \hat{g} \end{pmatrix} + \Gamma_u \begin{pmatrix} \epsilon_y \\ \epsilon_g \end{pmatrix}, \tag{45}$$

where Γ_u is lower triangular and (ϵ_y, ϵ_g) are independent and normally distributed random variables with mean 0 and variance 1. To allow an exploration of the role for economic uncertainty in the model, the VAR variance-covariance matrix is allowed to shift between periods of low and high growth uncertainty, designated as u_{low} and u_{high}, respectively. The transition between the states of uncertainty is governed by a two-state Markov transition matrix Π_u.

First, the VAR stochastic processes for $\hat{y}$ and $\hat{g}$ are estimated based on the observed data (summary statistics are presented in Table 1 and will be discussed in more detail in the next section). To keep things simple, we estimate a GARCH process for conditional GDP growth volatility and characterize periods as low (high) level of uncertainty when conditional volatility is below (above) the median GDP growth volatility across the entire sample. Hence, the VAR process incorporates a variance-covariance matrix, Γ_u that reflects either low or high GDP growth volatility (uncertainty) through a simple shift. To evaluate the expectations in the model based on this VAR process with volatility shifts, we employ quadrature techniques following Tauchen and Hussey (1991) to characterize the dynamic process. We employ 5 nodes for each of our two exogenous variables, GDP growth and the ratio of government debt to GDP, and an additional two nodes for the volatility shifts. This leaves a 50 total nodes for the economy ($5x5x2$), and a transition matrix that reflects the estimated VAR process.

To solve this model, we will use a policy-function iteration technique as described in Coleman (1990, 1991). Essentially, the technique exploits the recursive structure of the problem to specify a mapping from policy functions to policy functions whose fixed points correspond to equilibria. The algorithm simply iterates on this mapping, beginning from some initial guess, until convergence is obtained. In practice, this procedure seems quite robust in converging to a solution.

The values of all unknown parameters are reported in Table 2. Log utility ($\tau = 1$) is assumed, as this is frequently a benchmark choice for many calibration studies. Similarly, $\beta = .95$ is a value often chosen in the calibration literature. The values of φ, α_1, α_2, α_3 are chosen to roughly achieve simulated averages of transactions costs relative to GDP of 3 percent, a return on short-term government debt of 2 percent, a yield spread between short-term private and government debt of 1 percent, and a short-term private debt to GDP ratio of about 20 percent. All but the transactions cost estimate is based on the post-war U.S. data. The transactions costs are broadly in line with Marshall (1992) and Bansal and Coleman (1996). γ is chosen to equal 2. Last, ξ is chosen to reflect a 5% bankruptcy cost; this is a relatively conservative estimate based on evidence presented in Altman (1984) and Weiss (1990).

Given the above parameter values, key summary statistics based on simulations from the solution to the model are provided in Table 3. Several features are worth mentioning. First, the upper panel provides means and standard deviations of the variables of interest. The first two variables, quarterly GDP growth and the ratio of government debt to GDP are exogenous; their means and standard deviation largely match the figures provided in Table 1. It is important to note, however, that all other variables in the simulation are endogenously determined. We focus on five variables of interest: the ratio of private debt to GDP, the yield on government debt, the yield on private debt, the spread between the two, and the transaction cost. The average level of private debt to GDP, the government and private yields, and the yield spread are largely in line with the observed data. Finally, the average transaction cost is 2.25% in the model.

We also report several key correlations among the variables of interest. The correlation between GDP growth and government debt, as in the observed data, is negligible. Second, the correlation between government and private debt is negative. This correlation inside the model reflects a substitution effect; as the government issues more or less debt, the private sector responds. Next, the correlation between the supply of government debt and the real yield on government debt is positive. This is due to the fact that inside the model an increase in the supply of government debt lowers the liquidity premium on government debt and leads to a higher pecuniary return (yield). The correlation between the supply of government debt and the yield on private debt is also positive in the model as an increase in government debt also lowers the liquidity premium on private debt. That said, the correlation between the supply of government debt and the yield *spread* between private and government debt is highly negative, suggesting the direct effect on the government debt yield dominates. The correlation between the supply of private debt and the private debt yield is also positive and mirrors the logic for government debt as an increase in the supply of private debt reduces its own liquidity premium. Also, the correlation between the yields on private and government debt are positively correlated. This stems from the fact that their response to changes in the supply of debt are shared. A final notable feature of the simulations concerns the response of the supply of private debt to a rise in uncertainty. The correlation between the two is large and negative. A change in levels of economic uncertainty engenders and opposite reaction in the supply of private debt. Elevated levels of uncertainty in the model makes it more costly for banks to provide liquidity services, generating incentives for banks to reduce the supply. In the next section, we turn to an exploration of the extent to which the model's predictions are largely confirmed by the observed data.

