Identifying the Portfolio Balance Mechanism

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Abstract

The Portfolio Balance Mechanism (PBM) theorizes that reducing the supply of U.S. Treasuries (USTs) increases their prices and prompts the creation of similar assets for preferred-habitat investors. The PBM is recognized as a possible mechanism to explain various important phenomena. We identify the PBM using the suspension of 30-year UST bond auctions between 2002 and 2005. The suspension prompted the issuance of safe, long-term collateralized mortgage obligations (CMOs), created by tranching mortgage pools to meet the demand of habitat-preference investors. The heterogeneity of USTs and CMOs results in an unusually clean and unambiguous identification of the PBM.

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Empirically identifying the PBM is important, as it is widely recognized as a possible mechanism to explain various significant capital market phenomena.[1] Identifying the PBM is challenging because it requires observing changes in investors' portfolios due to UST supply shocks and attributing these changes to a substitution effect. Indeed, UST supply shocks are often accompanied by signals that convey expectations about interest rates. Thus, investors may respond to UST supply shocks due to a signaling mechanism rather than the need to substitute UST bonds with other securities. Hence, identifying the PBM requires studying how UST supply shocks affect investors' portfolios in a setting with falsification tests to attribute shifts to a substitution effect.

We address this identification challenge by capitalizing on the suspension of 30-year UST bond auctions announced on Oct. 31, 2001. On May 4, 2005, the U.S. Treasury announced the possible resumption of 30-year UST auctions, which resumed in Feb. 2006. During the suspension period, the U.S. Treasury did not issue any nominal USTs with a maturity greater than 10 years. Around this suspension, we examine the extent to which investors, specifically life insurance companies, substitute UST bond purchases with newly issued agency-CMOs called Planned Amortization Class (PAC).

Examining life insurers' substitution of long-term USTs with PACs during this supply shock helps identify the PBM for several reasons. First, PACs with long average lives and minimal prepayment risk may substitute well for 30-year UST bonds. Agency-CMOs have high credit quality, as they are created by tranching cash flows from mortgage pools, called pass-throughs, with credit guarantees from Fannie Mae, Freddie Mac, and the U.S. government (Ginnie Mae pass-throughs) (Gorton and Metrick, 2013). Thus, prepayment risk, rather than credit risk, is the primary concern of agency pass-throughs (Downing, Jaffee, and Wallace, 2009). PACs, by construction, have little exposure to prepayment risk. Hence, agency-PACs have both low credit and prepayment risks, similar to USTs. Second, agency CMOs, especially PACs, are issued regularly in large amounts. PACs comprise about 38% of agency-CMO issuance amounts, and according to SIFMA, CMOs constituted 18% of

[1] Bernanke (2010) suggests that the PBM can explain the impact of QE policies on the real economy. The PBM posits that QE purchases of USTs reduce their net supply, increase their prices, and encourage the issuance of substitute bonds to meet the demand of investors favoring safe long-term bonds, stimulating investment. Before the financial crisis, the PBM suggests that purchases of USTs by the Global Savings Glut (GSG) countries led to a significant increase in securitization to generate safe assets (Bernanke, 2006, 2011).

the total outstanding agency mortgage-related securities between 2002 and 2018.[2] Third, life insurers are often considered preferred-habitat investors because their demand for long-term bonds is relatively inelastic (e.g., Koijen, Koulischer, Nguyen, and Yogo, 2017, 2021; Greenwood and Vissing-Jorgensen, 2018), and insurers purchase agency PACs.[3] Fourth, the targeted shock to 30-year UST supply allows us to leverage variation in time-to-maturity for precise identification. According to the PBM, different USTs are not perfect substitutes, so the shock to 30-year UST supply pushes habitat-preference investors to hold PACs with long maturities. Thus, we can use life insurers' purchases of PACs with medium average lives (under 10 years) as a control group. Lastly, heterogeneity in the exposure of agency CMOs to prepayment allows for controls and falsification tests to identify the PBM.

We test two PBM-related hypotheses. First, a decrease in long-term UST supply increases the volume of long-term PACs created to cater to the demand for long-term safe bonds from habitat-preference investors. Second, a decrease in long-term UST supply increases the price of these bonds and of long-term PACs. We formalize these hypotheses with a model that builds on the gap filling theory in Greenwood, Hanson, and Stein (2010), grounded in the PBM assumption as stated by Bernanke (2010) that financial assets are not perfect substitutes for preferred-habitat investors and incorporates limits to arbitrage. Without limits to arbitrage, arbitrageurs can issue equivalent substitutes, making the supply of long-term bonds perfectly elastic and their prices unaffected by supply changes (Greenwood and Vayanos, 2014; Vayanos and Vila, 2021). And, without frictions, tranching adds no value. In contrast, in our model, limits to arbitrage make the supply of long-term safe assets not perfectly elastic. Thus, mortgage dealers add value by creating long-term PACs as alternatives to long-term USTs.

We find support for the first hypothesis that a decrease in UST supply increases the volume of long-term PACs created to cater to habitat-preference investors. Using a difference-

[2] Fleming (2000) observes that no corporation can match the U.S. Treasury in issuance size and frequency. Agency debt from Fannie Mae and Freddie Mac can generally substitute for USTs but not for the 30-year UST, as these agencies stopped issuing 30-year non-callable bonds in the early 2000s.

[3] From Life USA Holding's 1996 10-K, "Government agency obligations are predominantly held in the form of PAC CMOs, the most conservative type of CMO issued. These CMOs are specifically structured to provide the highest degree of protection against swings in repayments caused primarily by changes in interest rates and have virtually no risk of default. These securities are well suited to fund the payment of the liabilities they support."

in-difference analysis, we find that life insurers increased purchases of new long-term PACs relative to medium-term PACs during the suspension period. The drop in UST bond purchases is comparable to the increase in long-term PAC purchases, suggesting a strong substitution. This result holds with insurer and time fixed effects and controls for insurer purchases of CMOs with prepayment risk. Thus, the findings are not due to economic conditions, fixed insurer characteristics, or an insurer's time-varying demand for CMOs in general. Consistent with the parallel trend assumption, similar trends in long-term and medium-term PAC purchases are observed both before the 30-year UST auction suspension and after its resumption. Another difference-in-difference analysis shows that more mortgage pass-throughs were tranched to create PACs compared to other CMOs during the suspension.

We find strong support for the second hypothesis that a decrease in the net supply of 30-year USTs raises the price of 30-year USTs and of long-term PACs. Consistent with Bernanke, Reinhart, and Sack (2004), the daily return difference between 30-year and 10-year USTs was 2.1% on the day the U.S. Treasury announced the suspension of the 30-year UST bond auction (Oct. 31, 2001). We also show a significant reversal when the U.S. Treasury announced the possible resumption of 30-year UST auctions on May 4, 2005. Furthermore, we show that the effect on 30-year UST yields lasts for the duration of the suspension period. Moving beyond the direct effect on UST prices, the monthly return difference between long- and medium-duration PACs was 3.9% on announcement.

Several additional findings support the robustness of our identification of the PBM. Exploiting heterogeneity in PAC protection against prepayment, we find that the effect is concentrated in the safest PAC tranches. In addition, the increase in long-term PAC purchases is stronger for insurers with prior CMO experience. And, the increase in PAC purchases holds across insurer sub-samples based on AUM and for alternative specifications, including dollars purchased, purchase amount relative to AUM, and log transformations.

The PBM explains all of our findings, unlike the alternative signaling hypothesis. For example, the 30-year UST auction suspension could signal expected changes in mortgage prepayment patterns, affecting the demand for PACs. However, this signaling hypothesis does not explain the increased acquisition of new long-term PACs by life insurers compared to medium-term PACs, without changes in their typical and substantial investments in other long-term CMOs with prepayment risk during the suspension. Moreover, signaling also fails to explain the subsequent reversion to the baseline after the resumption of 30-year UST auctions in 2006. This example demonstrates the advantage of using the targeted 30-year UST supply shock for identification. During QE operations, USTs of various maturities are purchased at once, disrupting the term structure broadly and making it difficult to use a single maturity as a control group. This example also highlights the use of CMOs with prepayment risk for falsification tests. Thus, our findings—especially the diverse acquisition behaviors of CMOs by life insurers—result in an unambiguous identification of the PBM.

Our findings contribute significantly to the securitization literature. Gennaioli, Shleifer, and Vishny (2012, 2013) formalize the relation between the excess demand for safe assets and tranching volume. In their model, banks create new safe assets by pooling and tranching mortgage portfolios when investor demand for safe assets exceeds supply. The increase in long-term PAC acquisitions by life insurers during the suspension of 30-year UST auctions is direct empirical evidence of this relation between the excess demand for safe assets and tranching volume. Gorton and Metrick (2013) point out that one of the channels by which securitization adds value is the convenience yield channel, where investors pay a premium for certain securities. The convenience yield of long-term agency PACs may stem from preferred-habitat investors' need for safe long-term assets, as hypothesized in the PBM, or from agency CMOs serving as collateral in REPO agreements (Copeland, Martin, and Walker, 2011). We provide evidence of the convenience yield channel, as the price of long-term PACs relative to medium-term PACs increases at the announcement of the UST bond auction suspension, and habitat-preference investors increase PAC purchases during the no-auction period. Tranching may also address a 'lemons problem' when selling portfolios of illiquid assets (DeMarzo, 2005). Our findings cannot be attributed to information frictions, as they do not explain the increased acquisitions of long-term PACs relative to medium-term PACs and variation in UST and PAC prices due to the 30-year auction suspension.

We contribute to the literature that examines the gap-filling theory of Greenwood, Hanson, and Stein (2010), where corporations adjust debt maturity to cater to investors with habitat preferences when there is a gap between the supply and demand of safe, long-term bonds. Badoer and James (2016) shows an increase in the issuance of corporate bonds with maturities over 30 years relative to those over 20 years from 2002 to 2009. Like Badoer and James (2016), we focus on the issuance of long-term bonds, but we focus on the increase in tranching rather than corporate bond issuance. Indeed, in our model, mortgage dealers act similarly to corporations in Greenwood, Hanson, and Stein (2010). We extend this literature by analyzing the acquisitions by preferred-habitat investors in addition to aggregate issuance. Our findings document a direct switch from 30-year UST bonds to newly issued PACs in life insurers' portfolios, along with an increase in the issuance of long-term PACs, clearly identifying the practice of catering to habitat-preference investors to fill the gap left by a UST supply shock.

The PBM links the pre-crisis surge in securitization to a growing demand for safe assets from GSG countries, as discussed by Bernanke (2011). Another driver for increased tranching could be regulatory arbitrage, where tranching generates highly rated securities subject to more favorable capital requirements. Information frictions could also explain tranching, suggesting the pre-crisis surge in securitization was due to increased mortgage supply rather than demand for safe assets. Empirical evidence shows regulatory arbitrage and information frictions contributed to the pre-crisis rise in securitization (e.g., Acharya, Schnabl, and Suarez, 2013; Begley and Purnanandam, 2016), while evidence linking the surge in securitization to the PBM mainly shows a correlation between the foreign demand for safe US assets and the issuance of AAA-rated private label securities (Bernanke, Bertaut, DeMarco, and Kamin, 2011; Bertaut, DeMarco, Kamin, and Tryon, 2012).[4] Although the shock we investigate is distinct from GSG country purchases, our work shows that a UST supply shock increases tranching to cater to preferred habitat investors. Naturally, our findings do not rule out that pre-crisis tranching increased due to information frictions or regulatory arbitrage but support the idea that the PBM played a role.

Our identification of the PBM supports the idea that the PBM played a role in the effect of QE. Many different mechanisms could have played a role in QE. For example, QE purchases paid with reserves can reduce bank lending (Diamond, Jiang, and Ma, 2023). Our paper does not examine how the PBM interacts with other QE mechanisms. However, we

[4]Tranching non-agency loan pools (private labels) creates tranches with varying credit ratings, while tranching agency pass-throughs results in tranches with identical credit risk due to credit guarantees.

contribute to the QE literature by examining the PBM with inelastic-demand investors (life insurers) over a low-frequency (four-year) shock to the supply of long-term bonds. This extends the literature because, as Selgrad (2023) notes, most papers in the QE literature use high-frequency event studies to avoid endogeneity issues. By contrast, our long-term shock enables us to generalize our findings across several years of economic scenarios. Moreover, Selgrad (2023) focuses on how elastic-demand investors (mutual funds) use the QE windfall to buy corporate bonds.[5] In contrast, our findings show a persistent substitution effect in life insurers' holdings during the four-year suspension. Ray, Droste, and Gorodnichenko (2024) explore the role of preferred habitat in QE. Using high-frequency identification, they show that UST demand shocks affect low-risk asset yields. They show that demand shocks have minimal impact on economically sensitive asset returns, addressing the signaling hypothesis. Our findings show that a UST supply shock propagates to life insurers' portfolio holdings and the creation of substitutes, extending their analysis.

