Impact of Foreign Official Purchases of U.S. Treasuries on the Yield Curve

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Abstract

A surprisingly small amount of research focuses on the impacts of substantial U.S. Treasury purchases made by foreign governments following the 1997 Asian financial crisis. This paper employs a Gaussian affine term structure model (ATSM), augmented with macro variables, to test whether purchases of Treasuries by foreign governments have depressed U.S. interest rates. The advantage of using an ATSM is that it allows us to examine the impact of shocks over the entire yield curve, as opposed to a single maturity. To identify shocks to foreign official purchases of Treasuries, I embed a structural vector autoregression (SVAR) of macroeconomic variables in the model. I find that foreign official purchases have shifted the entire yield curve down with the largest and statistically significant impacts at the short end of the curve and more persistent effects at the long end of the curve.

Keywords: Foreign official purchases, Treasury securities, yields, term structure.

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1 Introduction

In 2005, Ben S. Bernanke, Chairman of the Federal Reserve, coined the term "global saving glut" in a speech to highlight the abundance of global savings financing the acquisition of foreign claims rather than domestic investment. Much of this global saving glut has its origins in the 1997 Asian financial crisis, where Asian emerging market economies suffered a loss of lender confidence and subsequently an outflow of capital. Since then, several countries in Asia that were previously net borrowers morphed into net lenders, building up their foreign reserves to use as a buffer against capital outflows in the wake of another crisis.

Figure 1 plots the rate of foreign reserve accumulation of all countries starting in 1995. The series displays a steeper slope in the early 2000s, suggesting that the rate at which governments acquired foreign exchange reserves increased after the Asian financial crisis. More recently the rate of accumulation has tapered, yet the total change over the last two decades is still over 1000%. In 1995 reserves totaled about $1 trillion, today they are close to $12 trillion.

Although the composition of foreign exchange reserves is often not publicly available, it is believed that the majority of Asia's international reserves are held in U.S. dollar assets. U.S. securities are particularly attractive to foreign governments because they are safe, liquid products denominated in the currency many emerging market economies use as a reference point on the foreign exchange market. Figure 2 plots the percent of U.S. Treasury securities held by foreigners. In 1985, foreigners held about 10 percent or $100 billion

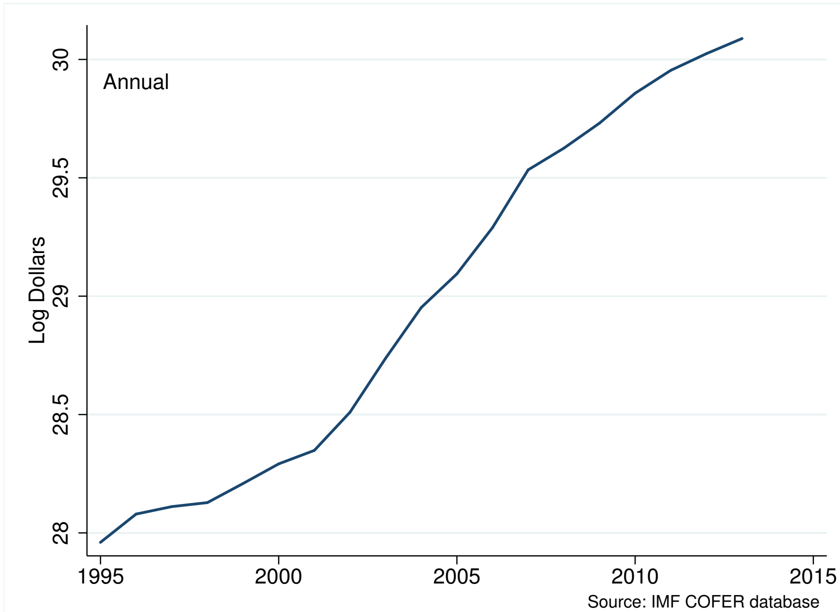

Figure 1: Global Foreign Exchange Reserves

of U.S. Treasury debt, while in 2011 they held over 40 percent or $4 trillion. The growth in foreign holdings is remarkable and China and Japan's acquisitions (blue and red regions), following the Asian financial crisis, account for a significant fraction of that growth.

To gauge how much of these foreign inflows are held by foreign governmental entities, Figure 3 plots the percent of Treasuries outstanding held by officials. Note, I will refer to flows into Treasuries by foreign governments as foreign official purchases. After the Asian financial crisis, the percent of Treasuries held by foreign officials immediately increased and has been trending upward ever since. In 2011, over 30 percent of U.S. federal debt was held by foreign governments. Additionally, after comparing Figures 2 and 3, we see that the majority of foreign-held Treasury securities are in the possession of governments.