3 Data Description

In Figure 1 discussed in the introduction, we present the patterns in government and private debt quantities and relative prices leading up to and throughout the recent financial crisis. Our theory provides one possible explanation for these patterns; however, we turn to an exploration of the broader relations shared among these variables using post-war data spanning the first quarter of 1950 to the first quarter of 2009. In our formal VAR estimation, we focus on the dynamic process jointly governing variation in debt quantities and prices (yields). To measure the variation of government and private debt quantities through time, we construct ratios of these amounts relative to GDP. Real U.S. GDP is obtained from the National Income and Product Accounts at the Bureau of Economic Analysis, and we include the growth rate in real GDP as a control variable in all our regressions.[1]

First, we measure the amount of government debt (relative to GDP). For our main measure of government debt, we focus on those bills, notes, or bonds that have less than 2-years maturity plus a measure of the monetary base (high powered money) that largely reflects the liabilities of the Federal Reserve. First, we measure the value of short-term U.S. government bonds from the CRSP bond database. Second, the monetary base, obtained from the Federal Reserve's Table H.3, consists of deposits held at the Federal Reserve by depository financial institutions, plus all coin and currency held by households and businesses. For robustness, we also consider an alternative measure of government debt as the overall level of U.S. Treasury debt (of any maturity) scaled by GDP by including all bonds covered in CRSP.

We measure short-term private sector debt (relative to GDP) from the Federal Reserve's *Flow of Funds* accounts, which tracks financial flows throughout the U.S. economy. We define short-term private debt as the sum of quarterly observations on open market paper (Table F.208). Open market paper includes commercial paper and bankers acceptances associated with both the domestic financial and non-farm, nonfinancial corporate sectors. These represent relatively high-rated, marketable securities.

For prices (yields), we consider several alternatives. First, we measure real Treasury bill rates as well as several relevant yield spreads. In the financial crisis period discussed above, we measure the TIPS yield directly. For the post-war sample, the real Treasury bill rate is computed as the 3-month Treasury bill rate, obtained from the Federal Reserve's release on interest rates (H.15), less a measure of expected inflation.[2] To measure expected inflation, we use the year-on-year percentage change in the GDP deflator, lagged one quarter to ensure that the information is known. To explore robustness to the measurement of the real yield, we also consider several alternative measures in the price dimension. In particular, we include the yield spread between AAA rated bonds and Treasury bonds of similar maturity. Employing the spread allows us to avoid the measurement of expected

[1]Our private and government debt measures are based on accounting values (market values at issuance) rather than current market values. Given that we focus largely on short-term private and government issuance, this is not likely a significant issue. Further, Hall (2001) constructs a market value series from the Flow of Funds accounts for a subset of these data. Using his data where available, constructed debt to GDP ratios, where debt is measured either as the accounting or market value, are very highly correlated.

[2]We compute the real Treasury bill rate as $\frac{(1+r_f)}{(1+\pi)} - 1$, where r_f is the nominal 3-month Treasury bill rate and π is our simple measure of expected inflation.

inflation. Krishnamurthy and Vissing-Jorgensen (2008) also employ the AAA - Treasury spread. In unreported results, we also consider the yield spread between BAA rated bonds and Treasury bonds of similar maturity and commercial paper and Treasury bills of similar maturity; the evidence is very similar. All necessary data items for the construction of these yield spreads are obtained from the Federal Reserve's release on interest rates (H.15).

Finally, we construct measures macroeconomic volatility and risk compensation to explore the relationships among these various quantities, prices, and levels of economic uncertainty. First, we compute conditional GDP growth volatility based on a GARCH process for the real quarterly GDP growth rate. Second, we also construct an estimated measure of the equity market risk premium. More precisely, the expected market risk premium is the fitted process implied by the following standard return predictability regression:

$$Ret_{mkt,t+1} = \alpha_0 + \alpha_1 \text{MktDividendYield}_t + \alpha_2 \text{TermSpread}_t + \alpha_3 \text{TbillRate}_t + \epsilon_{t+1} \tag{46}$$

where $Ret_{mkt,t+1}$ is the quarterly excess return on the CRSP market portfolio, $\text{MktDividendYield}_t$ is the dividend yield on the market portfolio, TermSpread_t is the term spread between long-run and short-run U.S. government bonds, and TbillRate_t is the 3-month Treasury bill rate. The regression results are provided in Table 4. While the predictive R^2 of this regression is only 0.043, it is generally consistent with the previous literature on return predictability. The regression suggests an important role for the lagged dividend yield, which is also consistent with the previous literature. For the remainder of the paper, we will use this constructed series to directly capture risk compensation associated with economic uncertainty.

For the post-war sample, summary statistics for each variable are provided in Table 1. As mentioned several of these quantities are employed directly in our model calibration. One aspect of the data that should be immediately acknowledged is the high level of persistence of several of the debt series. The auto-correlation exceeds 0.99 for the ratio of private debt to GDP; for visual inspection, debt quantities across the full sample are presented graphically in Figure 2. In our main empirical exercises (presented in the next section), we employ a Vector Auto-regression (VAR) to account for the persistence in these series as well as to provide a methodology to analyze independent variation across the various quantities of interest as opposed to simply documenting unconditional correlations.

Before moving the formal VAR estimated over the full post-war sample, however, we also provide some casual evidence on the our main quantities of interest over a shorter 1990-2009 period where the level of persistence is less pronounced. While informal, this permits an exploration of the shared relations among these variables over several business cycles. Table 5 provides correlations across the debt quantities and prices over the last two decades, and Figure 3 provide a graphical representation of these data. Several features of the data are worth highlighting. First, an increase in government debt in the model reduces the transaction-service return to government debt and private debt, resulting in a reduction in the relative amount of private debt. The correlation across the relative government and private debt measures are significantly negative, consistent with the implications of our model as presented above. For example, the correlation between total government debt and overall private debt is -0.61. Third, an increase in government debt in the model is also associated with a reduction in the spread between interest rates on private and government debt. The AAA-Treasury spread is inversely related to total government debt, with a correlation of -0.35, but positively related to private debt with a correlation of 0.43. Last, an elevated level of uncertainty makes it potentially more costly for banks to provide liquidity services. Economic uncertainty, as measured by our market risk premium variable, is associated with both an elevated AAA-Treasury yield spread, with a correlation of 0.12, and a lower level of relative private debt, with a correlation of -0.68. All these features of the data are in-line with the predictions of the model. Next, we turn to the formal VAR analysis on the post-war data.