Section 1 briefly describes different types of CMOs; Section 2 develops the tested hypotheses; Section 3 describes the identification strategy; Section 4 describes the data; Section 5 describes the empirics; and Section 6 concludes.

1 CMOs

Understanding our identification strategy requires knowing the differences between the CMOs in our analysis. Our main analyses use PACs. PACs are agency-CMOs whose principal payments are predetermined, provided that prepayment speeds of the underlying pass-through remain within specified ranges called "PAC bands". Prepayment speeds are typically defined in terms of the Bond Market Association's prepayment speed standard (PSA).[6] The PSA standard is commonly used as a simple metric to build different prepayment speed scenarios for mortgage pass-throughs. The cash flows of a PAC are predetermined provided the PSA of the underlying pass-through remains within the PAC bands. Panel A of Figure 1 illustrates the cash flows of a PAC with bands equal to 100% PSA to 250% PSA.

[5] Breckenfelder and De Falco (2023) estimate the elasticity of demand for government bonds, confirming that mutual funds' demand is far more elastic than that of life insurers.

[6] See Appendix A.1 and Duarte and McManus (2016) for details on the PSA standard.

The humped-shaped lines in Panel A represent the principal payments under the fast (250% PSA) and slow (100% PSA) prepayment scenarios. The promised principal amount of the PAC depicted in Panel A is the minimum principal amount between the scenarios of fast prepayment and of slow prepayment. Panel A also shows that a PAC is created with a companion Support (SUP) tranche that receives the residual cash flows of the underlying pool of mortgages after the payment of the PAC cash flows. The SUP tranche absorbs a disproportionate share of the underlying mortgage pass-through prepayment risk. Indeed, Panel A shows that in the 250% PSA (100% PSA) scenario the SUP tranche receives principal cash flows earlier (later).

[Insert Figure 1 Here]

Typically, PAC tranches are structured sequentially, with principal payments allocated to each tranche until its full amortization, before moving to the next, resulting in tranches with varying average lifespans. Figure 1, Panel B exemplifies the cash flows of three PACs with different weighted average lives and bands equal to 100% PSA to 250% PSA. The shorter-term PAC depicted in this panel is paid down completely in the first 60 months, the second PAC receives principal cash flows from months 61 to 120, while the longer-term PAC receives principal from months 121 to 360.

We also analyze life insurers' purchases of Sequential (SEQ) CMOs. SEQs are the second most common type of CMO. Figure 1, Panels C and D exemplify the cash flows of three SEQs with different weighted average lives under different prepayment scenarios. Although the sequential structure of cash flows in the SEQs in Panels C and D is similar to that of the PACs in Panel B, SEQ cash flows entail prepayment risk because they lack a companion SUP tranche. Indeed, the SEQs' principal cash flows when the pool PSA is 250% (Panel C) are paid earlier than when the pool PSA is 100% (Panel D). As a result, SEQs serve as less ideal substitutes for long-term UST bonds, which do not face prepayment risk.

Habitat-preference investors, such as life insurers, opt for PACs due to their stability and predictable cash flows. SEQs are also popular CMOs in life insurers' portfolios.[7] Conversely,

[7]As an example, the Travelers Group Inc. 1997 10-K exemplifies life insurers' investment strategy in CMOs: "The investment strategy of the Insurance Services segment is to purchase CMO tranches that are protected against prepayment risk, including planned amortization class (PAC) tranches. Prepayment-

investors with a lower aversion to prepayment risk, such as hedge funds, are more inclined to invest in the SUP tranches (Fabozzi and Ramsey, 1999). Dealers create agency CMO securities by selecting the collateral and structuring a CMO deal that appeals to investors with varying prepayment risk tolerance. Dealers also hold SUP tranches when attractive.

2 Hypotheses Development

We formalize two hypotheses related to the PBM with a model that adapts the framework presented in Greenwood, Hanson, and Stein (2010) to a scenario with a mortgage dealer. As in Greenwood, Hanson, and Stein (2010), we consider a three-period world. In the first period, the known short-term interest rate is r_1. The interest rate for the second period is r_2 with mean μ_r and variance σ_r^2. Preferred-habitat investors exhibit an inelastic demand for bonds maturing at $t = 3$. The excess supply of bonds with maturity at $t = 3$ is represented by g, which is equal to the amount of bonds the government issues minus the inelastic demand from preferred habitat investors.

Drawing parallels to Greenwood, Hanson, and Stein (2010), our model incorporates a yield curve arbitrageur that exploits arbitrage opportunities within the yield curve. This term-structure arbitrageur addresses the excess demand for long-term bonds by selling h dollars of long-term bonds at a price P and reallocating the proceeds at the short-term interest rate. The arbitrageur maximizes the mean variance utility of terminal wealth:

$$\max_h h[(1 + r_1)(1 + \mu_r) - \frac{1}{P}] - \frac{h^2}{2}\eta_h \tag{1}$$

where $\eta_h = (1 + r_1)^2\sigma_r^2/\lambda$ is the risk penalty of the yield curve strategy, and λ is the yield curve arbitrageur's risk tolerance.

The mortgage dealer can cater to the excess demand from preferred habitat investors by issuing f dollars of long-term bonds that cannot be prepaid and mature at $t = 3$ to finance the purchase of mortgage pass-through securities that can be prepaid. We refer to these long-term bonds sold by mortgage dealers as long-term PACs due to their resemblance to actual PACs, which have minimal exposure to prepayment and are collateralized by mortgage

protected tranches are preferred because they provide stable cash flows in a variety of scenarios. The segment does invest in other types of CMO tranches if a careful assessment indicates a favorable risk/return tradeoff; however, it does not purchase residual interests in CMOs."

pass-throughs. Specifically, homeowners borrow through fixed-rate mortgages with maturity at $t = 3$. Homeowners can prepay their mortgages at time $t = 2$ without a prepayment penalty. The mortgage rate is set in the pass-through market that is exogenous to the model. Preferred habitat investors do not invest in mortgage pass-throughs because mortgages can be prepaid. Let M_I be the value at time $t = 3$ of the amount of interest paid between time $t = 1$ and $t = 3$ on \$1 of mortgage principal. M_I is affected by prepayment and has mean μ_M and variance σ_M^2. Let P be the price at $t = 1$ of the PAC maturing at $t = 3$. Since M_I is affected by prepayment while P is not, the mortgage dealer assumes prepayment risk.[8] The mortgage dealer maximizes the mean variance utility of terminal wealth:

$$\max_f f(1 + \mu_M - \frac{1}{P}) - \frac{f^2}{2}\eta_f \tag{2}$$

where $\eta_f = \sigma_M^2/\theta$ is the risk penalty inherent to the mortgage dealer's problem, and θ is the risk tolerance of the mortgage dealer.

The first-order conditions of the mortgage dealer and the arbitrageur's problem along with the market clearing conditions lead to the following expressions for the expected return premium of the long-term bond and the amount of long-term PAC issuance:[9]

$$\frac{1}{P} - (1 + r_1)(1 + \mu_r) = \frac{\eta_f \eta_h}{\eta_f + \eta_h} g \tag{3}$$

$$f^* = -\frac{\eta_h}{\eta_f + \eta_h} g \tag{4}$$

It is interesting to compare the solution in Equations 3 to 4 with the implications in Greenwood, Hanson, and Stein (2010). Similarly to Greenwood, Hanson, and Stein (2010), the price of the long-term bond in Equation 3 responds to shocks on its excess supply. This contrasts with models without any limits to arbitrage. For example, when the yield curve arbitrageur is risk neutral ($\eta_h = 0$) resulting in no limits to the yield curve arbitrage, the price of the long-term bond, as outlined in Equation 3, is independent of its excess supply, which aligns with the expectation hypothesis. Moreover, in the scenario where the mortgage dealer's risk aversion approaches infinity ($\eta_f \to \infty$), the issuance of long-term PACs ceases

[8] In the model, the long-term PACs do not have PAC bands, implying that the mortgage dealers are completely assuming the risk of prepayment and not leaving any risk to the PAC buyers. Moreover, by assuming this prepayment risk, the dealers emulate the roles played by dealers and hedge funds in reality.

[9] We assume that prepayment risk is not priced in pass-throughs. See Appendix A.2 for details.

($f^* = 0$), rendering the price of the long-term bond in Equations 3 similar to that in the special case of the Greenwood, Hanson, and Stein (2010) model without corporations.

The model builds on Greenwood, Hanson, and Stein (2010) by incorporating the role of the mortgage dealer. In the Greenwood, Hanson, and Stein (2010) model, corporations aim for a specific debt maturity, driven by various constraints related to their capital structure decisions (e.g., Myers, 1977; Barclay and Smith, 1995; Harford, Klasa, and Maxwell, 2014). Corporations deviate from their target maturity to fill the gap left by a negative excess supply of safe long-term bonds. In our model, as well as in reality, mortgage dealers are not bound by the same constraints that corporations encounter when determining their debt's maturity. Indeed, the only constraints mortgage dealers face in our model relate to their risk aversion, paralleling the constraints that arbitrageurs confront. This framework aligns with the notion that catering to CMO buyers is the primary goal of dealers when structuring CMOs, which is supported by the iterative process of CMO design.[10]

The model provides a reason for tranching. Tranching is a blunt violation of the Modigliani and Miller (MM) proposition. In fact, when there are no limits to yield curve arbitrage, the yield curve arbitrageur completely absorbs shocks to the excess supply of long-term bonds, and tranching is not observed ($f^* = 0$).[11] In this scenario, the PBM would not be applicable, as the arbitrageur could fully supply long-term bonds to meet the excess demand from habitat-preference investors, eliminating the need for mortgage dealers to issue PACs and the need for corporations to adjust the maturity of their debt to fill the excess demand gap for safe long-term bonds (Greenwood, Hanson, and Stein, 2010). On the contrary, where there are limits to arbitrage ($\eta_h > 0$), mortgage dealers help absorb negative shocks to the excess supply for long-term bonds by issuing long-term PACs.

When neither the mortgage dealer nor the arbitrageur is risk neutral ($\eta_f > 0$ and $\eta_h > 0$),

[10] Dealers present hypothetical agency CMO structures and pricing to gauge market interest. If demand is weak, they offer alternatives. This iterative proposal and adjustment process continues until the final structure date, when collateral and cash flow rules are set.

[11] CMOs are structured as Real Estate Mortgage Investment Conduits (REMICs), resulting in no corporate tax advantages for CMO issuance (Gorton and Metrick, 2013). The model justifies tranching to create long-term PACs considering limits to arbitrage and the assumption of investor habitat preference for long-term bonds (e.g., Culbertson, 1957; Modigliani and Sutch, 1966). It may also rationalize the existence of various CMO types due to a segment of investors with an inelastic demand for securities not freely created by arbitrageurs. Practitioners cite this tranching rationale to justify the numerous CMO types observed (Davidson, Sanders, Wolff, and Ching, 2008).

the model delivers the two PBM hypotheses that we examine:

Hypothesis 1 *The issuance of long-term PACs increases when the excess supply of long-term USTs decreases, fulfilling the demand for long-term bonds from habitat-preference investors, such as life insurers.*

Hypothesis 2 *The price of long-term bonds, such as long-term USTs and long-term PACs, increases in response to negative supply shocks to long-term UST bonds.*

3 Identification Strategy

Our analysis examines the suspension of 30-year UST bond auctions (2001 Q4 – 2005 Q4) as a shock to long-term bond supply. We also exploit the reintroduction of the 30-year UST. The U.S. Treasury announced the possible resumption on May 4, 2005.

We map the bond with maturity at ($t = 3$) in our model to the real-world 30-year UST bond, deliberately excluding UST notes (time-to-maturity of 2-10 years) from our long-term bond category. This approach leverages UST and CMO maturity variations to identify the effects of suspending the 30-year UST bond auctions on quantities and prices (Hypotheses 1 and 2). Furthermore, the diversity of CMO types regarding prepayment exposure allows for multiple controls and falsification tests.

Our identification strategy is to show that a surprise shock to the supply of the 30-year UST results in a diverse set of outcomes consistent with the PBM and not alternative mechanisms. Specifically, the suspension of 30-year UST issuance increases the price of long-term bonds relative to medium-term bonds, increases the issuance of PACs relative to SEQs, and increases the demand for long-term PACs relative to medium-term PACs, without affecting the demand for long-term SEQs relative to medium-term SEQs. Moreover, these patterns unwind on the resumption of the auctions.[12]

Our identification strategy is based on two premises: First, there was no unobserved shock leading to the same diverse set of outcomes that the PBM predicts, which coincided with

[12] Gabaix, Krishnamurthy, and Vigneron (2007) also explore CMO heterogeneity by analyzing prepayment risk pricing in Interest-only (IO) and Principal-only (PO) tranches. Although common, IOs and POs are less prevalent than PACs and SEQs, and life insurers rarely purchase IOs and POs. Unlike IOs and POs, PAC cash flows remain stable during refinancing waves due to the SUP tranche absorbing prepayment risk.

the suspension and reversed when auctions resumed. Second, the suspension and subsequent resumption of the 30-year UST bond auction were at least partially unexpected.[13] The greater the anticipation of the 30-year UST bond auction's suspension and resumption, the more challenging it becomes to find evidence consistent with the PBM. Indeed, no price reactions would be observed at the time of the suspension and resumption announcements. Thus, price reactions to the auction suspension and resumption announcements support that the shocks were at least partially unexpected.