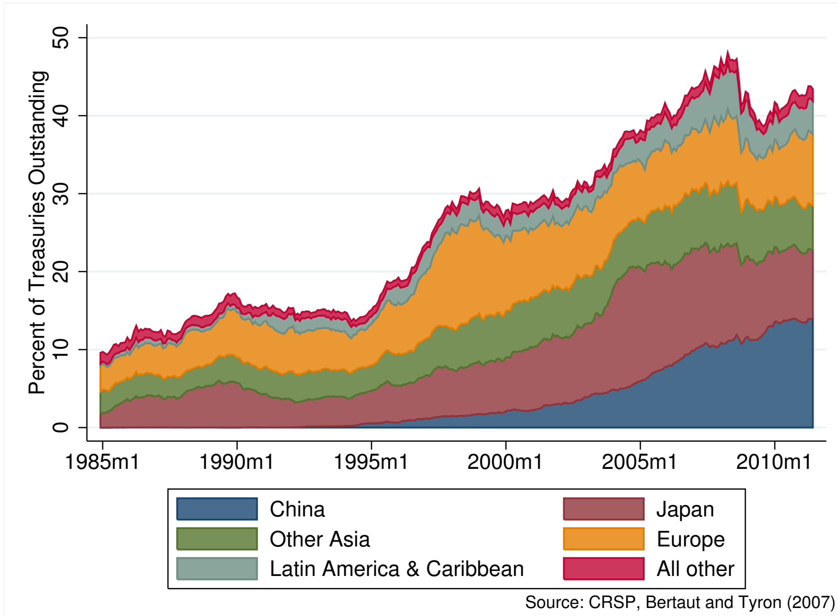

Figure 2: Percent of Treasuries Held by Foreigners

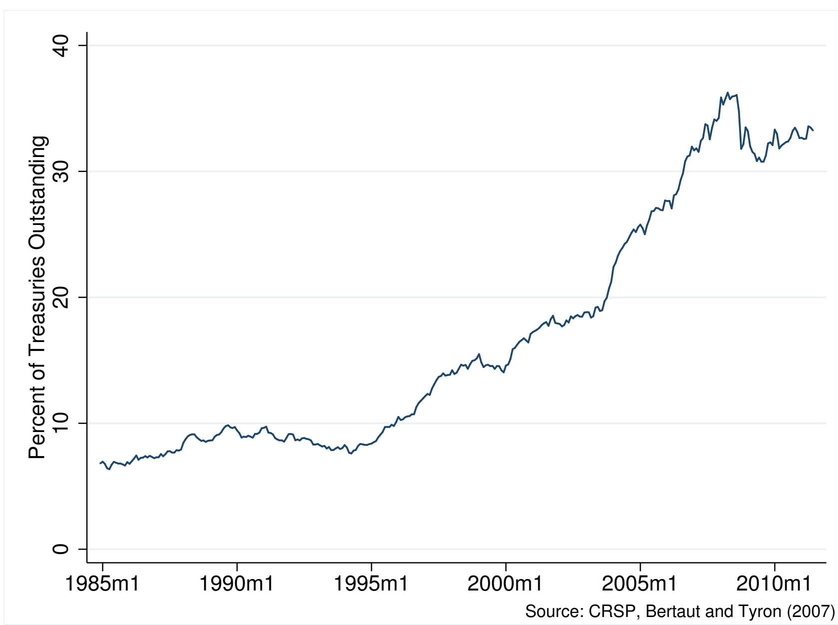

Figure 3: Percent of Treasuries Held by Foreign Governments

The massive increase of foreign official flows into U.S. securities begs the question of whether these purchases have depressed interest rates and altered the yield curve. This question has several important policy implications. The first regards monetary policy. If U.S. interest rates are increasingly determined by international financial markets, then the Federal Reserve may find it more difficult to implement their interest rate policy. For instance, the Fed may find it desirable to use unconventional monetary policies to offset the effects of foreign official purchases. Additionally, if foreign governments decide to sell off their sizable Treasury positions and the Fed is not prepared to implement counteractive measures, U.S. interest rates may increase and have a contractionary effect on the economy.

The second policy implication regards global financial stability. It is widely believed that the Great Recession, at least in part, was caused by persistently low interest rates in the early 2000s, of which some economists attribute to stimulative monetary policy (see Taylor (2009); Gambacorta (2009); Maddaloni and Peydró (2011)). However, if foreign official purchases of Treasuries are part of the story for why interest rates were so low, then they too may have fueled the Great Resession.

Previous work has asked whether the influx of foreign investment into U.S. securities has pushed down long-term interest rates in the U.S. This paper goes beyond that and asks how foreign official investment has affected the entire yield curve. I do this by estimating a Gaussian affine term structure model (ATSM), augmented with macro variables. ATSMs exploit no arbitrage in financial markets to identify factors explaining the yield curve. By embedding a structural vector autoregression (SVAR) of macro variables – one of which is foreign official purchases of Treasuries – in the model, I uncover how macro variables, in addition to three latent factors, explain the dynamics of the U.S. yield curve.

Section 2 reviews some key works in the foreign official positions literature and ATSM literature; Section 3 outlines the basic framework of ATSMs and their application to the question at hand; Section 4 describes the data; Section 5 explains the identification and estimation strategy; Section 6 presents and discusses the results; and Section 7 concludes.

2 Related Literature

2.1 Foreign Official Purchases

One of the most popular works investigating the impact of foreign official purchases on U.S. Treasury securities is Warnock and Warnock (2009). They regress the 10-year Treasury rate on foreign official purchases for the period January 1984 to May 2005, including a number of control variables, such as short-term interest rates, inflation expectations, growth expectations, the federal deficit, and a variable capturing the interest rate risk premium. They conclude that in the case of zero foreign accumulation of U.S. securities over the course of a year, long-term rates would be 80 basis points higher. From specifications with alternative dependent variables, they also conclude that foreign inflows have depressed U.S. corporate bond rates and mortgage rates, potentially fueling the financial and housing bubbles. Their identification strategy, however, relies on the unrealistic assumption that foreign official purchases are exogenous. Although foreign officials may not maximize returns the way private investors do, their actions are likely systematic and respond to economic circumstances.

Bernanke, Reinhart, and Sack (2004) use an event study approach to circumvent this exogeneity assumption and find a similar impact of foreign inflows on U.S. yields. Using Japanese announced foreign exchange interventions between 2000 and 2004, they find that each $100 billion intervention in the Treasury market reduced the 10-year yield by 70 basis points, which is comparable to what Warnock and Warnock (2009) find.

Lastly, Beltran, Kretchmer, Marquez, and Thomas (2013) use instrumental variables to relax the assumption that foreign official purchases are exogenous. They estimate the short-run impacts of foreign official purchases on the 5-year term premium with two-stage-least-squares, where instruments include an oil-specific supply shock variable, Japanese foreign exchange interventions, and the Chinese trade balance. Using data from January 1994 to June 2007, they find a smaller impact of foreign official purchases on yields. In particular, if foreign official purchases were to decrease by $100 billion, the 5-year Treasury rate would immediately rise by 40-60 basis points. To estimate the long-term impact of foreign official purchases, after private investors react to the yield change, they employ a co-integrated VAR and find the effect is about a 20 basis point rise in yields.

2.2 ATSM Literature

The above studies focus on estimating the impact of foreign official purchases on a particular maturity, such as the 5- or 10-year yield. Employing an ATSM extends the analysis to capture the entire yield curve. Even though foreign officials generally accumulate longer-term Treasuries, all yields are impacted by their purchases. By incorporating an ATSM, this paper is the first to document the response of the entire yield curve to foreign official purchase shocks.