4 Vector Auto-regression

To explore the dynamic features of the quantities and prices implied by the model, we estimate several vector auto-regressions (VARs) based on quarterly data. Employing a VAR structure has two advantages. First, we can directly deal with the extreme level of persistence exhibited by several of our series. Second, the VAR provides a framework for evaluating the correlations among the relevant independent (orthogonal) shocks to the system and their impact on the key variables of interest. We will primarily evaluate the latter through estimated impulse response functions.

We consider several alternative VAR representations of the data, including a VAR(4) [four-quarters], VAR(8) [eight-quarters], and a more parsimonious version that incorporates only the first quarter's, the first year's, and the second year's lag terms. The last specification is the one we will focus on since the lags associated with these particular periods appear to be the most important and presentation of the more parsimonious version is less cluttered. Nevertheless, these alternative specifications provide comparable empirical results. In particular, the impulse responses functions to which we will pay particular attention are largely unchanged. The variables in our VAR system are (1) the real GDP growth rate, (2) the (estimated) market risk premium, (1) the log of the government debt to GDP ratio, (4) the log of the private sector debt to GDP ratio, and (5) the real Treasury bill rate. For the impulse response functions, we will retain this ordering as the first two variables of interest are exogenous to the model (and the associated simulations presented in an earlier section). We are interested in the response of final two endogenous variables to shocks in the supply of government debt and levels of economic uncertainty. However, we do place the government debt to GDP ratio after the GDP growth rate and our measure of uncertainty. While we are primarily interested in exploring the reaction of private debt and associated prices to changes in the amount of public debt, we must acknowledge that active policy may confound that exploration. To the extent that public policy makers react to shocks associated with growth or uncertainty by changing public debt levels, we want to correctly attribute a movement in government debt levels to those deeper stimuli before then judging the degree to which private debt levels or market prices are affected by changes in the amount of public debt. In essence, by placing relative government debt levels third in our ordering, we will isolate the degree to which private debt levels and Treasury bill rates respond after controlling for deeper growth and uncertainty shocks.

Table 6 presents estimates for our baseline VAR. Several key results are worth noting. First, as mentioned, the series are generally quite persistent, as is evidenced by the large and highly significant auto-regressive coefficients associated with each series (other than GDP growth). This suggests that taking account of the dynamic structure of these data is very important for exploring the role for unexpected variation in each. The standard error associated with each variable in the system implies that the variability of the unexpected shocks are much smaller than the overall level of each variable. For comparison, the unconditional standard deviations for each variable are provided in Table 6. Second, the R^2 associated with each variable in the system are large. While we are able to capture most of the temporal variation, this is almost certainly due in large part to the highly persistent nature of each series (again, excluding GDP growth). Third, there are important cross-predictability effects. In particular, the market risk premium effects suggest an important role for economic uncertainty.

As mentioned, we place the government debt variable third in the VAR ordering given that policy makers may react to the economic conditions they face. While the model does not have an active role for government policy in this regard, an examination of the relationships between government and private debt levels should account for the fact that changes in government debt may indeed reflect a response to the macroeconomic environment. To properly explore the relationship between government and private debt activity, we need to first account for these features of the data. Figure 4 presents two impulse responses associated with the reaction of the log government debt ratio to either GDP growth or market uncertainty shocks. The log government debt level responds positively (and persistently) to a GDP growth shock and negative (and persistently) to an uncertainty shock.

To evaluate the dynamic relation between our variables, Figure 5 provides a set of *four* impulse response functions of particular interest based on the estimated VAR. To explore the predictions of our model detailed above, we focus exclusively on the responses of (1) the log of the short-term private sector debt to GDP ratio and (2) the short-term real Treasury bill rate to one-standard deviation impulses in (1) the log of short-term government debt to GDP ratio and (2) the estimated market risk premium. These responses describe the manner in which the private sector responds to unexpected shocks in either the supply of government debt or economic uncertainty, controlling for the fact that the government debt levels themselves are responding to the macroeconomic environment. We also provide 95% confidence intervals around each impulse response.

Several features deserve attention. First, as predicted by the model, private sector debt falls in a statistically significant manner in response to a positive shock to government debt. The magnitude is economically meaningful as well. An unexpected (one standard deviation) increase in the government debt ratio of about 5% engenders a decline in relative private sector debt of about 1.7%. The negative response in the log private debt ratio is at its largest point (in absolute magnitude) after about eight quarters. Second, the response of the private debt ratio to economic uncertainty is even more pronounced. As predicted by the model an unexpected increase in economic uncertainty, as measured by an increase in the market risk premium of about 200 basis points, yields a decline in the ratio of short-term private sector debt of about 4% after 8 quarters. This response of private sector debt to unexpected changes in economic uncertainty persists for several years.