Our identification strategy addresses the two alternative hypotheses that often plague the identification of the PBM. The signaling hypothesis indicates that the suspension may, for instance, signal anticipated mortgage prepayment behaviors, prompting increased demand from life insurers for PACs, which are prepayment-insensitive, and a reduced appetite for SEQs with no protection against prepayment. Therefore, this alternative does not predict a greater increase in long-term PAC purchases compared to medium-term PACs, unless the prepayment information pertains to a period more than 10 years into the future, which is unlikely. Furthermore, if such a scenario were to occur, there should be a corresponding decrease in long-term SEQ purchases relative to medium-term SEQs.

Information frictions are another alternative theoretical justification for tranching.[14] If the auction suspension is accompanied by an increase in information frictions, we would observe changes in the life insurers' acquisitions of CMOs with prepayment risk (SEQs) and in medium-term PACs. Moreover, an increase in information frictions between mortgage originators and CMO buyers does not affect the price of long-term USTs.

[13]Some anecdotal evidence suggests that a general decline in the net issuance of 30-year USTs might have been anticipated. For example, in Feb. 2000, Gary Gensler, Under Secretary of the Treasury for Domestic Finance, hinted that the 10-year UST might replace the 30-year UST as the long-term interest rate benchmark. Conversely, other anecdotal evidence suggests the market was surprised by the discontinuation. Notably, news coverage by the Wall Street Journal (https://www.wsj.com/articles/SB1004548380881711360), CNN (https://money.cnn.com/2001/10/31/markets/longbond/), and The Economist (https://www.economist.com/finance-and-economics/2001/11/01/cut-short) described the discontinuation as a 'surprise move'. The resumption of the auction may also have been partially anticipated due to the large federal budget deficit at the time.

[14]Originators generally have better information than investors. They can gauge the likelihood of borrowers prepaying their mortgages by using a points-contract rate trade-off, encouraging mobile borrowers to choose contracts with lower points and higher rates (Stanton and Wallace, 1998). Mortgages in a pass-through pool come from one lender's origination pipeline, so private information carries over to the pool (Downing, Jaffee, and Wallace, 2009). To address this 'lemons problem,' dealers can tranche their mortgage pass-throughs and retain the CMO tranches most susceptible to prepayment risk (DeMarzo, 2005).

4 Data

Our empirical analysis spans from 1997 Q1 to 2007 Q4, beginning in 1997 Q1 because of the availability of CMO pricing data, and concluding in 2007 Q4 to ensure that our findings are not influenced by the 2008 financial crisis.

We gather data for all non-callable UST bonds and notes trading during our sample period from the CRSP Treasury files. CRSP data contain information on each UST, including CUSIP, daily return, total amount outstanding, issuance date, and maturity date.

Figure 2 shows the shock on the supply of long-term UST bonds we explore. Figure 2, Panel A shows the total amount of UST notes and bonds issued between 1997 and 2007. For each Treasury CUSIP, we include the initial issuance amount and subsequent reopenings based on increases in the outstanding amount (*TDTOTOUT* in CRSP Treasury daily files). We divide all UST issuances into two categories based on the term of the USTs: notes are medium-term (two to ten years to maturity) and bonds are long-term (with maturities greater than ten years). The issuance of UST notes increased during the event period from about $0.4 trillion in 2002 to $0.6 trillion in 2005. UST bond issuance decreased from about $16 billion in 2001 to zero dollars between 2002 and 2005. About $26 billion worth of UST bonds were issued in 2006 with surprisingly strong demand.[15] Figure 2, Panel B shows the issuance of UST bonds relative to the total issuance of UST bonds and notes. In 2001, the issuance of UST bonds was about 6% of the total issuance of bonds plus notes. Between 2002 and 2005, there was no issuance of UST bonds. Bond issuance increased to approximately 4% of the total issuance of bonds plus notes in 2006.

[Insert Figure 2 Here]

To evaluate Hypothesis 1, which predicts an increase in the production of long-term PACs to meet the demand of habitat investors, we merged our CRSP Treasury data with a CMO database that we assembled and data on life insurance companies' bond portfolios from the

[15] See `https://home.treasury.gov/news/press-releases/po749` and `https://home.treasury.gov/news/press-releases/js2420` for the announcement of the suspension and the announcement of the possible resumption of 30-year UST bond auctions. See `https://www.nytimes.com/2006/02/09/business/30year-treasury-bond-returns-and-demand-is-strong.html` for evidence that the demand at resumption was surprisingly strong in Feb 2006.

National Association of Insurance Commissioners (NAIC) database. Below, we describe the components and the process of creating this merged database.

Our CMO database is a comprehensive panel of all agency-CMOs issued between 1997 Q1 and 2007 Q4 by the Federal Home Loan Mortgage Company (FHLMC "Freddie Mac"), the Federal National Mortgage Association (FNMA "Fannie Mae"), and Government National Mortgage Association (GNMA "Ginnie-Mae"). The data related to FHLMC and FNMA CMOs are from Bloomberg and the data for GNMA CMOs are obtained from the GNMA data disclosure website[16] The raw data consist of 3,325 individual CMO deals with 148,386 individual tranches. A deal can have multiple groups of collateral that are separately tranched to create PACs or SEQs. For each tranche, we have an exhaustive array of characteristics, including the CUSIP, issue size, and weighted average life (WAL) calculated at the time of issuance based on the benchmark prepayment scenario used in the CMO deal's prospectus. We also have information on the collateral whose cash flows are being tranched.

Using Bloomberg and GNMA classifications of the tranche types, we remove those CMOs that do not fall within the following three classes of tranche types: planned amortization class (PAC), support tranches (SUP), and sequential pay securities (SEQ). Our final database has 3,182 deals and 88,431 CMO tranches, all falling within these three classes of tranches.[17] Table 1 provides summary statistics for our CMO data.

[Insert Table 1 Here]

Table 1, Panel A presents descriptive statistics of agency CMO deals in our initial CMO sample with all types of tranches. Each deal has on average $2.3 billion in principal and 45 tranches. Table 1, Panel B shows descriptive statistics for the PAC and SUP tranches in the database. PACs and SUPs comprise the largest class of CMOs in the sample, with 60,715 tranches in this category and approximately 41% of the tranches issued in our initial CMO

[16] https://www.ginniemae.gov/investors/investor_search_tools/Pages/default.aspx

[17] There are hundreds of CMO types in the data. We remove from our data CMOs such as hybrid CMOs (e.g. IO+PAC) that cannot clearly be assigned to the three classes mentioned above. Specifically, we counted the number of occurrences of the most common types of CMOs which are "PAC", "SEQ", "SUP", "IO", "PO", and "TAC" in the type description. Then, for this set of tranche types, we classified a tranche as a PAC if the term "PAC" is the only term appearing in the type description from this set of types. Likewise, a SEQ tranche only has "SEQ" in the type description. The discarded CMO tranches that we cannot cleanly categorize make up a much smaller fraction of the principal amount of CMOs in the data than PAC, SUP, and SEQ. Arcidiacono, Cordell, Davidson, and Levin (2013) describe the many different types of CMOs.

sample with all tranche types and 38% of the dollar amount issued in the initial sample. Table 1, Panel C shows descriptive statistics for SEQs. These SEQs represent the second largest class of CMOs with 27,716 tranches and 27% of the dollar amount issued in the initial CMO sample.

In our empirical work, we take advantage of the average lives at the issuance of PACs and SEQs. Table 1, Panel B shows that the mean weighted average life of PACs and SUPs is 7.7 years with the first and third quartiles at 3.3 and 11.0 years, respectively. The weighted average life of SEQs is similar to that of PACs with a mean of 7.8 years.

Our life insurance companies' bond portfolio data are sourced from the NAIC database. Specifically, we use NAIC Schedule D - Part 1 data. These data include details about individual life insurers, such as their end-of-year assets under management (AUM) and bond holdings at the CUSIP level. The initial NAIC data are from 1997 to 2007. We remove years when an insurance company is not active and keep insurers in the top 250 of assets under management in 1999, which predates the shock. Although there are 1,305 insurers in the sample in 1999, the top 250 (100) insurers control 95% (82%) of the fixed income assets or $1.4 ($1.2) trillion. This filter prevents the results from being affected by a large number of companies that have a small portfolio.[18] Because some holdings are non-US and not denominated in dollars, we use the reported total AUM of the insurer, which is dollar-denominated.[19]

As mentioned above, to analyze how preferred-habitat investors responded to the interruption of UST bond auctions, we merged our CRSP Treasury data with the CMO data and the NAIC data by CUSIP. The result of merging these three different data sources is a comprehensive database containing life insurance companies' holdings, along with the

[18] Appendix Figure A1 shows the number of life insurance companies by year in our sample. The number of insurers is exactly 250 in 1999 because we limited the sample to the top 250 insurers by AUM in 1999. The figure shows that the number of insurers decreases during the sample period to 203 insurers in 2007. This decrease of 18.8% is in line with the overall decrease in the number of life insurers of 25.1% during the same period of time, as documented by the American Council of Life Insurers (ACLI, 2022). (Table 1.7 of the *Life Insurers Fact Book 2022* shows that the number of life insurers is 1347 in 1999 and 1009 in 2007, a 25.1% decrease.) Figure A1 also shows trends in the aggregate size of the fixed income portfolios of life insurers during the sample period. In 1999, life insurers managed about $1.4 trillion, and in 2007, despite a decline in the number of life insurers in the sample, life insurers managed about $2.1 trillion.

[19] The structure of NAIC data varies annually, necessitating meticulous assembly of multiyear datasets. For example, the line numbers that refer to the total AUM vary from year to year.

characteristics of the USTs and CMOs in their portfolios.

Using these unique merged data, we identify purchases by life insurance companies of newly issued USTs and CMOs, which is fundamental to addressing the PBM idea that the creation of new bonds is motivated by the demand of preferred habitat investors. Although the raw NAIC data do not include the issuance date of the bonds, which is necessary to identify purchases of newly issued securities, the CRSP Treasury data and the CMO data contain issuance dates. Additionally, the NAIC data include the date a security is purchased.[20] Hence, our merged dataset includes the issuance date, the purchase date, and the amount that a given insurance company holds of a given bond at the end of the year. With this information, we build a quarterly dataset of purchases of newly issued securities. This quarterly panel dataset affords sharper timing with respect to key announcements. Examining newly issued securities is also more appropriate because the WAL in the CMO data is as of the origination.

Each quarter, we then aggregate the bond purchases of a given insurance company to calculate the total purchases of newly issued medium- and long-term USTs, PACs, and SEQs in the sample. We classify CMOs as medium-term if they have average lives at issuance of 2 to 10 years, and long-term if they have average lives of more than 10 years. This classification of medium- and long-term CMOs mimics the definition of UST notes and bonds, respectively. We use these purchases in Section 5 to analyze the impact of the elimination of the 30-year UST bond auction on the CMO holdings of life insurance companies.

Table 2 shows the summary statistics of these purchases by life insurance companies of various types of CMOs and USTs. About 12.4% (1,241/9,984) of the 9,984 insurer-quarter observations in the final sample include the purchase of new long-term PACs. Conditional on at least one long-term PAC purchase in a quarter, the mean purchase amount is $45.7 million, or about 0.7% of an insurer's total fixed income portfolio. About 3.6% (355/9,984) of the observations involve the purchase of new UST bonds. The number of new UST bond purchases is low because there are no new issuances from 2002 to 2005 due to the

[20]From 2001 onward, the NAIC includes the purchase date, but for 1997 to 2000, only the purchase year is given. Using 2001 holdings data, we fill in purchase dates for 1997 to 2000 when possible. We have purchase dates for 75%, 62%, 48%, and 40% of CMO holdings for 2000, 1999, 1998, and 1997, respectively. If the purchase date is missing, we use the issuance quarter if the acquisition year matches the issuance year.

suspension. In contrast, for 1997 to 2001, about 5.9% of firm-quarters involve the purchase of new UST bonds. Conditional on an insurer purchasing newly issued UST bonds in a given quarter, the mean purchase amount is $45.1 million, or 0.5% of an insurer's total fixed income portfolio. In addition, life insurers are also frequent purchasers of long-term SEQ tranches. Approximately 11.2% (1,117/9,984) of the observations involve the purchase of new long-term SEQs, and the average purchase amount is $33.1 million, or 0.5% of an insurer's total fixed income portfolio.