ATSMs exploit the convenient property of bonds that different maturities of the same asset are traded at the same time. This allows the researcher to compare bond prices of varying maturities and infer something about investors' risk preferences. Specifically, ATSMs assume that any gap between long-term yields and the expected value of future short-term yields is the price of risk and not an arbitrage opportunity. ATSMs essentially assume no arbitrage; and in deep markets, like the U.S. Treasury market, it is likely that all arbitrage opportunities are instantaneously traded away. By imposing restrictions across maturities so that long rates equal risk-adjusted future short rates, the researcher attains a parsimonious model of the entire yield curve based on only a few parameters.[1]

Originally, ATSMs were used to uncover latent factors explaining the yield curve. The norm was to include three latent factors and interpret them as "level," "slope," and "curvature" (see Dai and Singleton (2000), (2002); Duffee (2002); Kim and Orphanides (2005); Kim and Wright (2005)). How-

[1]See Piazzesi (2010) for a thorough survey of the literature.

ever, Ang and Piazzesi (2003) popularized the inclusion of both observable and unobservable factors in ATSMs. Specifically, they include observed inflation and economic growth factors, along with three latent factors, to investigate how macro variables contribute to bond prices and the yield curve. They find that macro factors explain a significant portion of movements in the yield curve (up to 85%), particularly for short- and middle-length maturities.

Pericoli and Taboga (2008) similarly study ATSMs that include observed macro variables. They suggest a less restrictive set of identifying restrictions than Ang and Piazzesi (2003), namely, that macro variables need not be orthogonal to latent factors. However, they also conclude that shocks to output and inflation explain a significant portion of yield-curve dynamics.

Hamilton and Wu (2012) show that both Ang and Piazzesi (2003) and Pericoli and Taboga's (2008) canonical representations are not identified. Hamilton and Wu suggest additional restrictions and an alternative method for uncovering structural parameters from reduced-form estimates. Their minimum-chi-square approach is asymptotically equivalent to the commonly used maximum likelihood, but advantageously allows the researcher to know if estimates are at a global or only local optimum.

In what follows, I estimate an ATSM using four observed macro variables – one of which is foreign official purchases – and three unobserved latent factors. I use Hamilton and Wu's suggested identification restrictions along with their minimum-chi-square estimation to ensure a global optimum is achieved.

3 Gaussian Affine Term Structure Models

3.1 The General Case

In typical macro models where a representative agent maximizes expected utility and smooths consumption using one-period bonds, the following consumption Euler equation holds:

$$P_{1,t} = \beta E_t \frac{U'(C_{t+1})}{U'(C_t)} \Pi_{t+1}^{-1}, \tag{1}$$

where $P_{1,t}$ is the price of a one-period bond at time t; β is the discount rate; $U'(C_t)$ is the marginal utility of consumption; and Π_t is the inflation rate. The right-hand side of the equation is the expected discounted value of one dollar delivered at $t+1$. Let us define the pricing kernel M_{t+1} to be the stochastic discount factor in equation (1), i.e.

$$M_{t+1} \equiv \frac{U'(C_{t+1})}{U'(C_t)} \Pi_{t+1}^{-1}. \tag{2}$$

Using this pricing kernel, we can price the return of bonds. Specifically, an n-period bond is the expected discounted value of an $n-1$ period bond,

$$P_{n,t} = E_t M_{t+1} P_{n-1,t+1}. \tag{3}$$

Equation (3) provides a recursive condition linking bond prices across maturities.

Now let us rewrite the price of an n-period bond $P_{n,t}$ that pays one dollar at time $t+1$ in terms of the risk-free, one-period interest rate r_t. For a continuously compounded $1, 2, ..., n$-period bond at time t, we can compute prices as follows:

$$\begin{aligned}
P_{1,t} &= E_t M_{t+1} = e^{-r_t} \\
P_{2,t} &= E_t M_{t+1} P_{1,t+1} = \underbrace{E_t M_{t+1} E_t P_{1,t+1}}_{e^{-r_t} E_t e^{-r_{t+1}}} + \underbrace{Cov(M_{1+t}, P_{1,t+1})}_{\text{risk-adjustment}} \\
&\vdots \\
P_{n,t} &= E_t M_{t+1} P_{n-1,t+1}.
\end{aligned} \tag{4}$$

The equations in (4) illustrate that the price of a long-term bond is equal to the price that a risk-neutral investor would pay plus a risk-adjustment term. In the absence of the risk-adjustment term these equations can be interpreted as no-arbitrage conditions for a risk-neutral investor. ATSMs impose this no-arbitrage condition while accounting for the risk component of bond prices.

In order to bring this structure to data, we assume a particular functional form for the pricing kernel. Affine term structure models assume the following:

$$M_{t+1} = \exp[-r_t - \frac{1}{2}\lambda_t' \lambda_t - \lambda_t' u_{t+1}], \tag{5}$$

where λ_t characterizes investor attitude toward risk. Note that $\lambda_t = 0$ corresponds to risk neutrality and to the strong form of the expectations hypothesis.[2]

[2]The strong form of the expectations hypothesis is in contrast to what Gürkaynak and Wright (2012) refer to as the weak form, which allows for maturity-specific term premia that are constant over time.

Gaussian affine term structure models make four additional assumptions. First, factors that underly interest rates, denoted F_t, are assumed to be an affine function of their lags,

$$F_t = c + \rho F_{t-1} + \Sigma u_t. \tag{6}$$

Next, the residuals of equation (6) are assumed to be Gaussian,

$$u_t \sim \text{i.i.d.} N(0, I), \tag{7}$$

which implies that $F_{t+1}|F_t, F_{t-1}, ..., F_1 \sim N(\mu_t, \Sigma\Sigma')$ for $\mu_t = c + \rho F_t$. ATSMs further assume that the market price of risk is itself an affine function of F_t,

$$\lambda_t = \lambda_0 + \lambda_1 F_t. \tag{8}$$

Lastly, ATSMs assume the short rate r_t is an affine function of the factors,

$$r_t = \delta_0 + \delta_1' F_t. \tag{9}$$

Given assumptions (5)-(9), it can be shown that an n-period bond yield (defined as $y_{n,t} \equiv -\frac{1}{n} \ln P_{n,t}$) can be written as an affine function of the factors,[3]

$$y_{n,t} = \alpha_n + \beta_n' F_t, \tag{10}$$

and that the constant and slope coefficients take the following recursive for-

[3]See Ang and Piazzesi's (2003) Appendix A for a derivation.