We also report the responses of the real Treasury bill rate to shocks in either the government debt ratio or economic uncertainty. Both effects are statistically significant, but the responses are not as significant in economic terms as the responses documented for private debt levels. In response to an unexpected change in the ratio of government debt to GDP of about 5%, the real Treasury bill rate increases by about 20 basis points. The responses of the real T-bill rate to a shock in economic uncertainty is somewhat more economically significant. An one-standard deviation increase in the market risk premium engenders a decline in the real T-bill rate of about 70 basis points.

Taken together, the estimated VARs and the particular impulse responses we highlight are largely in line with the model's predictions. That said, one important issue requires some attention. In some cases, we observe a delayed response to the various shocks we consider. The model has no role for these kinds of dynamics. A more involved model with additional frictions or costs could potentially deliver this kind of temporal dependency, but that detail is beyond the aims of the current paper. Rather, acknowledging this issue, we want to demonstrate that the data are largely in line with the implications of a fairly simple model of aggregate liquidity provision.

4.1 Alternatives Measures

To explore the robustness of our long-history results, we also consider several cases where we replace key variables with plausible alternatives that may capture the relevant components implied by the model. In each case, we estimate the parsimonious VAR, but we replace either the debt quantity or price measure with a reasonable alternative. In the interests of space, we do not report the VAR estimates nor all the impulse responses, but rather we plot two example sets of the four particular impulse response functions of interest implied by the estimated VARs. As above, these are the responses of (1) the relevant private debt quantity measure and (2) the relevant price (yield) measures to shocks in (1) the government debt measure and (2) the estimated market risk premium, where each case considers alternatives for each of these.

First, we consider the following alternatives along the debt quantity dimension where we replace the log of short-term government debt to GDP ratio with the overall government debt to GDP ratio (all maturities). The aggregate amount of government debt may be a reasonable alternative as the full maturity spectrum of Treasury bonds is potentially important in aggregate liquidity provision. As before, we place the government debt ratio after the primary macroeconomic shocks to control for the degree to which policy makers may react to these stimuli. Figure 6 shows that the impulse response functions are quite similar to that presented above, and, in fact, suggest that the negative reaction of the private debt levels to an increase in *overall* government debt is somewhat stronger.

Third, we consider the following alternatives along the price (yield) dimension where we replace the real Treasury bill rate with the AAA spread. The AAA (relative to comparable Treasuries) provides some gauge of the relative pricing of government and private debt, and also avoids the difficult direct measurement of expected inflation. The AAA spreads describe long-dated debt instruments (though the yields there are highly correlated with near to medium term issues of similarly rated debt). Our view is that the extent to which the evidence is robust across an alternative choices only bolsters our claim that the data are largely in-line with the predictions of the model. As can be seen in Figure 6, the debt quantity responses are nearly identical (as you might expect); however, the yield spread response now moves in the opposite direction. This is as the model simulations predict. The yield spread response to an increase in government debt (relative to GDP) is negative, potentially reflecting a diminished liquidity premium of lower cost (in our model) government debt relative to the private alternatives. As with many of the other responses, though, the reaction is again delayed. Finally, the yield spread does increases significantly (and swiftly) with market uncertainty, potentially reflecting the increased probability of insolvency among issuers. In unreported results, we also considered two additional spreads: (1) the BAA spread relative to comparable Treasuries and (2) the commercial paper spread relative to comparable Treasuries. In either case, the evidence is also largely in-line with the results presented above.

5 Conclusions

We present a model which helps understand the links between liquidity premia, the supply of government debt, and the supply of private debt. In particular, the model endogenizes the supply of private debt and captures three key features: (i) a higher supply of government debt lowers the liquidity premium in Treasury-bills and hence raises the real risk free rate, (ii) higher levels of government debt lower the supply of private debt as the incentives of the private sector to capture the liquidity premia diminish (iii) a rise in economic uncertainty raises the insolvency costs for intermediaries and hence also lowers the supply of short-term private debt. Using extensive data analysis, we show that these implications have strong empirical support. Our quantitative and empirical analysis suggests that episodes of a liquidity crisis which exhibit sharp declines in issuance of commercial paper and other short-term private securities reflect the forces featured in the model — higher aggregate risk and an increased supply of short-term government debt. That is, financial intermediaries facing higher levels of uncertainty optimally choose to reduce their borrowing and lending activities as their ability to capture the liquidity premium has to be traded-off against the increased cost of insolvency.