[Insert Table 2 Here]

To examine Hypothesis 2, predicting that a shock to UST bond supply affects long-term PAC prices, we gather monthly PAC index returns from the ICE Bank of America - Merrill Lynch CMO Index database. These indices are available from the ICE Index Platform on the last trading day of each month during our sample period.[21] The data for PACs (CMOP and CMPZ indices) include market value, total return, effective yield, and effective duration of CMO portfolios grouped by effective duration. The effective yields and durations are calculated by the ICE Bank of America Merrill Lynch index provider using their model.[22] Since price reactions to interest rate fluctuations are influenced by bond durations, we categorize medium- and long-duration PACs based on their effective duration for examining Hypothesis 2. We also gather data on SUPs (CMSZ). There are limitations: (1) we do not observe the underlying constituents of the indices, so the composition may change monthly, and (2) at longer maturities, the number of constituents is sparse. Specifically, the portfolio of PACs with a duration longer than that of the 10-year note (about eight years) has a median of 12 constituents.

[21] https://www.ice.com/fixed-income-data-services/index-solutions/fixed-income-indices. See Galdi, Goldblatt, and Zhang (2006) for details on these indices.

[22] The effective yields and durations of CMOs are calculated with a prepayment model that estimates variations in CMO cash flows due to changes in interest rates.

5 Empirical Results

5.1 Newly Issued, Long-term PAC Purchases by Habitat Investors

We now examine Hypothesis 1, which predicts that a negative shock to the excess supply of long-term USTs leads to an increase in the issuances of long-term PACs to fulfill the demand of habitat preference investors, such as life insurers. We first examine the purchase behavior of life insurers of newly issued PACs and SEQs. Then, we examine the aggregate amount of mortgage collateral tranched to create PACs relative to that used to create SEQs during the suspension period. We call the period from 2001 Q4 to 2005 Q4, during which UST bond auctions were suspended, the *No Auction* period. We call the subsequent period from 2006 Q1 to 2007 Q4, when 30-year UST auctions resumed, the *Post Period*.

We estimate a difference-in-difference specification. The first difference is the change in the principal amount of newly issued medium- and long-term PACs purchased by life insurers during the *No Auction* period relative to the period with UST bond auctions. The second difference captures differences in this change in PAC holdings between long-term and medium-term PACs. To do so, we estimate the following specification:

$$\begin{aligned}\Delta PAC_{i,j,q} = {} & \beta_1 \times \mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q \\ & + \beta_2 \times \mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{Post Period})_q \\ & + \beta_3 \times \mathbb{1}(\text{LT})_{i,j} + \mu_j + \eta_q + \text{Controls}_{i,j,q} + \epsilon_{i,j,q}.\end{aligned} \tag{5}$$

The dependent variable is the amount of purchases of newly issued medium- or long-term PACs by the insurance company j in quarter q.[23] We separately aggregate the purchases of medium- and long-term PACs, resulting in two observations (i) per quarter q for insurance company j. The volume of PACs purchased is in millions of dollars. We classify medium-term PACs as those that have a weighted average life between 2 and 10 years at the time of issuance (similar to that of UST notes) and long-term PACs as those that have a weighted average life greater than 10 years at the time of issuance (similar to that of UST bonds).

[23] We focus on purchases because the PBM predicts increased creation of substitutes to meet the demand of preferred habitat investors for a specific security. It does not provide specific predictions regarding sales of existing holdings. Moreover, life insurers are primarily buy-and-hold investors (Chodorow-Reich, Ghent, and Haddad, 2021). Lastly, decreases in insurer holdings of a bond may also result from amortization.

$\mathbb{1}(\text{LT})_{i,j}$ is an indicator variable that equals to one for the time series of insurer j's aggregate purchases of long-term (i=1) securities and zero for the series of aggregate purchases of medium-term ($i = 0$) securities. $\mathbb{1}(\text{No Auction})_q$ is an indicator variable equal to one for the quarters between 2001 Q4 and 2005 Q4 when UST bond auctions were suspended. $\mathbb{1}(\text{Post Period})_q$ is an indicator variable equal to one for the quarters between 2006 Q1 and 2007 Q4, when UST bond auctions resumed. β_1 measures if long-term PAC purchases change during the *No Auction* period. β_2 measures if long-term PAC purchases return to pre-suspension levels after the suspension ends. μ_j is a fixed effect for the insurance company j that accounts for all fixed determinants of PAC investment activity. For example, these insurer fixed effects control for different average propensities to purchase PACs across insurers. η_q is a fixed effect for the quarter to control for aggregate trends and absorbs the standalone $\mathbb{1}(\text{No Auction})_q$ and $\mathbb{1}(\text{Post Period})_q$ variables. In $\text{Controls}_{i,j,q}$, we account for insurer j's purchases of newly issued medium-term ($i = 0$) and long-term ($i = 1$) SEQs in quarter q ($SEQ_{i,j,q}$) to control for time-varying firm-specific factors affecting demand for medium- and long-term CMOs in general. We double cluster standard errors by insurer and quarter.

The key identifying assumption underlying our difference-in-difference specification is that insurance companies' investments in long-term PACs and medium-term PACs, controlling for investments in SEQs and the fixed effects, would have had similar trends if the U.S. Treasury had not suspended the 30-year UST bond auctions. Figure 3 shows the dynamics of Equation 5. It is clear that the purchases of the two types of PACs had similar activity prior to the suspension of the UST bond auctions. After the suspension announcement, purchases of newly issued long-term PACs increased significantly following 2001 Q4, with an increase in the average quarterly purchase amount reaching \$18.0 million per life insurer in 2002 Q3. Such a sudden increase in the purchase of long-term PACs relative to medium-term PACs would not be observed if the auction suspension were fully anticipated.[24] Long-term PAC purchases remained elevated through 2004. In 2005, the long-term PAC purchases decreased, possibly because the resumption of the 30-year bond auction was anticipated, as

[24] Abadie, Athey, Imbens, and Wooldridge (2023) note that with company fixed effects, the criteria for clustering at the company level is whether there are heterogeneous treatment effects between firms. This heterogeneity is evident in the results in Tables 7 and 8, which compare the response to the shock by life insurers with and without experience with CMOs, as well as by large and small life insurers. This heterogeneity is also indicated by the larger standard error bars in Figure 3 during the suspension period.

the Treasury announced on May 4, 2005, the possibility that the 30-year UST bond auctions would resume. After the auctions resumed in Feb. 2006, there is no evidence of differences in purchase behavior relative to the period before the suspension of the UST bond auctions.

[Insert Figure 3 Here]

Our estimation results support the prediction that long-term PACs are created to fill the gap in habitat-preference investors' portfolios created by the reduced net supply of long-term safe assets. Table 3 shows the estimation results for Equation 5. Examining Column (1), the β_1 coefficient indicates that the average insurance company increased its purchases of newly issued long-term PACs during the *No Auction* period by approximately \$7.0 million dollars per quarter. Column (4) scales the purchases by the lagged AUM of the insurer and indicates that the quarterly increase in long-term PAC purchases represents about 0.06 percentage points of an insurer's total fixed income portfolio. The \$7M (0.06 percentage point) increase in PAC purchases represents 19.4% (17.2%) of the standard deviation of quarterly PAC purchase amounts of \$36.2M (0.35 percentage points). When UST bond auctions resumed in the *Post Period*, the β_2 coefficient shows no change in PAC purchases compared to the pre-suspension period, emphasizing that any unobserved shock explaining our results would need to reverse after the auction resumption.[25]

[Insert Table 3 Here]

To assess the economic significance of these results, we analyze the extent to which the increase in PAC purchases during the *No Auction* period substitutes for UST bonds. Specifically, we estimate the volume of newly-issued UST bonds that life insurance companies would have bought had auctions taken place with a difference-in-difference specification similar to Equation 5 in which the first difference is the change in the principal amount of newly issued UST notes and bonds purchased by life insurers during the *No Auction* period relative to other years. The second difference captures differences in the change in purchases of UST bonds (long-term) and notes (medium-term).

[25]Table A1 shows that these results are robust to using the logarithmic transformation to reduce the possible influence of skewness. Table A2 finds similar results including purchases in the secondary market.

Column (2) shows that life insurers reduce the purchases of UST bonds by $12.5 million. And again, the β_2 coefficient shows no difference in UST bond purchases when UST bond auctions resumed in the *Post Period* compared to the pre-suspension period. The increase in long-term PAC purchases of $7.0 million in Column (1) is similar in magnitude to the $12.5 million decrease in UST bond purchases in Column (2). Examining the quantities scaled by insurer's AUM, the increase in long-term PAC purchases relative to the insurer's AUM of 0.06 percentage points in Column (4) is similar to the decrease in UST bond purchases of 0.07 percentage points in Column (5). Together, these results suggest an economically significant substitution between UST bonds and long-term agency PACs, which is consistent with the PBM.

Part of our PBM identification assumption is that the suspension of 30-year UST issuance results in an increase in the demand for long-term PACs relative to medium-term PACs, without affecting the demand for long-term SEQs relative to medium-term SEQs. Although life insurers could replace UST bonds with SEQs that have a long weighted average life at issuance, they would be exposed to the risk of prepayments, which could substantially shorten the weighted average life of their SEQs. Therefore, long-term PACs are close substitutes for long-term UST bonds, while SEQs are not. The PBM posits that changes in the portfolios of habitat investors due to a shock in the UST supply happen because of the substitution effect and hence are not accompanied by changes in SEQ purchases. In contrast, the signaling and information friction hypotheses predict changes in life insurers' acquisitions of various assets, especially information-sensitive SEQs with prepayment risk.

We therefore exploit the heterogeneity in prepayment risk between PACs and SEQs to provide falsification tests. To do so, we estimate a difference-in-differences specification similar to Equation 5. The first difference is the change in the principal amount of medium- and long-term SEQs in insurance company portfolios during the *No Auction* period relative to the period with UST bond auctions. The second difference captures differences in this change in SEQ holdings for long-term and medium-term SEQs.

Consistent with the PBM, the coefficient β_1 in Columns (3) and (6) of Table 3 indicates that insurance companies did not increase their long-term SEQ purchases during the *No Auction* period. The coefficient β_2 also shows no difference in SEQ bond purchases when

UST bond auctions resumed in the *Post Period* compared to the pre-suspension period. Taken together, insurers' purchases of long-term SEQs remain unchanged over the sample period, although Table 2 shows that insurers regularly buy newly issued SEQs in amounts similar to PACs.[26]

Motivated by the strong substitution by insurers to long-term PACs, we examine whether mortgage dealers responded by creating more PACs relative to SEQs during the *No Auction* period with the following panel regression:

$$\begin{aligned}\text{Mortgage Collateral}_{i,q} = {} & \beta_1 \times \mathbb{1}(\text{No Auction})_q \times \mathbb{1}(\text{PAC})_i \\ & + \beta_2 \times \mathbb{1}(\text{Post Period})_q \times \mathbb{1}(\text{PAC})_i \\ & + \beta_3 \times \mathbb{1}(\text{PAC})_i + \eta_q + \epsilon_{i,q}.\end{aligned} \tag{6}$$

The outcome is the total amount of pass-through collateral tranched to create security i (PACs or SEQs) in quarter q. Because we aggregate separately for PACs and SEQs, the data have two observations per quarter. $\mathbb{1}(\text{PAC})_i$ is an indicator variable equal to one for the time series of the total collateral tranched to create PACs and equal to zero for the time series of the total collateral tranched to create SEQs. $\mathbb{1}(\text{No Auction})_q$ is an indicator variable equal to one for the quarters between 2001 Q4 and 2005 Q4 when UST bond auctions were suspended. $\mathbb{1}(\text{Post Period})_q$ is an indicator variable equal to one for the quarters between 2006 Q1 and 2007 Q4, when UST bond auctions resumed. η_q is a fixed effect for the quarter to isolate the difference between the volumes of collateral supporting PACs and SEQs in a quarter (absorbs the standalone $\mathbb{1}(\text{No Auction})_q$ and $\mathbb{1}(\text{Post Period})_q$ variables).

[Insert Table 4 Here]

In Column (1) of Table 4, the β_1 shows that the amount of collateral tranched to create PACs increased on average for the entire suspension period by about $30.2 billion per quarter relative to the amount of pass-through used to create long-term SEQs. Again, the coefficient β_2 shows no difference in the collateral tranched to create PACs when UST bond auctions resumed in the *Post Period* compared to the pre-suspension period. Figure 4 plots the

[26]The Protective Life Corporation 2004 10-K reports that 41.6% of the mortgage-backed security portfolio is in the form of PAC tranches, while 38.1% is in the form of SEQ tranches. The Americo Life, Inc. 2001 10-K shows that 33% of the CMO portfolio is in the form of SEQ tranches.

difference in collateral supporting PACs and SEQs by quarter. It is clear that the amount of pass-through collateral to create long-term PACs and SEQs had similar activity prior to the suspension of the UST bond auctions. After the suspension announcement, the amount of pass-throughs used to create long-term PACs increased significantly following 2001 Q4, with the average quarterly collateral amount reaching about $100 billion in 2003 Q3. The amount of collateral for PACs returned to normal in 2006 when the UST bond auctions resumed.