mulations:

$$\alpha_n = -\frac{1}{n}(-\delta_0 + \alpha_{n-1} + \beta'_{n-1}c - \beta'_{n-1}\Sigma\lambda_0 + \frac{1}{2}\beta'_{n-1}\Sigma\Sigma'\beta_{n-1}) \tag{11}$$

$$\beta_n = -\frac{1}{n}(-\delta_1 + \beta'_{n-1}\rho - \beta'_{n-1}\Sigma\lambda_1). \tag{12}$$

Equations (10)-(12) reveal that given $\{c, \rho, \lambda_0, \lambda_1, \delta_0, \delta_1, \Sigma\}$ and F_t, we can calculate the yield of any bond.

3.2 The Foreign Official Purchase Application

Following Ang and Piazzesi (2003) and Hamilton and Wu (2012), I estimate a macro finance model. My model differs from the literature by letting $N_m = 4$ observed macro factors explain yields, namely, output growth, inflation, stock price volatility, and net foreign official purchases of U.S. Treasuries.[4] I stack these variables in a $(N_m \times 1)$ vector f_t^m. In addition, I use $N_\ell = 3$ latent factors stacked in the $(N_\ell, \times 1)$ vector f_t^ℓ.

$$F_t = \begin{bmatrix} f_t^m \\ f_t^\ell \end{bmatrix}, \tag{13}$$

[4]Ang and Piazzesi (2003), Pericoli and Taboga (2008), and Smith and Taylor (2009) use $N_m = 2$ observed macro factors, namely, inflation and a measure of output.

where F_t is a vector containing $N_m + N_\ell$ elements. The factor dynamics in (6) and risk-free yield equation in (9) can be partitioned as follows:

$$f_t^m = c_m + \rho_{mm} f_{t-1}^m + \rho_{m\ell} f_{t-1}^\ell + \Sigma_{mm} u_t^m \tag{14a}$$

$$f_t^\ell = c_\ell + \rho_{\ell m} f_{t-1}^m + \rho_{\ell\ell} f_{t-1}^\ell + \Sigma_{\ell m} u_t^m + \Sigma_{\ell\ell} u_t^\ell \tag{14b}$$

$$r_t = \delta_0 + \delta_{1m}' f_t^m + \delta_{1\ell}' f_t^\ell . \tag{14c}$$

Since data is monthly, (14a) is better suited as a VAR(12) in macro variables, rather than a VAR(1), so I impose this assumption. I also follow the literature and impose three types of identifying restrictions to equations (14a-c).

First, I assume macro dynamics are independent of the unobserved latent factors (i.e. $\rho m\ell, \rho\ell m = 0$). Then, I assume a Cholesky identification scheme for the macro variables (i.e. Σ_{mm} is lower triangular). This implies that variables ordered last in vector f_t^m do not contemporaneously impact the other macro variables. The goal of this paper is to identify shocks of foreign official purchases, so I order this variable last to allow foreign officials to react to contemporaneous growth, inflation, and volatility, but not vice versa. Together these first two assumptions allow me to estimate a SVAR in the macro variables, which is independent from the latent variables, to identify how innovations in foreign official purchases impact macro outcomes. I then feed these predictions into the ATSM model – since equations (10)-(12) give closed-form solutions for how macro factors influence yields – to trace out the implied path of yields.

The next set of identification assumptions are normalizations. I assume $\rho_{\ell\ell}$ is lower triangular with diagonal elements ordered as follows $\rho_{\ell\ell(1,1)} \geq \rho_{\ell\ell(2,2)} \geq \rho_{\ell\ell(3,3)}$ and that the slope coefficients for the process of risk associated with the latent factors is non-negative (i.e. $\delta_{1\ell\ell} \geq 0$). As discussed in Hamilton and Wu (2012), without restrictions on $\rho_{\ell\ell}$ and $\delta_{1\ell\ell}$, there are multiple parameter configurations of the latent variables that lead to observationally equivalent yields implied by the model. I choose one set of restrictions so that the model is identified, but this is without economic content since other choices would result in the same implied path for yields. Additionally, I assume $\Sigma_{\ell\ell} = I_{N_\ell}$, meaning the 3 latent factors are orthogonal to each other. And last, I assume $c_\ell, c_m = 0$, which is inconsequential since it normalizes the latent factors and, as stated in the next section, I demean the macro variables.

The last set of restrictions ensures there is not an overabundance of structural parameters to recover from the reduced form in Section 5. Ang and Piazzesi (2003) attempt to improve the efficiency of their model by fixing parameters with large standard errors in the first stage to zero, but Hamilton and Wu (2012) show that at least one of these restrictions is, in fact, needed for their model to be identified. Therefore, I impose one of Ang and Piazzesi's ad-hoc zero restrictions for identification purposes. In particular, I set the last element of λ_0 to zero.[5] This means that the time-varying risk associated with the third latent factor, which is the (1,7) element of λ_t, is not an affine function of the factors (i.e. $\lambda_{t(1,7)} = \lambda_{0(1,7)} + \lambda_{1(1,7)}F_t$), but rather a linear combination

[5]Following Ang and Piazzesi (2003) I assume parameters in λ_0 and λ_1 correspond to only current macro and latent variables, not lagged macro variables, so that λ_0 contains $N_m + N_\ell = 7$ parameters.

of the factors (i.e. $\lambda_{t(1,7)} = \lambda_{1(1,7)}F_t$).[6]