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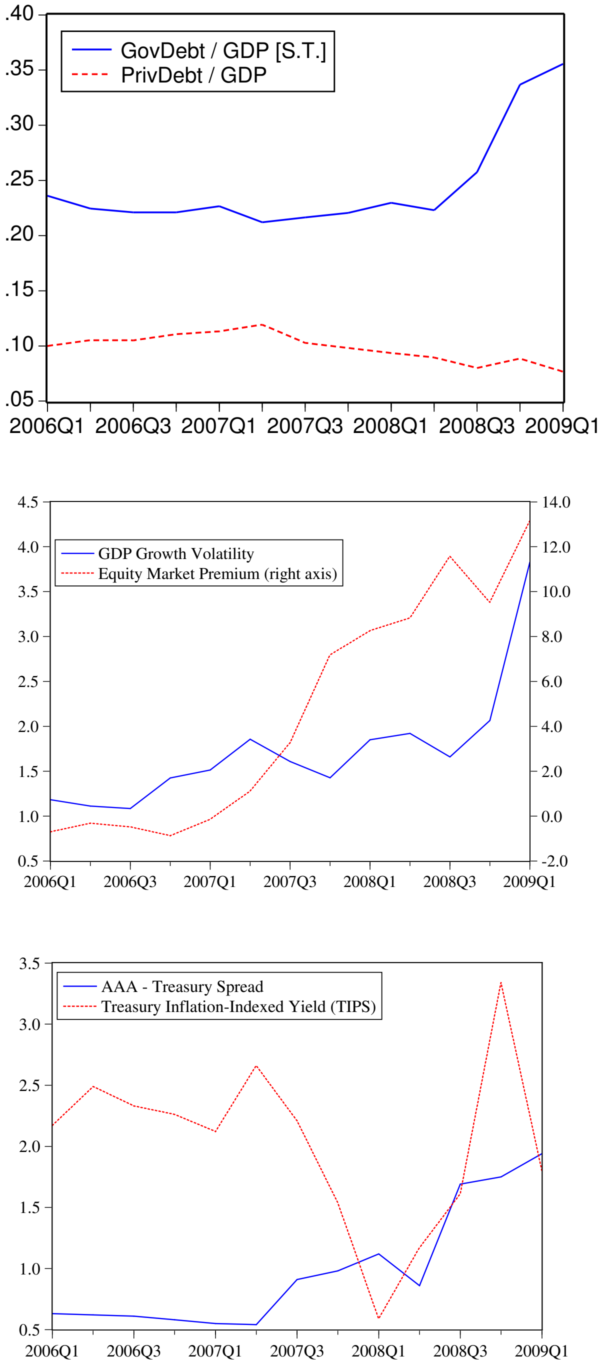


Figure 1: Quantities and Yields (2006-2009)

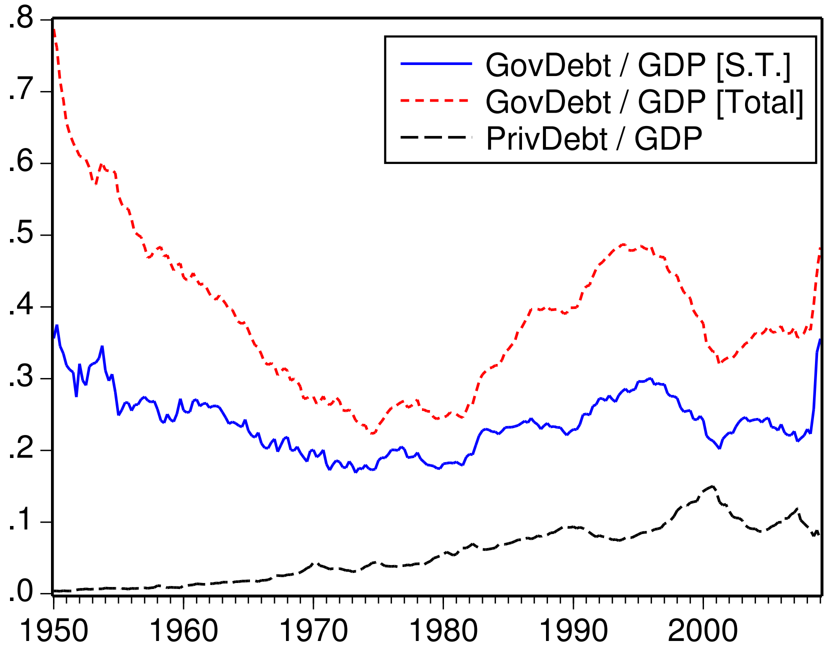
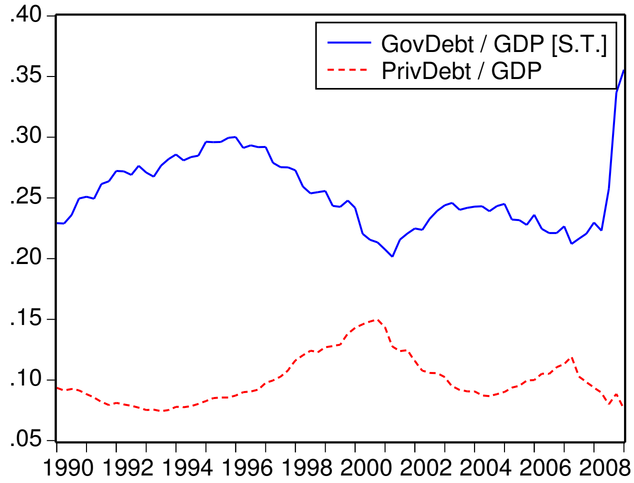


Figure 2: Quantities (Ratios) 1950-2009



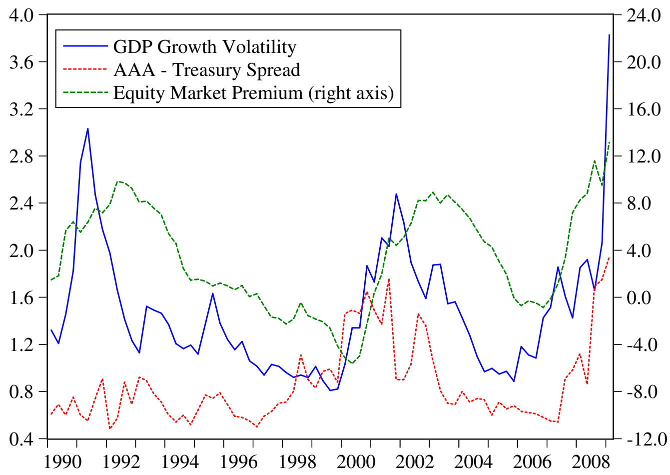


Figure 3: Quantities and Yields (1990-2009)