[Insert Figure 4 Here]

The PBM states that a decrease in UST bond supply results in an increase in the issuance of substitutes to satisfy the demand from preferred-habitat investors. Therefore, it is interesting to compare the economic significance of the results in Tables 3 and 4. Our results indicate that, during the *No Auction* period, a segment of the preferred-habitat investors (life insurers) increased their PAC purchases by $7.0 billion per year ($4 \times 250 \times$ $7.0 million from Table 3) to substitute for $12.5 billion per year of UST bonds that they would have bought without the suspension ($4 \times 250 \times$ $12.5 million from Table 3). At the same time, the issuance of long-term PACs relative to long-term SEQs increased by $14.8 billion per year ($4 \times$ $3.7 billion).[27] These magnitudes are similar and of the same order of magnitude as the drop in UST bond offerings per year of $16 billion shown in Figure 2.

5.2 Price Reactions to the 30-year UST Auction Suspension

Hypothesis 2 predicts that a negative shock to the excess supply of long-term UST bonds causes an increase in their prices and the prices of long-term PACs. To examine this hypothesis, we investigate the daily returns of USTs and monthly returns of PACs on Oct. 31, 2001, which is when the U.S. Treasury announced the indefinite suspension of the 30-year UST bond auctions. We also examine their returns when the U.S. Treasury announced the possible reversal of the suspension on May 4, 2005.

[27] Figure 1, Panel B, shows that only a fraction of a pass-through becomes a long-term PAC during the tranching process. In our sample, long-term PACs represent 12.1% of the total pass-through collateral used to create them. Using this fraction, we calculate that the increase in the amount of pass-throughs to create PACs of $30.2 billion per quarter from Column (1) of Table 4 results in an average increase of $3.7 billion of long-term PACs.

Figure 5 reveals that on Oct. 31, 2001 – the date the U.S. Treasury announced the suspension of UST bond auctions – the mean daily return of long-term UST bonds (with 25-30 years until maturity), weighted by the outstanding amount, minus the daily weighted return of UST notes with 9 to 10 years to maturity, was approximately 2.1%.[28] This marks the largest positive daily difference in long-term UST bond and 10-year note returns within the sample period from 1997 Q1 to 2007 Q4. This pronounced reaction suggests that the market was taken by surprise by the discontinuation of the 30-year bond issuance. This estimated price reaction is downward biased to the extent that the suspension was not a complete surprise. On May 4, 2005, when the possible reversal of the suspension was announced, UST bond returns less note returns were about -1.2%, aligning with our model's limits to arbitrage mechanism. See Appendix Figure A4 for additional annotations.

[Insert Figure 5 Here]

Table 5 evaluates the statistical significance of these market reactions. To do so, we calculate the distribution of the daily difference in the returns between long-term UST bonds (with 25-30 years to maturity) and UST notes (with 9-10 years to maturity) in the period Jan. 1, 1997 to Aug. 30, 2001. This sample period precedes the announcement. Then, we compare the difference in returns on the announcement with the distribution of preceding returns. The t-statistic is 8.0 for UST bonds on Oct. 31, 2001 when the suspension is announced, and the t-statistic is -4.6 on May 4, 2005 when the possible reversal of the suspension is announced.

[Insert Table 5 Here]

It is instructive to compare the effect shown in Table 5 with the outcomes of QE. The suspension announcement return in Figure 5 is in line with the findings of Bernanke, Reinhart, and Sack (2004), which noted a 43 basis point drop in the yield of the constant maturity 30-year UST bond between Oct. 30 and Nov. 1, 2001. In comparison, Wiliams (2014) notes that the impact estimates of QE suggest that $600 billion in asset purchases led to a reduction

[28] We focus on UST bonds with 25 to 30 years of maturity to ensure that some UST bonds are trading during the four-year suspension period. The results are robust to using 29-30, but then there is a gap in Figure 5 during the suspension period.

in the yield of 10-year notes by approximately 15 to 25 basis points. Considering that only $16 billion of UST bonds were issued in 2001, the price reactions on the long-term bonds are quite large compared to those of QE in the 10-year notes. This significant price reaction can be attributed to the fact that the suspension was permanent and, to some extent, unexpected.

The long-term shock to the UST bond supply implies a long-term shock to the premium on these bonds in our model (Equation 3). Next, we examine the persistence of the shock to 30-year UST prices and yields. To do so, we need to remove events that affect the other parts of the yield curve during the sample period. Thus, we residualize the returns and changes in yields of 30-year UST bonds to those of other maturities. Specifically, we regress the weighted average daily return and daily yield change of traded 30-year USTs (maturities between 25 and 30 years) on those with maturities of less than 1 year, 1-2 years, 2-3 years, 3-5 years, 5-7 years, 7-15 years, 15-20 years, and 20-25 years. Then we use the regression residuals to calculate the cumulative returns and cumulative changes in yields. Figure 6 Panel A (B) shows the cumulative daily returns (yield changes). We find on Oct. 31, 2001 a large increase in the cumulative returns (decrease in yields) that persists for the suspension period. On May 4, 2005, we observe a decrease in cumulative returns (increase in yields). The vertical red (dashed) lines mark the key events: the suspension announcement of 30-year UST auctions (Oct. 31, 2001) and the possible resumption announcement (May 4, 2005). Notably, no unobserved shocks explain our results, as the residualized 30-year UST yields show no significant shocks during the no-auction period. See Appendix Figure A4 for additional annotations.

[Insert Figure 6 Here]

Now, we turn our attention to the prices of long-duration PACs, around the announcement of the suspension. Table 5 shows the monthly difference in the value-weighted average return for agency PAC bonds with a long effective duration (nine or more years) and a medium duration (seven to eight years). The medium-duration PAC bonds have a duration similar to that of the 10-year UST note.[29] The difference in monthly returns on the day

[29]On Oct. 30, 2001, the 10-Year UST note yield to maturity was 4.5% resulting in a duration of between seven and eight years.

of the announcement was 3.9% (t-statistic of 4.3). Figure 7 Panel A plots this difference in monthly returns for the sample period, showing that the price move in Oct. 2001 was atypical.

[Insert Figure 7 Here]

Our identification of the PBM is independent of SUPs' price reactions. For instance, increased demand for SUPs cannot explain why life insurers bought more long-term PACs over medium-term PACs. Since PACs and SUPs are created together, we briefly consider SUP price scenarios. One scenario is a price drop due to the 30-year UST bond supply shock, as SUP holders capture the prepayment risk of additional PACs. Consistent with this scenario, Figure 7 Panel B shows a slight return decrease for agency SUPs (CMSZ index) following the 30-year UST bond auction suspension announcement.[30] Another scenario is that SUP prices remain stable, allowing mortgage dealers to profit by selling PACs and SUPs above collateral prices. Data on mortgage dealers' profitability would clarify these scenarios. Testing these alternatives for SUP prices is beyond our PBM analysis, but could be explored in future research.

The price movements that we observe align with Hypothesis 2. These findings support the notion that UST supply shocks impact bond prices due to the inability of arbitrageurs to fully absorb the excess demand from investors with an inelastic demand for long-term safe assets. Hence, a shock to the supply of long-term USTs leads to adjustments in the term premium as depicted in Equation 3. The impact on PAC prices aligns with our results showing that the UST bond supply shock increases demand for alternative safe assets among habitat-preference investors.

5.3 Additional Evidence Supporting PBM Identification

Next, we perform several additional tests that take advantage of the heterogeneity in CMOs and life insurer characteristics to further support our identification of the PBM.

First, further supporting previous findings that life insurers demand long-term safe assets with a stable life, we exploit the fact that not all PACs have the same protection against

[30]During our sample period, SUP tranches have a 49bp higher effective yield than long-term PACs due to higher prepayment exposure.

prepayment. Specifically, there are PACs with different bands. For example, there are PACs with bands equal to 100% PSA - 300% PSA and PACs with bands of 120% PSA - 250% PSA. PACs with narrower bands are riskier because their cash flows are stable only within a narrower prepayment band. PACs are often identified with an accompanying number. PACs with lower numbers (e.g., PAC-1) are safer because they have wider bands than PACs with higher numbers (e.g., PAC-2).

We therefore examine whether life insurers increased their purchases of long-term PAC-1 and PAC-2 relative to medium-term PAC-1 and PAC-2. To do so, we estimate a difference-in-differences specification similar to Equation 5. The first difference is the change in the principal amount of medium and long-term PAC-1s (PAC-2s) in insurance company portfolios during the *No Auction* period relative to the period with bond auctions. The second difference captures differences in this change in PAC-1s (PAC-2s) holdings during the *No Auction* period for long-term and medium-term PAC-1s (PAC-2s). In Table 6, Columns (1) and (3), we show that life insurers significantly increased purchases of PAC-1 tranche types during the *No Auction* period. And, in the *Post Period*, there is no difference in PAC-1 purchases relative to the period before the suspension. By contrast, Columns (2) and (4) show no change in purchases of PAC-2 tranche types in the *No Auction* period. These findings exploiting the degree of prepayment protection of PACs, along with the results in Table 3 that insurers do not increase purchases of SEQs but do increase purchases of long-term PACs, cleanly identify the PBM.

[Insert Table 6 Here]

Second, we examine whether the effects are stronger for life insurers with previous experience purchasing CMOs and UST bonds. For insurers with previous experience, the costs of acquiring information on CMOs may be lower (Van Nieuwerburgh and Veldkamp, 2010; Zhu, 2021). To measure an insurer's experience with CMOs, we count each insurer's number of purchases of newly issued PAC and SEQ CMOs from 1997 Q1 to 2001 Q3, which predates the announcement of the suspension in 2001 Q4. Then, we repeat Column (1) of Table 3 on sub-samples of insurers based on their experience. In Table 7 Column (1), we find that insurers with PAC or SEQ experience increased purchases of PACs during the suspension period by $9.5 million per quarter on average, while Column (2) shows that insurers without previous experience with PACs or SEQs did not increase purchases of PACs. Columns (3) and (4) show the same result scaling purchases by an insurer's lagged AUM.

[Insert Table 7 Here]

Third, our results in Table 3 showing that insurers substitute UST bonds with long-term PACs are not driven by the largest or smallest insurers. Instead, Table 8 Columns (1)-(2) and (4)-(5) show a significant increase in PAC purchases for insurers with ranks based on 1999 AUM of 1 to 75 and 76 to 150. Although the coefficients for insurers of ranks 151 to 250 are not statistically significant, the coefficients are positive and economically meaningful.

[Insert Table 8 Here]

6 Conclusion

The PBM has been used to explain a variety of important capital market phenomena. For instance, the PBM can help explain the impact of QE policies on the real economy as well as the connection between the purchases by the GSG countries of long-term UST bonds and the significant increase in securitization before the financial crisis (Bernanke, 2006, 2010, 2011). Although the PBM provides a possible explanation for the events leading up to the financial crisis and the effectiveness of QE, identifying the PBM poses challenges, as it requires observing changes in habitat-preference investors' portfolios due to UST supply shocks and attributing these changes to a substitution effect.

Our findings provide unusually clean evidence for the PBM. We provide direct evidence that, in response to the shock to the supply of 30-year UST, the prices and issuances of a close substitute (agency-PAC) also increased. Most importantly, habitat investors, namely life insurers, substituted their regular purchases of UST bonds during the suspension period with purchases of agency-PACs. And, these changes revert with the reintroduction of 30-year UST auctions.

Our setting capitalizes on the suspension of UST bond auctions (and its reversal), as well as the heterogeneity in USTs and agency CMO tranche types. Any alternative explanation for our findings would have to account for the variation in the price of long-term bonds relative to medium-term bonds at the suspension announcement, why life insurers intensified their acquisitions of newly issued long-term PACs over medium-term ones without altering their typical purchases of SEQs during the no-auction period, and the increase in pass-through collateral tranched to create PACs relative to SEQs. Therefore, the totality of our findings allows us to unambiguously identify the PBM.

Our paper indicates at least two areas for future research. First, the heterogeneity of the agency-CMO market is relatively unexplored. Our clean identification of the PBM exploring the diversity of the agency-CMO market indicates that it is an excellent laboratory to study important questions in Financial Economics. Second, the identification of the PBM suggests that future research investigating the role of the PBM in the pre-crisis increase in securitization and in QE is promising. Although our identification of the PBM supports the idea that the PBM played a role in the pre-crisis increase in securitization and the effect of QE, the importance of the PBM relative to other mechanisms influencing these significant phenomena is still an open question.