By altering the lag structure and including the above identifying restrictions, (14a-c) becomes:

$$f_t^m = \rho_1 f_{t-1}^m + \rho_2 f_{t-2}^m + ... + \rho_{12} f_{t-12}^m + \Sigma_{mm} u_t^m \tag{15a}$$

$$f_t^\ell = \rho_{\ell\ell} f_{t-1}^\ell + u_t^\ell \tag{15b}$$

$$r_t = \delta_0 + \delta_{1m}' f_t^m + v_t. \tag{15c}$$

Since I assume the latent factors f_t^ℓ are orthogonal to the macro factors f_t^m, the short rate r_t in equation (15c) can be interpreted as arising from a version of the Taylor rule, where the error $v_t = \delta_{1\ell}' f_t^\ell$ is an unpredictable component of monetary policy. The policy rule recommended by Taylor (1993) specifies how the central bank should react to changes in output and inflation when setting the short rate. Here, I allow the central bank to react to all macro variables in f_t^m, namely, output growth, inflation, stock price volatility, and foreign demand for Treasuries. The Federal Reserve considers hundreds of variables when conducting monetary policy. This approach is simply a more general treatment of the monetary policy rule assumed by Ang and Piazzesi

[6] Ang and Piazzesi (2003) assume that the risk associated with all the macro factors and all but the first latent factor is a linear combination of the factors rather than an affine function. They also impose additional ad-hoc zero restrictions on the slope parameters of latent factor risk $\lambda_{1\ell\ell}$.

(2003).[7] Values of δ_0 and δ_{1m} can directly be obtained from OLS estimation of (15c). Uncovering the remaining parameters is more involved and Section 5 is dedicated to describing the process.

4 Data

Time series data for net foreign official purchases of U.S. Treasury securities is from Bertaut and Tryon (2007) which they periodically update on their website.[8] Treasury International Capital (TIC) system reports foreign and foreign official net purchases, but as acknowledged by Warnock and Warnock (2009) and others, there are major issues with the data. For example, the system cannot differentiate between foreign official investors and private investors when the transaction goes through a third-country intermediary. This is potentially a very confounding feature because governments of oil-exporting countries are thought to accumulate large amounts of Treasuries through intermediary countries. Bertaut and Tryon (2007) work with other sets of cross-boarder securities data to correct these issues and publish an adjusted series of monthly purchases very similar to that constructed by Warnock and Warnock (2009). The exact variable I use in this analysis is Bertaut and Tryon's measure of net foreign official purchases, scaled by the value of Treasuries outstanding

[7]Ang and Piazzesi perform specification tests for including lags of inflation and real activity in their Taylor rule estimation. They find mixed results and thus estimate two ATSMs, one including a Taylor rule base on only contemporaneous variables, which they refer to as the "Macro Model" and another including a Taylor rule that incorporates lags, which they refer to as the "Macro Lag Model." I estimate an ATSM with a monetary policy rule that only depends on contemporaneous variables, but includes four rather than two macro variables.

[8] see `http://www.federalreserve.gov/pubs/ifdp/2007/910/ticdata.zip`.

held by the public. Data for total Treasury securities outstanding minus the amount held in U.S. government accounts and Federal Reserve Banks is from the Center for Research in Security Prices (CRSP).

Data for the other observed macro factors, such as U.S. output growth and inflation, are the 12-month percentage change in industrial production and CPI, respectively, from the FRED database of the Federal Reserve Bank of St. Louis. Lastly, data for the VIX index of stock market volatility is published by the Chicago Board Options Exchange (CBOE). I use the measure that is calculated from the S&P 100 rather than the S&P 500 because it extends back further to June 1986. As in Beltran et al. (2013), I include the VIX index because it is correlated with flight-to-safety flows and dollar appreciation, which presumably influence foreign official investing decisions. All macro variables are demeaned.

The $N_\ell = 3$ latent factors are estimated using monthly data on $N = 6$ bond yields. In order to explain 3 latent factors using 6 yields, I follow the literature and assume 3 yields contain measurement error. Specifically, I assume the 3-, 12-, 120-month bond yields are priced *without* error ($Y_t^1 = (y_t^3, y_t^{12}, y_t^{120})'$) and the 6-, 24-, 60-month bond yields are priced *with* error ($Y_t^2 = (y_t^6, y_t^{24}, y_t^{60})'$). I use the 3-month yield y_t^3 as a proxy for the observed short rate r_t. Yields are constructed using constant-maturity Treasury yields from FRED and divided by 1200 in order to convert to monthly fractional rates.

The sample period runs from June 1986 through June 2011; however, results are robust to a sample period that excludes the Great Recession.

5 Identification and Estimation

Hamilton and Wu (2012) show that Gaussian affine term structure models, where exactly N_ℓ linear combinations of yields are assumed to be priced without error, can be written as a restricted vector autoregression. Imposing the assumptions outlined in Section 3.2, which allow for one lag of the N_ℓ latent factors and 12 lags of the N_m macro variables, results in the following reduced from:

$$f_t^m = \phi_{mm}^* F_{t-1}^m + u_{mt}^* \tag{16a}$$

$$Y_t^1 = A_1^* + \phi_{1m}^* F_{t-1}^m + \phi_{11}^* Y_{t-1}^1 + \psi_{1m}^* f_t^m + u_{1t}^* \tag{16b}$$

$$Y_t^2 = A_2^* + \phi_{2m}^* F_t^m + \phi_{21}^* Y_t^1 + u_{2t}^*, \tag{16c}$$

where F_t^m is a $12 \times N_m$ element vector of contemporaneous and lagged macro variables; F_{t-1}^m is a $12 \times N_m$ element vector of lagged macro variables; Y_{t-1}^1 is an N_ℓ element vector of the one-month lags of exactly priced yields; and Y_{t-1}^2 is an $N - N_\ell$ element vector of the one-month lags of yields priced with error.