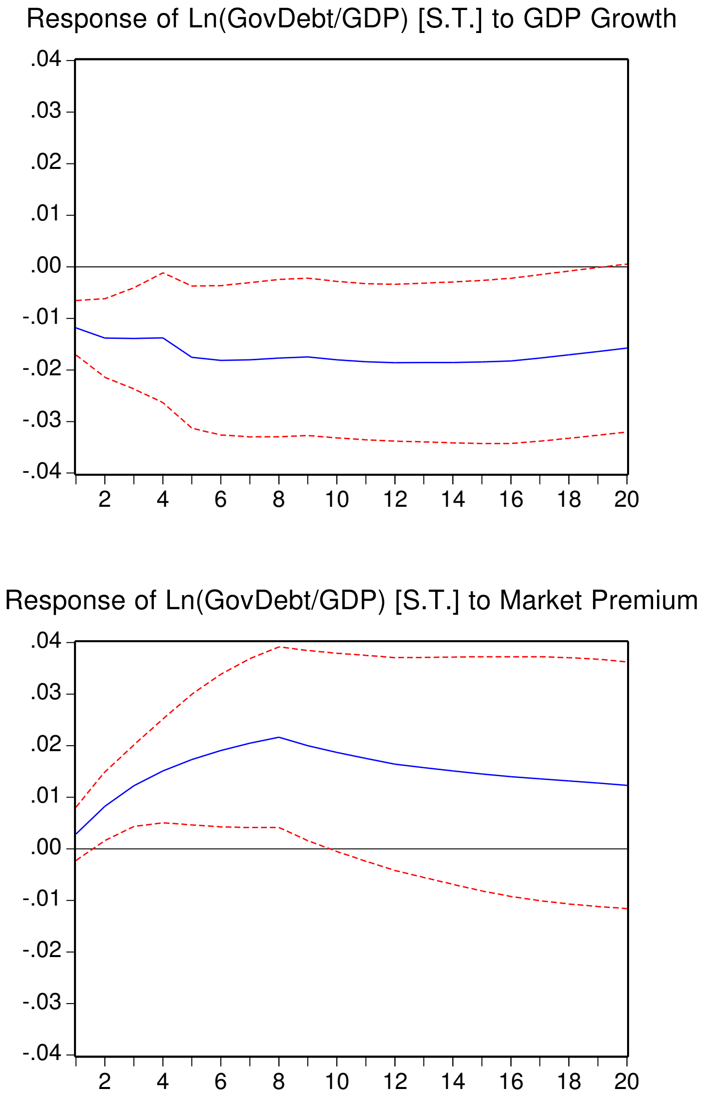


Figure 4: Baseline VAR: Government Reaction

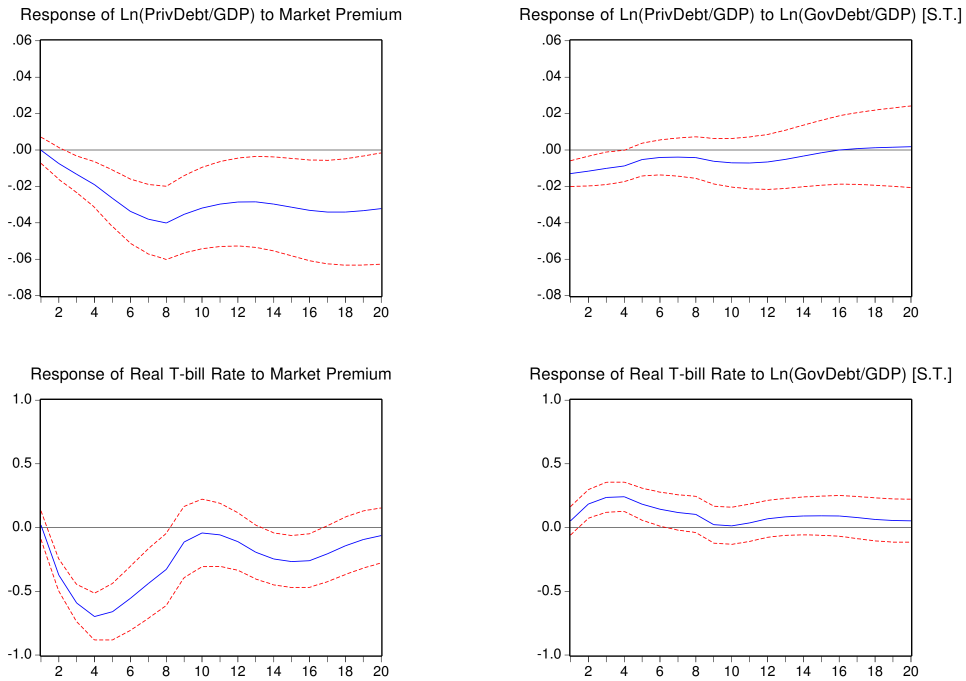


Figure 5: Baseline VAR: Impulse Response Functions

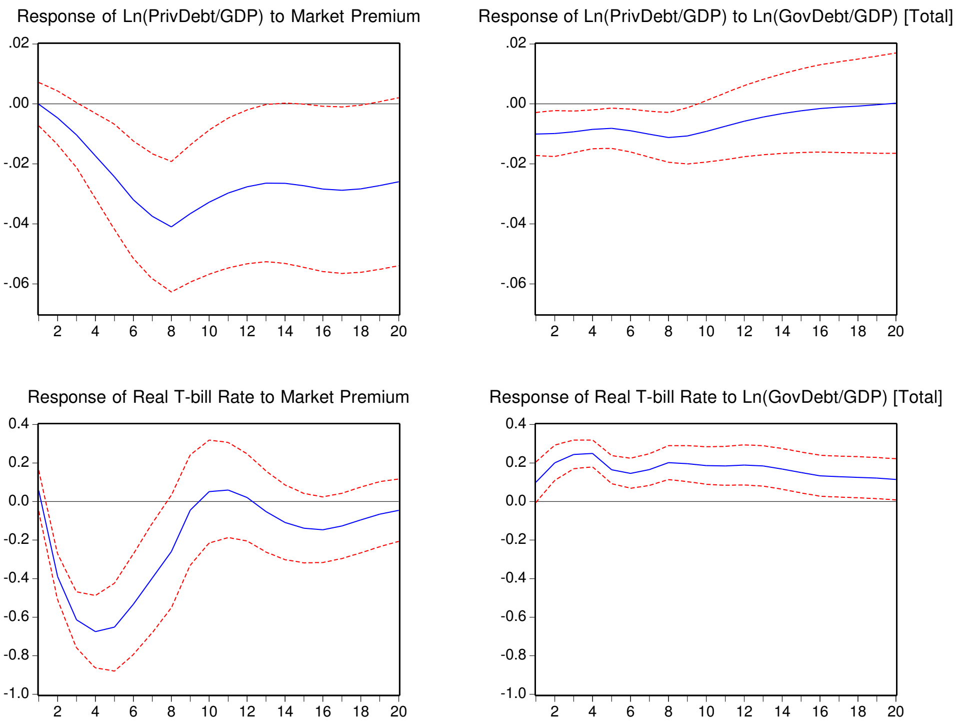


Figure 6: Alternative VAR: Impulse Response Functions

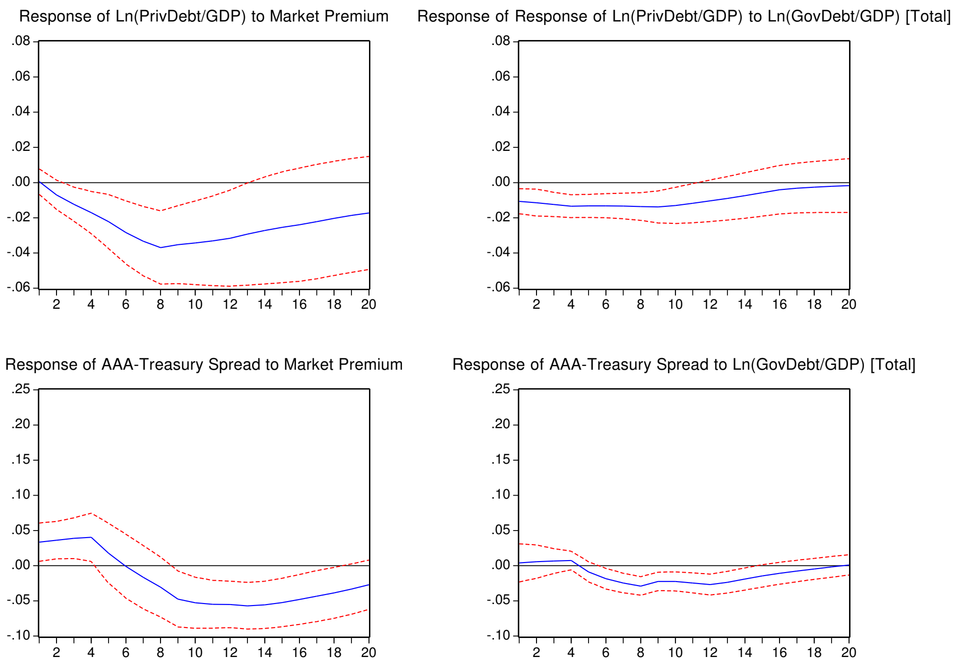


Figure 7: Alternative VAR: Impulse Response Functions

Table 1: **Summary Statistics: 1950-2009**

Quantities (Ratios)

Series	Mean	Std. Deviation	ρ
GovDebt/GDP [S.T.]	0.238	0.042	0.954
GovDebt/GDP [Total]	0.388	0.110	0.967
PrivDebt/GDP	0.056	0.039	0.994

Prices (Yields and Spreads %)

Series	Mean	Std. Deviation	ρ
Real T-bill Rate	1.329	2.144	0.873
AAA Spread	0.686	0.395	0.842

Macro-Environment %

Series	Mean	Std. Deviation	ρ
Market Premium	6.415	6.461	0.930
Real GDP growth	3.276	1.978	0.352
GDP Conditional Volatility	1.897	0.800	0.763