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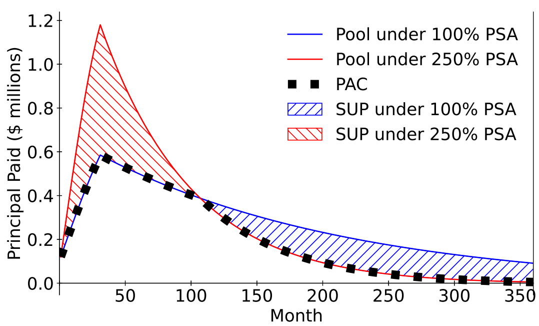
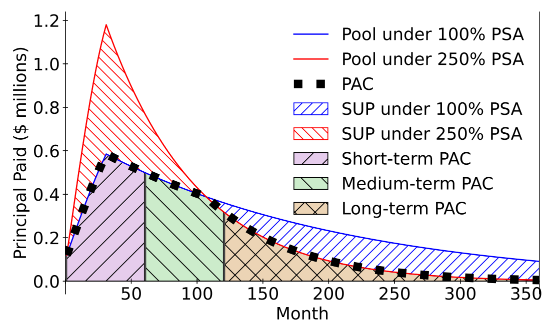
Figure 1: **Principal Cash Flows for PACs, SUPs, and SEQs.**
Panel A shows the principal cash flows of a PAC with 100% to 250% PSA bands and its SUP under 100% and 250% PSA prepayment scenarios. Panel B displays the cash flows of three PACs with different average lives and with bands equal to 100% to 250% PSA. These PACs pay the principal amount at the top of each colored (hatched) area. Panel C illustrates the cash flows of three SEQs under a 250% PSA scenario, with the line above the colored (hatched) areas indicating each SEQ's principal cash flows. Panel D shows the cash flows of the same SEQs as in Panel C under a 100% PSA scenario, with the line above the colored (hatched) areas indicating each SEQ's principal cash flows. All figures assume a $100 million unpaid principal at time zero.

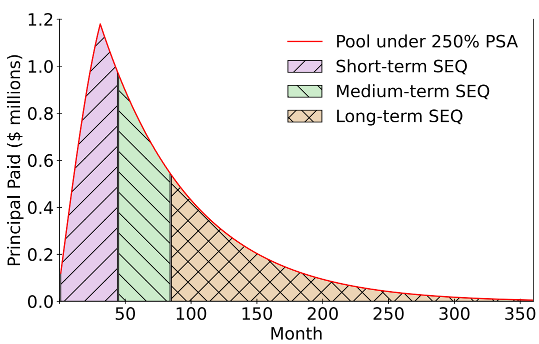
(a) PAC and SUP Tranches



(b) Varied Life PACs



(c) Varied Life SEQs (250% PSA)



(d) Varied Life SEQs (100% PSA)

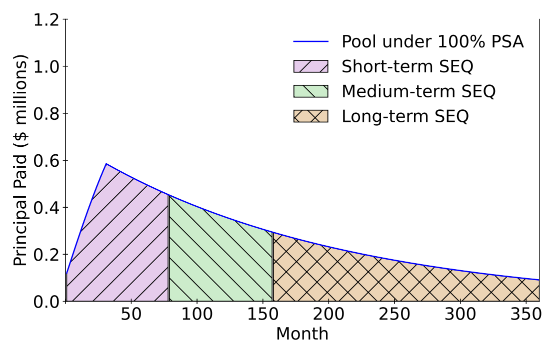
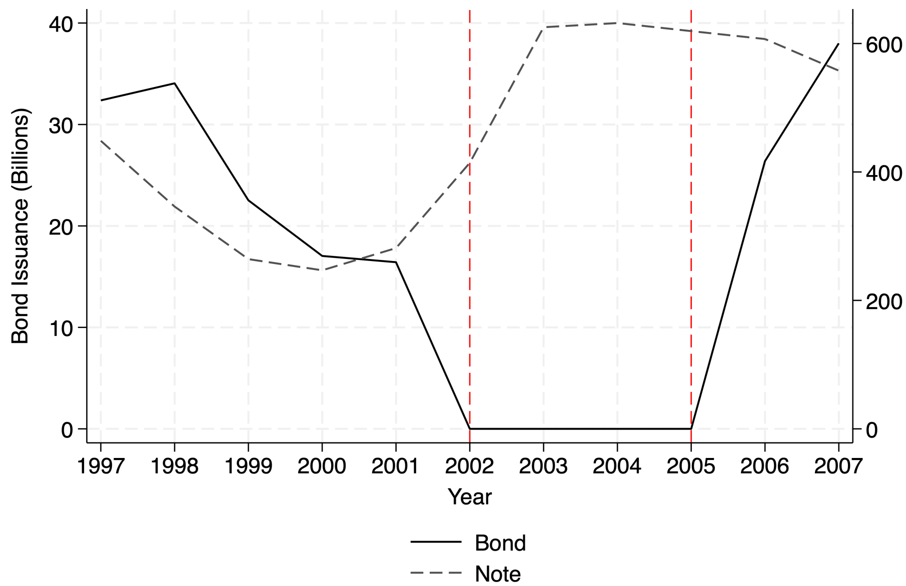
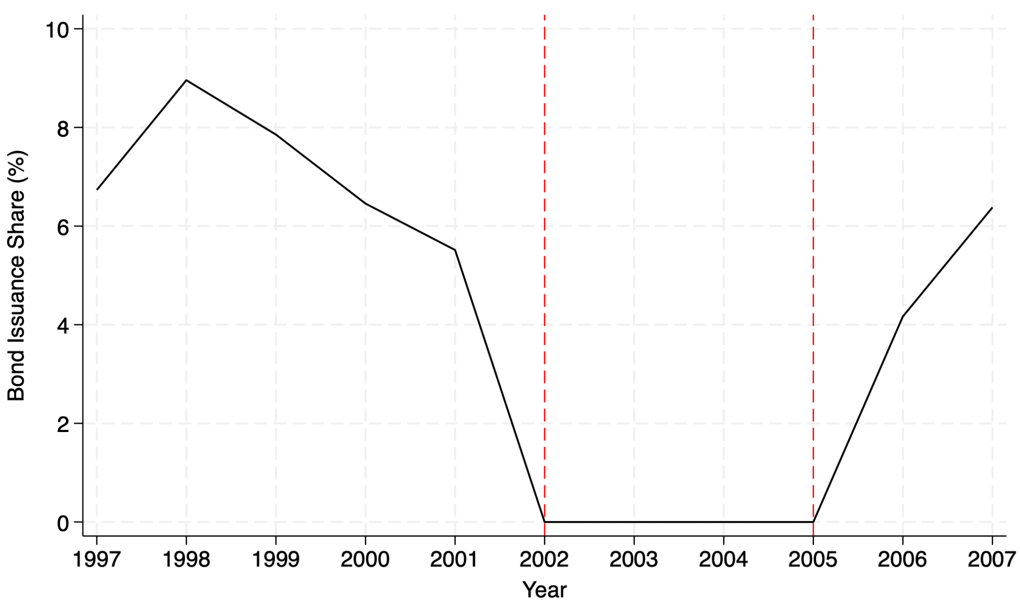


Figure 2: **Total amount of UST Notes and Bonds Issued by Year.**
Panel A shows the yearly total issuance of UST notes (maturity 2 to 10 years) and bonds (maturity over 10 years). Panel B shows the yearly bond issuance as a fraction of total notes and bonds. No UST bonds were issued from 2002 to 2005. The red (dashed) vertical lines represent boundaries of the no-auction period. The suspension of UST bond auctions was announced on Oct. 31, 2001. On May 4, 2005, the U.S. Treasury announced a possible resumption, confirmed on Aug. 3, 2005, for Feb. 2006.



(a) Gross Issuance of Notes and Bonds



(b) Bond Issuance as Fraction of Total Note and Bond Issuance

Figure 3: **Effect of UST Bond Auction Interruption on PAC Purchases.**
This figure shows that life insurers purchased more newly issued long-term PACs compared to medium-term PACs when 30-year UST bond auctions were suspended. It plots the dynamics of Column (1) in Table 3. The dependent variable is the aggregate value (in millions) of purchases of newly issued medium-term ($i = 0$) and long-term ($i = 1$) PACs by insurer j in quarter q. We aggregate these purchases separately, resulting in two observations i per quarter q for insurer j. Medium-term PACs have a weighted-average life (WAL) of 2 to 10 years, and long-term PACs have a WAL of more than 10 years, mimicking UST notes and bonds, respectively. The plot shows the coefficients on the interactions of $\mathbb{1}(\text{LT})_{i,j}$ with quarter dummies. $\mathbb{1}(\text{LT})_{i,j}$ is an indicator variable equal to one for insurer j's aggregate purchases of long-term ($i = 1$) PACs and zero for medium-term ($i = 0$) PACs. We control for insurer j's purchases of newly issued medium-term ($i = 0$) and long-term ($i = 1$) SEQs in quarter q ($SEQ_{i,j,q}$) to account for time-varying firm-specific factors affecting demand for medium- and long-term CMOs in general. We include insurance company and quarter fixed effects to control for fixed differences between insurers and aggregate trends. The red (dashed) vertical lines denote the $\mathbb{1}(\text{No Auction})_q$ period from 2001 Q4 (30-year UST suspension) to 2005 Q4 (resumption announcement). The coefficient of 18.0 in 2002 Q3 indicates an average increase of \$18.0 million in quarterly purchases of newly issued long-term PACs relative to medium-term PACs, accounting for SEQs and fixed effects. We double cluster standard errors by insurer and quarter. We show the 90% confidence intervals. The baseline omitted interaction is 2007 Q4.

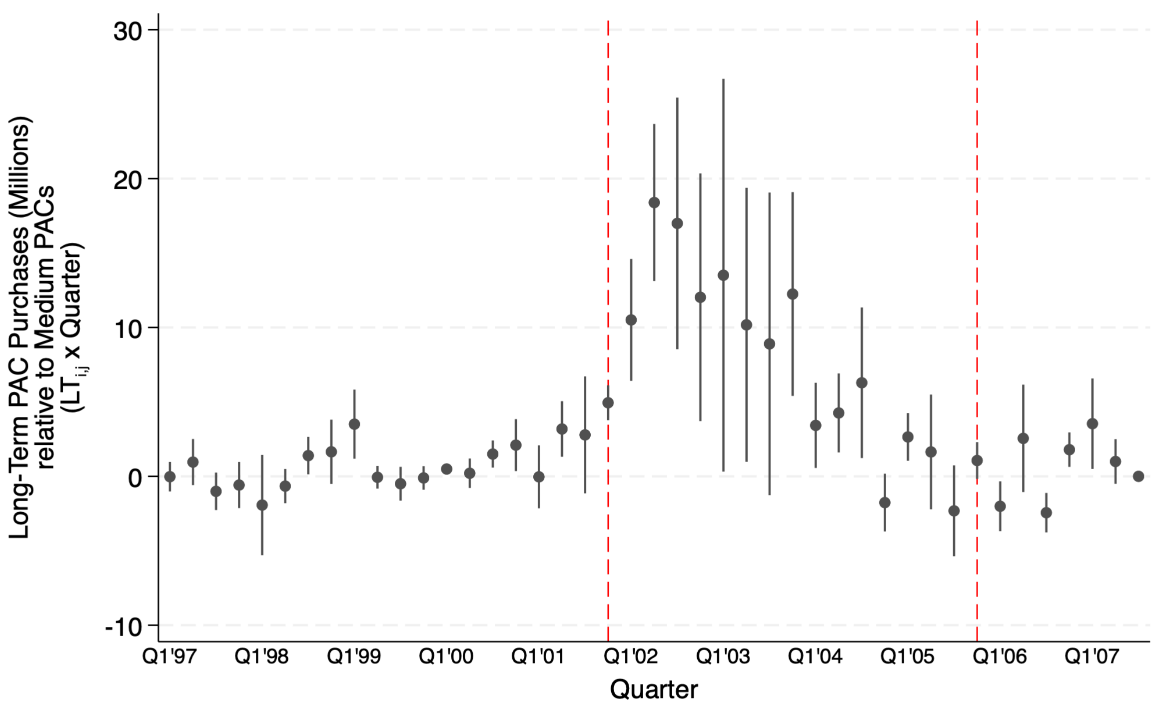


Figure 4: **UST Bond Auction Suspension & Collateral Supporting PAC Issuance.** This figure shows that the pass-through collateral supporting groups of tranches with PACs increased relative to the collateral supporting SEQs. The dependent variable is the difference in the aggregate value (in billions) of collateral backing PACs in quarter q and the aggregate collateral backing SEQs. The red (dashed) vertical lines denote the $\mathbb{1}(\text{No Auction})_q$ period from 2001 Q4 (30-year UST bond auction suspension) to 2005 Q4 (auction resumption announcement). The sample includes collateral groups supporting PACs or SEQs, not both.