The mapping between the structural and reduced-form parameters for the $N_m = 4$, $N_\ell = 3$, and $N = 6$ case is as follows:

$$\phi^*_{mm} = [\rho_1 \; \rho_2 \; ... \; \rho_{12}] \tag{17a}$$

$$A^*_1 = A_1 - B_{1\ell}\rho_{\ell\ell}B^{-1}_{1\ell}A_1 \tag{17b}$$

$$\phi^*_{1m} = \begin{bmatrix} B^{(1)}_{1m} & 0 \end{bmatrix} - B_{1\ell}\rho_{\ell\ell}B^{-1}_{1\ell}\begin{bmatrix} B^{(0)}_{1m} & B^{(1)}_{1m} \end{bmatrix} \tag{17c}$$

$$\phi^*_{11} = B_{1\ell}\rho_{\ell\ell}B^{-1}_{1\ell} \tag{17d}$$

$$\psi^*_{1m} = B^{(0)}_{1m} \tag{17e}$$

$$A^*_2 = A_2 - B_{2\ell}B^{-1}_{1\ell}A_1 \tag{17f}$$

$$\phi^*_{2m} = B_{2m} - B_{2\ell}B^{-1}_{1\ell}B_{1m} \tag{17g}$$

$$\phi^*_{21} = B_{2\ell}B^{-1}_{1\ell} \tag{17h}$$

$$\text{Var}\begin{bmatrix} u^*_{mt} \\ u^*_{1t} \\ u^*_{2t} \end{bmatrix} = \begin{bmatrix} \Omega^*_m & 0 & 0 \\ 0 & \Omega^*_1 & 0 \\ 0 & 0 & \Omega^*_2 \end{bmatrix} = \begin{bmatrix} \Sigma_{mm}\Sigma'_{mm} & 0 & 0 \\ 0 & B_{1\ell}B'_{1\ell} & 0 \\ 0 & 0 & \Sigma_e\Sigma'_e \end{bmatrix}, \tag{17i}$$

where $\hat{\Sigma}_{mm}$ is the Cholesky factorization of $\hat{\Omega^*_m}$ and $\hat{\Sigma}_e$ is the square root of the diagonal elements of $\hat{\Omega}^*_2$.[9] Additionally, A_1, A_2, B_1, and B_2 are defined as:

$$\begin{bmatrix} A_1 \\ A_2 \end{bmatrix} = \begin{bmatrix} \alpha_3 \\ \alpha_{12} \\ \alpha_{60} \\ \alpha_6 \\ \alpha_{36} \end{bmatrix} \tag{18}$$

[9]Macro variables in f^m_t are ordered as follows, but are but are robust to alternative orderings: output growth, inflation, VIX, foreign official purchases scaled by Treasuries outstanding.

$$\begin{bmatrix} B_{1m}^{(0)} & B_{1m}^{(1)} & B_{1\ell} \\ B_{2m}^{(0)} & B_{2m}^{(1)} & B_{2\ell} \end{bmatrix} = \begin{bmatrix} \beta_3' \\ \beta_{12}' \\ \beta_{60}' \\ \beta_6' \\ \beta_{36}' \end{bmatrix}, \tag{19}$$

where for $i = 1, 2$, $B_{im}^{(0)}$ are (3×4) matrices relating the observed yields to the 4 contemporaneous macro factors. $B_{im}^{(1)}$ are (3×44) matrices relating the observed yields to 11 lags of the 4 macro factors. Lastly, $B_{i\ell}$ are $(3{\times}3)$ matrices relating the observed yields to the latent factors.

The above system satisfies the necessary conditions for identification. In fact, the system is over-identified; it contains more estimated reduced-form parameters (535) than unknown structural parameters (516). I obtain the reduced-form coefficients from estimating equations (16-c) via OLS. I then use Hamilton and Wu's minimum-chi-square estimation strategy to recover the structural parameters from (17-i). The system converges, which unlike maximum likelihood, ensures a global solution has been reached.[10]

6 Results

The impact of each factor on an n-length bond is determined by the weights in β_n. The first four rows of β_n are the initial response of yields to shocks in the four factors (recall equation (10)). Figure 4 plots these factor loadings – which have been scaled to correspond to movements of a one stan-

[10]There still may be multiple global optimum, however, results are robust to many initializations.

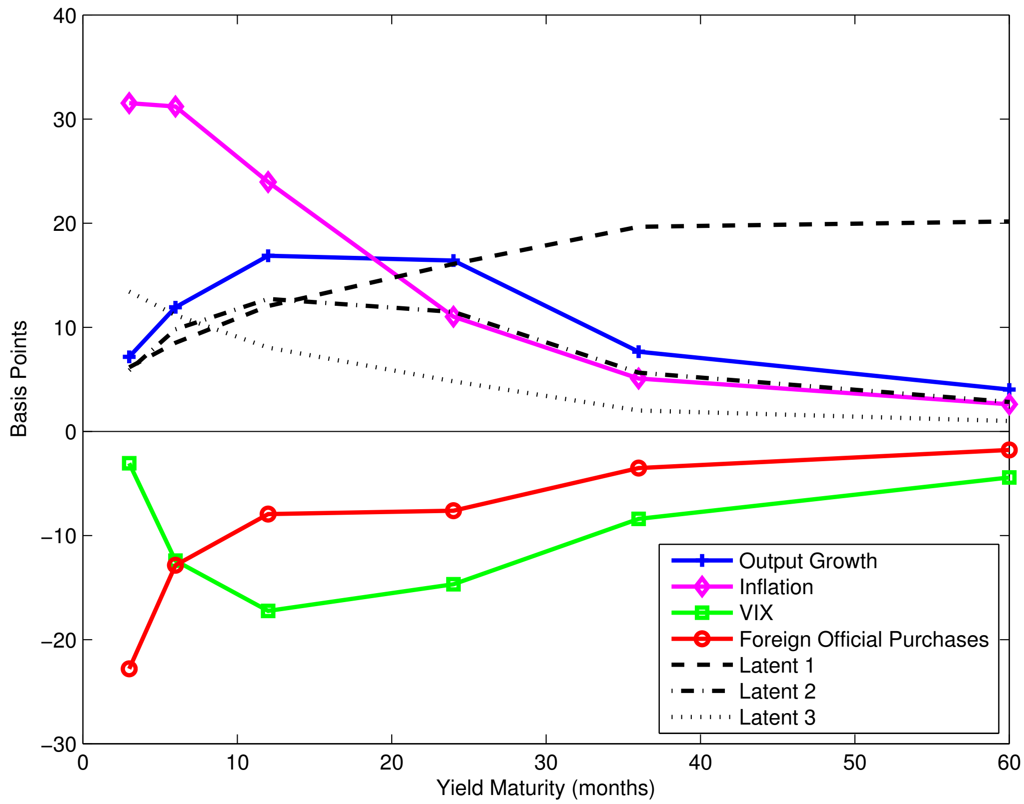

Figure 4: Factor Loadings

dard deviation of the factors – as a function of yield maturity. Note that β_n is first multiplied by 1200 to annualize and then multiplied by 100 to convert to basis points.