Table 2: **Parameter Values**

Parameter	Value
τ	1
β	.95
γ	.02
ξ	.05
$\bar{\varphi}$	.01
α_1	1.5
α_2	-.25
α_3	-.25

Table 3: **Simulations**

	GDP Growth %	GovDebt/ GDP	PrivDebt/ GDP	GovDebt Yield %	PrivDebt Yield %	Yield Spread %	Trans. Cost %
mean	3.20	0.165	0.207	2.42	3.30	0.88	2.25
std.dev.	1.86	0.016	0.009	0.62	0.39	0.43	0.05

Key Correlations

(GDP Growth, GovDebt/GDP)	(GovDebt/GDP, PrivDebt/GDP)	(GovDebt/GDP, GovDebt Yield)	(GovDebt/GDP, PrivDebt Yield)
0.006	-0.257	0.871	0.351

(GovDebt/GDP, Yield Spread)	(PrivDebt/GDP, PrivDebt Yield)	(GovDebt Yield, PrivDebt Yield)	(PrivDebt/GDP, Uncertainty)
-0.949	0.454	0.737	-0.655

Table 4: **Measuring Economic Uncertainty**

Coefficient	Estimate	Std. Error
α_0	-2.414	7.764
α_1	4.123	1.568
α_2	1.754	3.328
α_3	-1.184	0.727

R^2	0.043

Table 5: **Correlations: 1990.1 - 2009.1**

	GovDebt/GDP [Total]	GovDebt/GDP [S.T.]	PrivDebt/GDP	Cond. GDP Volatility	AAA Spread	Eq. Market Premium
GovDebt/GDP [Total]	1.00					
GovDebt/GDP [S.T.]	0.874	1.00				
PrivDebt/GDP	-0.606	-0.564	1.00			
Cond. GDP Volatility	-0.024	0.132	-0.145	1.00		
AAA Spread	-0.350	-0.110	0.432	0.361	1.00	
Eq. Market Premium	0.086	0.190	-0.679	0.500	0.115	1.00

Table 6: **Baseline VAR**

	Real GDP Growth$_t$	Market Premium$_t$	Ln(GovDebt/GDP)$_t$	Ln(PrivDebt/GDP)$_t$	Real T-bill Rate$_t$
Real GDP Growth$_{t-1}$	0.1677	-19.0048	-0.3019	-1.0358	8.6109
	-0.0751	-18.2116	-0.3583	-0.4954	-7.5037
Real GDP Growth$_{t-4}$	0.0320	-32.5590	-0.4910	0.7177	0.0239
	-0.0700	-16.9740	-0.3340	-0.4617	-6.9938
Real GDP Growth$_{t-8}$	-0.0047	-22.0296	0.0331	0.6717	-7.7034
	-0.0649	-15.7273	-0.3094	-0.4278	-6.4801
Market Premium$_{t-1}$	-0.0008	0.8933	0.0026	-0.0035	-0.1906
	-0.0002	-0.0543	-0.0011	-0.0015	-0.0224
Market Premium$_{t-4}$	0.0010	-0.0856	0.0001	-0.0013	0.0393
	-0.0003	-0.0651	-0.0013	-0.0018	-0.0268
Market Premium$_{t-8}$	-0.0003	0.0718	-0.0008	0.0019	0.0598
	-0.0002	-0.0551	-0.0011	-0.0015	-0.0227
Ln(GovDebt/GDP)$_{t-1}$	-0.0057	2.8355	0.9374	-0.0191	4.2769
	-0.0107	-2.5845	-0.0509	-0.0703	-1.0649
Ln(GovDebt/GDP)$_{t-4}$	0.0213	-1.6971	-0.0263	0.0910	-1.1183
	-0.0143	-3.4570	-0.0680	-0.0940	-1.4244
Ln(GovDebt/GDP)$_{t-8}$	-0.0109	-0.5009	0.0468	-0.0421	-2.2814
	-0.0098	-2.3680	-0.0466	-0.0644	-0.9757
Ln(PrivDebt/GDP)$_{t-1}$	-0.0066	-2.0104	-0.0118	0.8571	1.4270
	-0.0066	-1.6007	-0.0315	-0.0435	-0.6595
Ln(PrivDebt/GDP)$_{t-4}$	0.0126	0.1226	-0.0136	0.0587	-0.6917
	-0.0083	-1.9988	-0.0393	-0.0544	-0.8236
Ln(PrivDebt/GDP)$_{t-8}$	-0.0072	1.3146	0.0319	0.0542	-0.8661
	-0.0055	-1.3336	-0.0262	-0.0363	-0.5495
Real T-bill Rate$_{t-1}$	0.0000	0.0713	0.0026	0.0051	0.6583
	-0.0005	-0.1118	-0.0022	-0.0030	-0.0461
Real T-bill Rate$_{t-4}$	0.0000	0.0247	-0.0006	-0.0034	-0.0398
	-0.0005	-0.1119	-0.0022	-0.0030	-0.0461
Real T-bill Rate$_{t-8}$	0.0000	-0.0440	0.0011	0.0015	0.1276
	-0.0004	-0.0887	-0.0017	-0.0024	-0.0365
Constant	0.0101	0.4389	-0.0471	-0.0240	1.6267
	-0.0077	-1.8712	-0.0368	-0.0509	-0.7710
R^2	0.249	0.898	0.945	0.997	0.847