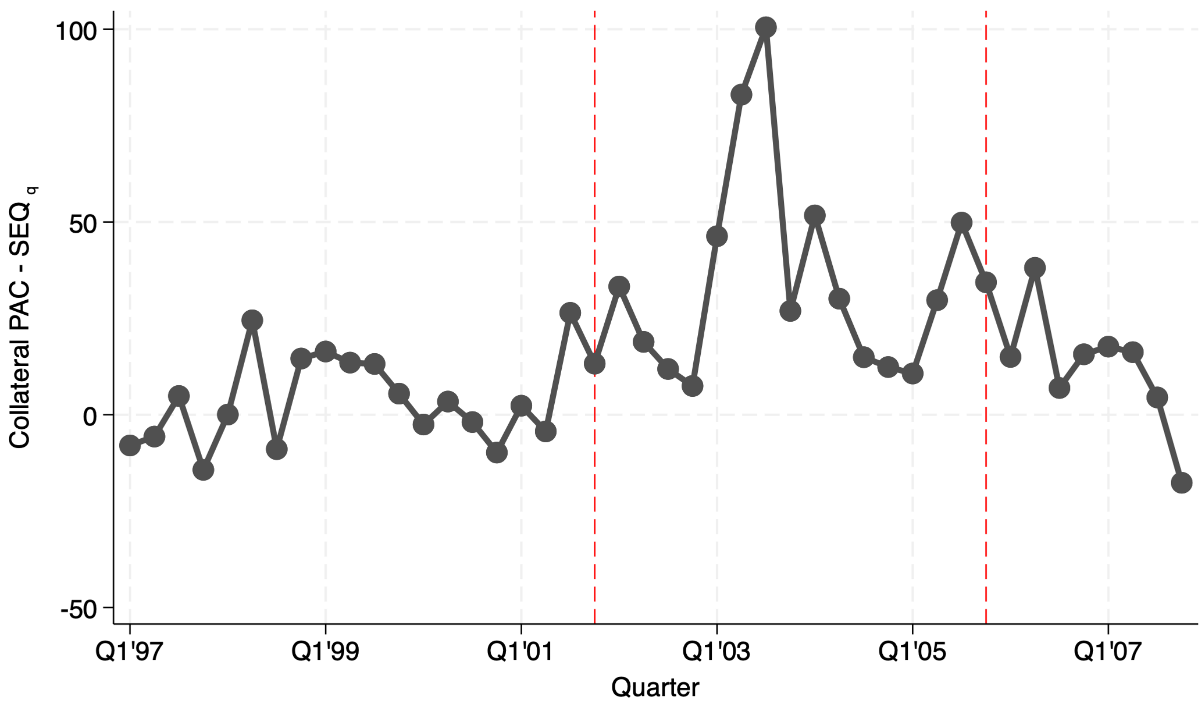


Figure 5: **Daily UST Returns & the Suspension Announcement.**
The figure shows the daily difference in returns for UST bonds (25-30 years maturity) and 10-year UST notes (9-10 years maturity). Daily returns are calculated as the price change plus accrued and paid interest, divided by the previous day's price plus accrued interest (TDRETNUA in CRSP). We calculate the principal-weighted average of daily returns for UST bonds and notes. Data points are circled for Oct. 31, 2001 (discontinuation of 30-year UST bond auctions) and May 4, 2005 (announcement of possible resumption of UST bond auctions). We annotate other points in Figure A3.

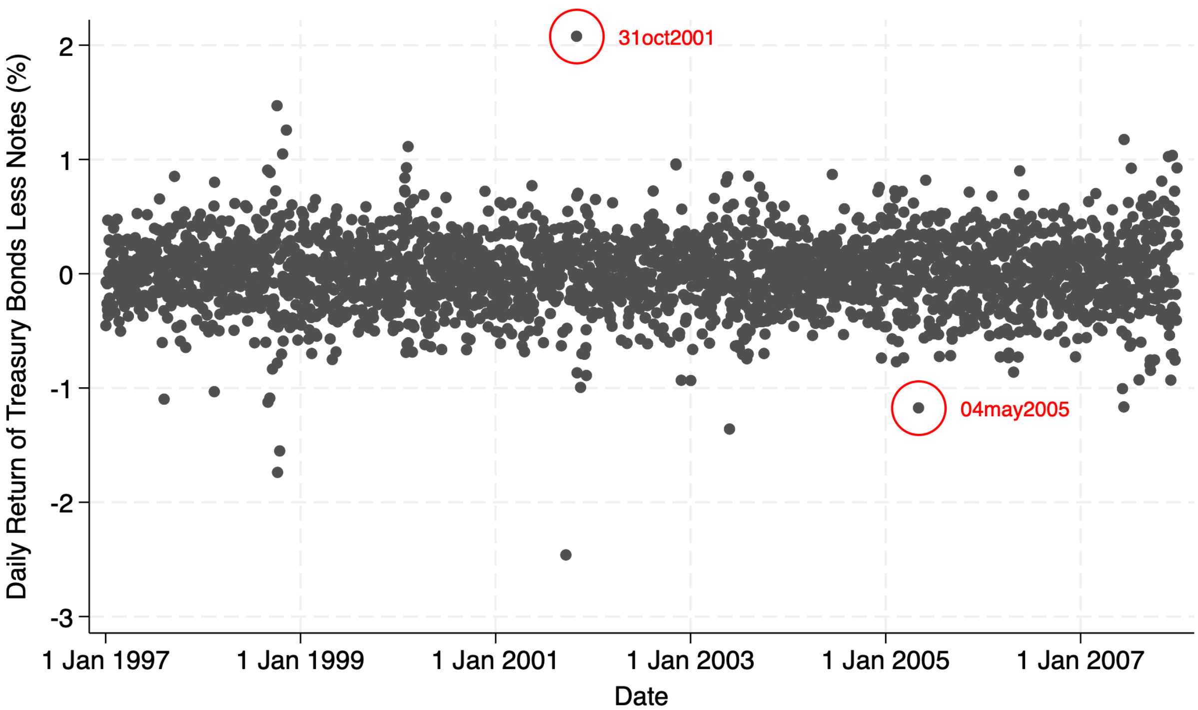
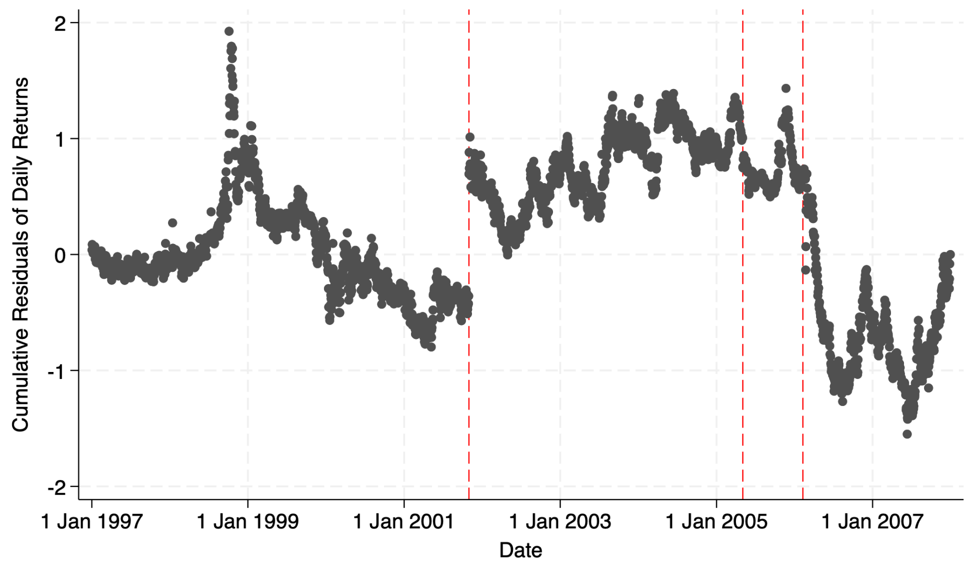
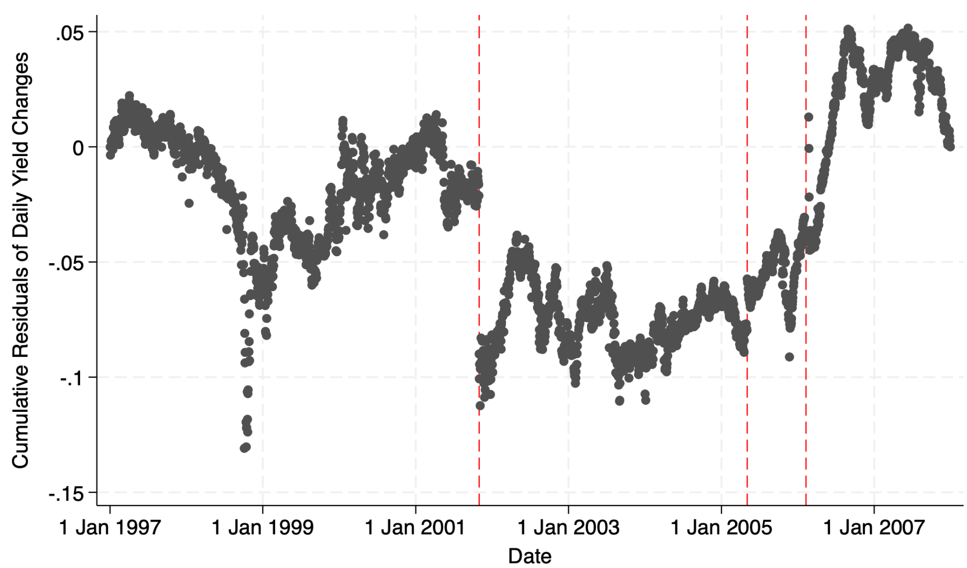


Figure 6: **Cumulative Residual Returns & Changes in Yields.**
Panel A shows the cumulative residual daily return of the 30-year UST. This is calculated by regressing the daily returns of UST bonds with maturities of 25-30 years on those with maturities of less than 1 year, 1-2 years, 2-3 years, 3-5 years, 5-7 years, 7-15 years, 15-20 years, and 20-25 years. Panel B shows the residual daily change in YTMs, calculated similarly to Panel A. Table A3 shows the regressions used to generate the residual returns and changes in YTM. Vertical red (dashed) lines mark key events: suspension announcement of 30-year UST auctions (Oct. 31, 2001), possible resumption announcement (May 4, 2005), and auction reintroducing the 30-year UST bond (Feb. 9, 2006). We annotate other key events in Figure A4.