Figure 4 reveals that the macro factors, relative to the latent factors, can explain a significant portion of movements in the yield curve. Shocks to inflation shift the entire yield curve up, with the largest impact at the short end of the curve. Shocks to output growth also shift the yield curve up, but the effect is more uniform across maturities. In contrast, shocks to the VIX

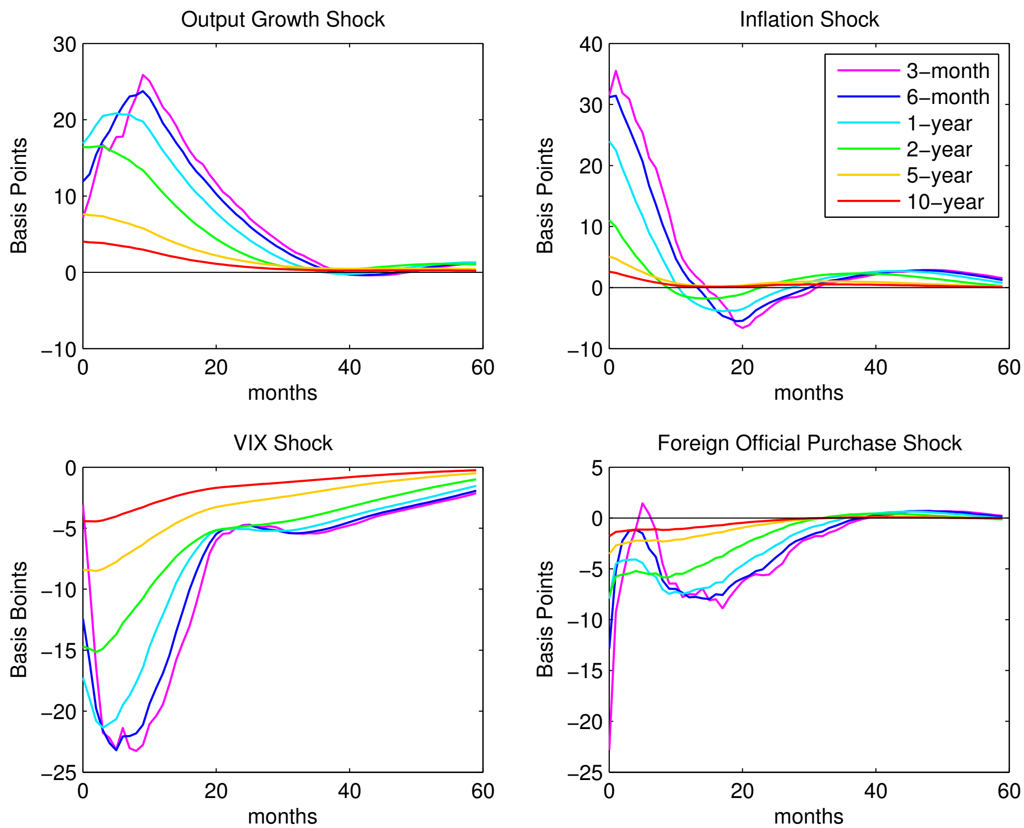

Figure 5: Impulse Responses of Yields

index and foreign official purchases shift the yield curve down. The negative contribution of foreign official purchases aligns with the hypothesis that an increase in demand for Treasuries by foreign governments depresses interest rates.

Figure 5, displays impulse response functions of a one standard deviation shock to the macro variables. Responses of six maturities are plotted. Starting with the upper left corner, we see that output growth is associated with a rise in yields, which for maturities under a year, peak about a year after the shock.

As the U.S. economy grows, investors pull out of safe assets, such as Treasury securities. This results in elevated yields.

Moving to the upper right plot, we see that innovations in inflation initially increase the nominal rates of all maturities and the positive effect persists for a year. The instantaneous increase is expected, since nominal interest rates equal real rates plus inflation.

The lower left plot shows that innovations in stock market volatility reduce yields. When stock market volatility rises, investors generally flock to safe assets, like Treasuries. This subsequently lowers their yields.

Lastly, we turn to the lower right plot, the plot of interest. A one standard deviation shock to foreign official purchases initially reduces the longest maturity, the 10-year, yield by 1.8 basis points and the shortest maturity, the 3-month, yield by 23 basis points. Since the standard deviation of foreign official purchases is 0.30 of a percentage point, this means that an inflow equal to one percent of the amount of Treasuries outstanding lowers the 10-year yield by 6 basis points and 3-month yield by about 80 basis points.

These results are on par with previous work. Recall that Beltran et al. (2013) examine the impact of foreign official purchase shocks on only the 5-year yield. They find that an inflow equal to one percent of the amount of Treasuries outstanding lowers the 5-year yield by 13.5 basis points when using their two-stage-least-squares approach and 5-6 basis points when using their VAR approach. I find a consistent impact for the 5-year yield of about 10 basis points.

Unlike the aforementioned paper, however, I examine how foreign official

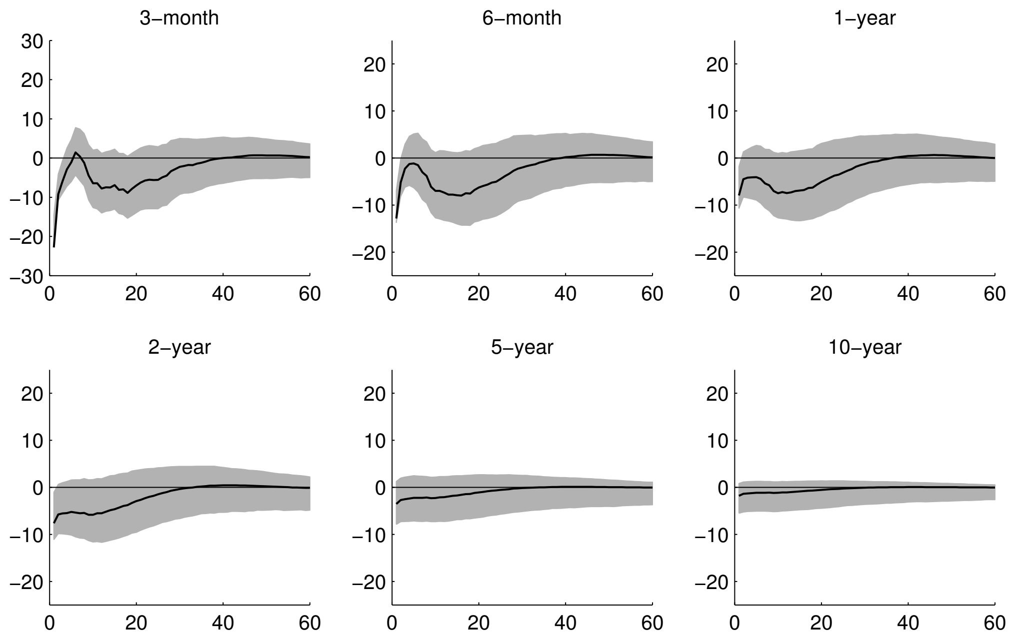

Figure 6: Response of Yields to Foreign Official Purchase Shock [11]

purchases influence the dynamics of the entire yield curve of which five more maturities, in addition to the 5-year yield, are displayed with confidence bands in Figure 6. I find that the impact of foreign official purchases is initially strongest, and statistically significant, at the short end of the yield curve, but this effect quickly reverses after a few months. In contrast, maturities over a year have smooth, albeit less statistically significant, transitions back to their pre-shock levels that last nearly three years. Confidence bands are at the 90 percent level and reveal that shocks of foreign official purchases to maturities two years and under statistically differ from zero on impact. The initial volatility of short rates likely results from a basic property of the yield

[11] Confidence bands are bootstrapped at the 90 percent level.

curve, namely, that long rates smooth over expected future short rates.

As illustrated in Figure 3, foreign governments have accumulated nearly 30 additional percentage points of Treasuries outstanding from 1986 to 2011. The above findings suggest that interest rates would have been considerably higher in the absence of foreign official purchases.

7 Conclusion

This paper asks whether the massive acquisition of U.S. Treasury securities by foreign official entities has altered the yield curve. Results suggest that yes, in fact, the increase in demand for Treasuries by foreign governments has shifted the entire yield curve down. The largest and statistically significant effects are at the short end of the yield curve, but there are more persistent effects at the long end.

This has important policy implications. The recent financial crisis has, in part, been attributed to persistently low interest rates leading up to 2008. If foreign official purchases of U.S. Treasury securities are part of the story for why the U.S. experienced low interest rates in the early 2000s, then it is likely that the "global saving glut" contributed to the Great Recession. Ironically, foreign governments bought U.S. Treasury securities to fend off one type of crisis – another Asian financial crisis – but may have fueled a different crisis – the global financial crisis.

References

Ang, A. and M. Piazzesi (2003). A no-arbitrage vector autoregression of term structure dynamics with macroeconomic and latent variables. *Journal of Monetary economics 50*(4), 745–787.

Beltran, D. O., M. Kretchmer, J. Marquez, and C. P. Thomas (2013). Foreign holdings of us treasuries and us treasury yields. *Journal of International Money and Finance 32*, 1120–1143.

Bernanke, B., V. Reinhart, and B. Sack (2004). Monetary policy alternatives at the zero bound: An empirical assessment. *Brookings papers on economic activity 2004*(2), 1–100.

Bernanke, B. S. (2005). The global saving glut and the us current account deficit. *Board of Governors of the Federal Reserve System (US) Speech* (Mar 10).

Bertaut, C. C. and R. W. Tryon (2007). *Monthly estimates of US cross-border securities positions*. Board of Governors of the Federal Reserve System.

Dai, Q. and K. J. Singleton (2000). Specification analysis of affine term structure models. *The Journal of Finance 55*(5), 1943–1978.

Dai, Q. and K. J. Singleton (2002). Expectation puzzles, time-varying risk premia, and affine models of the term structure. *Journal of financial Economics 63*(3), 415–441.

Duffee, G. R. (2002). Term premia and interest rate forecasts in affine models. *The Journal of Finance 57*(1), 405–443.

Gambacorta, L. (2009). Monetary policy and the risk-taking channel. *BIS quarterly review 400*, 43–53.

Gürkaynak, R. S. and J. H. Wright (2012). Macroeconomics and the term structure. *Journal of Economic Literature 50*(2), 331–367.

Hamilton, J. D. and J. C. Wu (2012). Identification and estimation of gaussian affine term structure models. *Journal of Econometrics 168*(2), 315–331.

Hamilton, J. D. and J. C. Wu (2014). Testable implications of affine term structure models. *Journal of Econometrics 178*, 231–242.

Kim, D. H. and A. Orphanides (2005). *Term structure estimation with survey data on interest rate forecasts*, Volume 5341. Cambridge Univ Press.

Kim, D. H. and J. H. Wright (2005). An arbitrage-free three-factor term structure model and the recent behavior of long-term yields and distant-horizon forward rates.

Maddaloni, A. and J.-L. Peydró (2011). Bank risk-taking, securitization, supervision, and low interest rates: Evidence from the euro-area and the us lending standards. *Review of Financial Studies 24*(6), 2121–2165.

Pericoli, M. and M. Taboga (2008). Canonical term-structure models with observable factors and the dynamics of bond risk premia. *Journal of Money, Credit and Banking 40*(7), 1471–1488.

Piazzesi, M. (2010). Affine term structure models. *Handbook of financial econometrics 1*, 691–766.

Smith, J. M. and J. B. Taylor (2009). The term structure of policy rules. *Journal of Monetary Economics 56*(7), 907–917.

Taylor, J. B. (1993). Discretion versus policy rules in practice. In *Carnegie-Rochester conference series on public policy*, Volume 39, pp. 195–214. Elsevier.

Taylor, J. B. (2009). The financial crisis and the policy responses: An empirical analysis of what went wrong. Technical report, National Bureau of Economic Research.

Warnock, F. E. and V. C. Warnock (2009). International capital flows and us interest rates. *Journal of International Money and Finance 28*(6), 903–919.