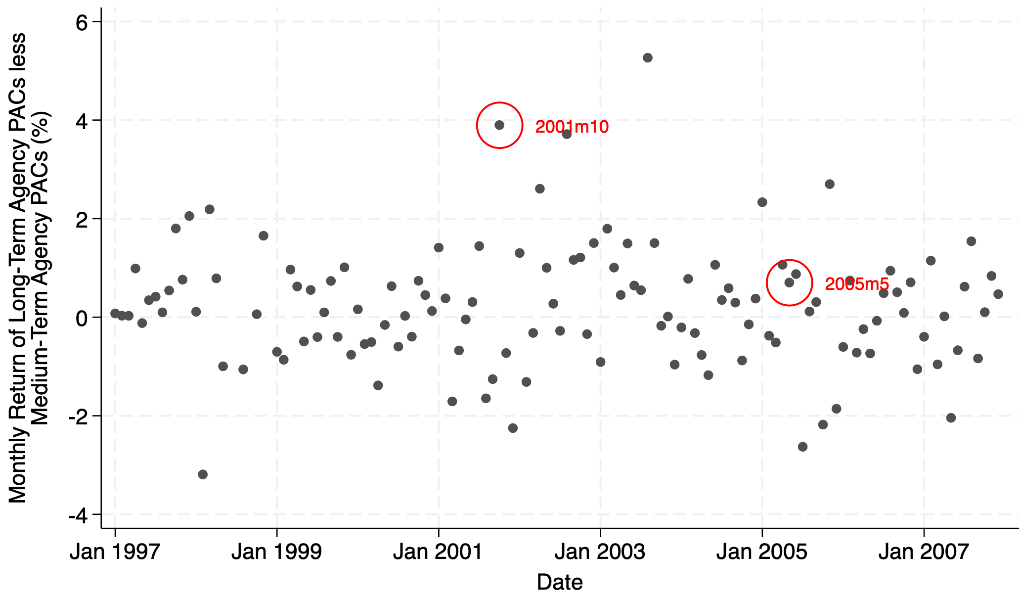


(a) Cumulative residual daily 30-year UST returns

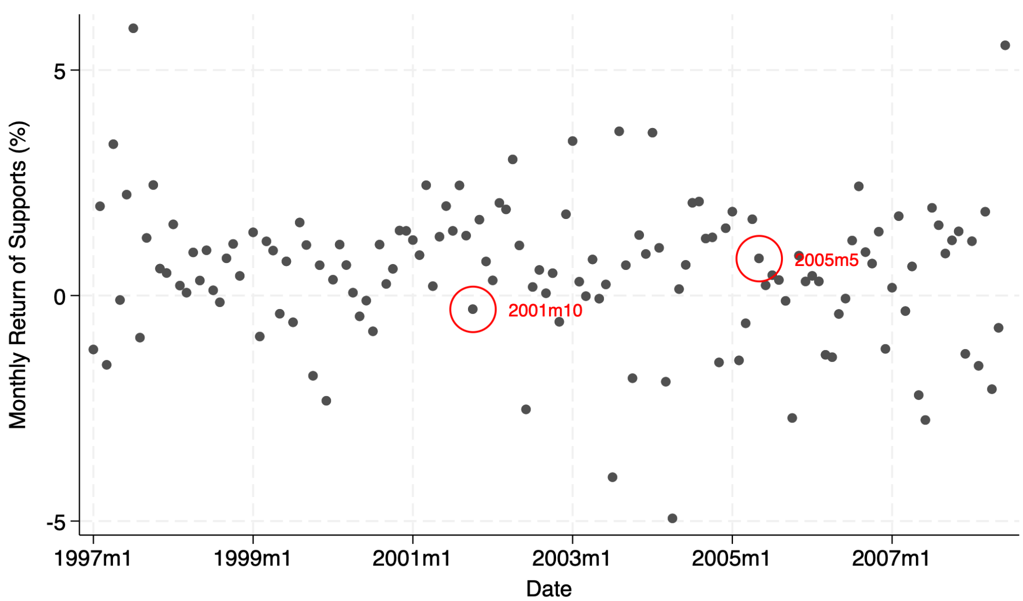


(b) Cumulative residual daily changes in 30-year UST YTM

Figure 7: **Monthly PAC and SUP Returns and the Suspension.**
Panel A shows the monthly difference in returns for long-duration (duration greater than 9 years) and medium-duration (duration of 7-8 years) agency PAC bonds. Medium-duration PAC bonds have a duration similar to that of the 10-year UST note. We circled Oct. 2001 (suspension of 30-year UST bond auctions) and May 2005 (possible resumption of UST bond auctions). Panel B shows the monthly weighted average returns for agency Support (SUP) bonds.



(a) Monthly Agency PAC Returns



(b) Monthly Agency SUP Returns.

Table 1: **Summary Statistics.**
This table summarizes CMO issuances from 1997 Q1 to 2007 Q4. Panel A combines all CMO tranche issuances by deal. Panels B and C provide summary statistics for PAC/SUP and SEQ tranche types. Winsorized at 1%.

	N	Mean	St. Dev.	Q1	Median	Q3
A - CMO Deals						
Total Issuance (Million $)	3,325	2,299.5	2,999.6	643.4	1,319.2	2,703.6
Number of Tranches	3,325	44.7	38.1	18	35	59
B - PAC/SUP Tranches						
Tranche Amount (Million $)	60,715	46	63	8	25	57
Weighted Average Life at Issuance	60,715	7.7	5.8	3.3	6.0	11.0
Tranches by Deal	2,540	24	22	9	18	32
C - SEQ Tranches						
Tranche Amount (Million $)	27,716	72	93	13	34	97
Weighted Average Life at Issuance	27,716	7.8	5.4	3.7	5.4	11.2
Tranches by Deal	2,398	12	12	4	8	15

Table 2: **Summary Statistics of Insurers' Purchases of USTs and CMOs.**
This table shows the number (N) of insurer-quarters with purchases of newly issued bonds by type from 1997 Q1 to 2007 Q4 for the 250 largest life insurers (as of 1999). And, conditional on a quarter with purchases, the table shows the total amounts of such bonds purchased. Medium-term USTs and CMOs have an average life of 2-10 years, while long-term bonds exceed 10 years. Estimates are in millions of dollars. We also show purchases as a percentage of the prior year's fixed income portfolio. There are 9,984 firm-quarters in the final sample. For example, insurers purchased newly issued long-term PACs in 12.4% (1,241/9,984) of firm-quarters. We winsorize purchases scaled by AUM at the 5% level to reduce outliers. Winsorizing unscaled purchases would eliminate large firms, but results are robust to both approaches.

Panel A: PACs						
	N	Mean	St. Dev.	Q1	Median	Q3
Medium Term	945	30.9	61.7	5.0	12.1	27.8
Long Term	1,241	45.7	83.3	7.0	16.6	43.8
% Medium Term	945	0.6	0.8	0.1	0.3	0.7
% Long Term	1,241	0.7	0.9	0.1	0.4	0.9

Panel B: USTs						
	N	Mean	St. Dev.	Q1	Median	Q3
Medium Term	1,984	43.9	114.5	1.6	7.5	30.0
Long Term	355	45.1	111.1	2.8	9.0	28.3
% Medium Term	1,984	0.6	0.9	0.0	0.2	0.7
% Long Term	355	0.5	0.7	0.1	0.2	0.6

Panel C: SEQs						
	N	Mean	St. Dev.	Q1	Median	Q3
Medium Term	985	26.1	42.9	5.0	11.3	26.6
Long Term	1,117	33.1	51.8	6.0	13.5	35
% Medium Term	985	0.4	0.5	0.1	0.2	0.5
% Long Term	1,117	0.5	0.5	0.1	0.3	0.7

Table 3: **Halted UST Bond Auctions & Insurers' PAC Purchases.**
This table shows that life insurers purchased more newly-issued long-term PACs relative to medium-term PACs during the suspension of 30-year UST bond auctions. In Column (1), the dependent variable is the aggregate value (in millions) of purchases of newly issued medium-term ($i = 0$) and long-term ($i = 1$) PACs by insurer j in quarter q, resulting in two observations i per quarter q for insurer j. Medium-term PACs have a weighted-average life (WAL) between 2 and 10 years, and long-term PACs have a WAL of more than 10 years. In Column (2), we aggregate purchases of newly issued medium-term and long-term USTs, where a UST's WAL is its time to maturity. In Column (3), we aggregate purchases of newly issued medium-term and long-term Sequential CMOs (SEQs). In Columns (4) to (6), we repeat Columns (1) to (3) after scaling by the insurer's fixed income portfolio size at the end of year $y - 1$. $\mathbb{1}(\text{LT})_{i,j}$ is an indicator variable equal to one for insurer j's aggregate purchases of long-term ($i = 1$) securities and zero for medium-term ($i = 0$) securities. $\mathbb{1}(\text{No Auction})_q$ equals one for quarters from 2001 Q4 (when the U.S. Treasury suspended 30-year UST bond auctions) to 2005 Q4. The Treasury resumed UST bond auctions in Feb. 2006, and $\mathbb{1}(\text{Post Period})_q$ equals one for quarters from 2006 Q1 to 2007 Q4. We control for insurer j's purchases of newly issued medium-term ($i = 0$) and long-term ($i = 1$) SEQs in quarter q ($SEQ_{i,j,q}$) to account for time-varying firm-specific factors affecting insurer j's demand for medium- and long-term CMOs. We include insurance company and quarter fixed effects to control for insurer-specific and aggregate trends. We double cluster standard errors by quarter and insurer. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively.

	$\text{PACs}_{i,j,q}$	$\text{UST}_{i,j,q}$	$\text{SEQs}_{i,j,q}$	$\frac{\text{PACs}_{i,j,q}}{\text{AUM}_{j,y-1}}$	$\frac{\text{UST}_{i,j,q}}{\text{AUM}_{j,y-1}}$	$\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}}$
	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	6.99**	-12.45*	-1.50	0.06***	-0.07*	-0.01
	(3.32)	(7.09)	(1.60)	(0.02)	(0.04)	(0.01)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{Post Period})_q$	0.24	-1.91	-0.28	-0.01	0.00	-0.01
	(0.95)	(2.56)	(0.60)	(0.01)	(0.02)	(0.01)
$\mathbb{1}(\text{LT})_{i,j}$	0.21	-4.31***	1.55**	0.01	-0.08***	0.02***
	(0.50)	(1.29)	(0.62)	(0.01)	(0.02)	(0.01)
$\text{SEQs}_{i,j,q}$	0.45***					
	(0.16)					
$\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}} \times 100$				0.29***		
				(0.04)		
Constant	1.62	11.13***	2.96***	0.05***	0.12***	0.04***
	(0.97)	(1.34)	(0.45)	(0.01)	(0.01)	(0.00)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes	Yes	Yes
% Adjusted R^2	23.51	12.29	19.68	12.20	11.81	9.59
# Insurers	250	250	250	250	250	250
# Quarters	44	44	44	44	44	44
# Observations	19960	19960	19960	19960	19960	19960

Table 4: **UST Bond Auctions & Aggregate Collateral Tranched into PACs.**
In Column (1), the dependent variable is the pass-through collateral amount (in billions), and in Column (2), it is its natural logarithm. The results show that pass-through collateral backing PAC tranches increased during the UST suspension period versus SEQs. The sample includes collateral supporting PACs or SEQs, not both. $\mathbb{1}(\text{No Auction})_q$ equals one for quarters from 2001 Q4 (when the U.S. Treasury suspended 30-year UST bond auctions) to 2005 Q4. The Treasury resumed UST bond auctions in Feb. 2006, and $\mathbb{1}(\text{Post Period})_q$ equals one for quarters from 2006 Q1 to 2007 Q4. Standard errors are clustered at the quarter level, and quarter fixed effects are included, absorbing the standalone $\mathbb{1}(\text{No Auction})_q$ and $\mathbb{1}(\text{Post Period})_q$ variables. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively.

	Billions	Log
	(1)	(2)
$\mathbb{1}(\text{No Auction})_q \times \text{PAC}_i$	30.19***	0.48**
	(6.86)	(0.19)
$\mathbb{1}(\text{Post Period})_q \times \text{PAC}_i$	8.41	0.24
	(5.97)	(0.29)
PAC_i	3.66	0.19
	(2.69)	(0.16)
Constant	24.88***	3.00***
	(1.43)	(0.05)
Quarter FE	Yes	Yes
% Adjusted R^2	73.6	71.4
# Observations	88	88

Table 5: **Halted UST Bond Auctions & the Returns of Bonds and PACs.**
This table examines the returns on UST bonds and PACs when the U.S. Treasury announced the suspension of 30-year UST bond auctions on Oct. 31, 2001. UST returns are daily from CRSP, while PAC returns are monthly from the ICE Bank of America - Merrill Lynch CMO Indices. UST returns are calculated as the price change plus accrued and paid interest, divided by the previous day's price plus accrued interest (TDRETNUA in CRSP). We calculate the daily difference in returns for UST bonds (maturing in 25+ years) and notes (maturing in 9-10 years). Column (1) shows the return difference on the suspension announcement, and Column (2) shows the t-statistic relative to the prior distribution (Jan. 1, 1997 to Aug. 30, 2001). Columns (3) and (4) report the return difference and t-statistic for the possible reversal announcement on May 4, 2005. For PACs, we calculate the monthly difference in value-weighted average returns (TRRMTD in ICE Index) for agency PAC bonds with long (9+ years) and medium (7-8 years) durations. Medium-duration PAC bonds have a duration similar to the 10-year UST note. ***, **, and * denote statistical significance at 1%, 5%, and 10%, respectively.

	Suspension Announced Oct. 31, 2001		Possible Reversal Announced May 4, 2005	
	Effect	t-stat	Effect	t-stat
Instrument	(1)	(2)	(3)	(4)
Treasury Bond Less Note Returns (Daily)	2.08***	8.0	-1.17***	-4.6
Long Less Medium PAC Returns (Monthly)	3.90***	4.3	0.70	0.7

Table 6: **Heterogeneity in PAC Safety & Insurer's Purchases.**
This table uses PAC prepayment risk heterogeneity to show that life insurers preferred the safest PAC tranches. In Column (1), the dependent variable is the aggregate value (in millions) of purchases of newly issued medium-term ($i = 0$) and long-term ($i = 1$) PAC-1 CMOs by insurance company j in quarter q, resulting in two observations i per quarter q for insurer j. Medium-term CMOs have a weighted average life (WAL) between 2 and 10 years, and long-term CMOs have a WAL of more than 10 years. In Column (2), we use the WAL of newly issued PAC-2 CMOs. PAC-1 tranches offer more prepayment risk protection than PAC-2 CMOs. In Columns (3) and (4), we repeat Columns (1) and (2) after scaling by the insurer's fixed income portfolio size at the end of year $y-1$. $\mathbb{1}(\text{LT})_{i,j}$ equals one for insurer j's long-term ($i = 1$) securities purchases and zero for medium-term ($i = 0$) purchases. $\mathbb{1}(\text{No Auction})_q$ equals one for quarters from 2001 Q4 (when the U.S. Treasury suspended 30-year UST bond auctions) to 2005 Q4. The Treasury resumed UST bond auctions in Feb. 2006, and $\mathbb{1}(\text{Post Period})_q$ equals one for quarters from 2006 Q1 to 2007 Q4. We control for insurer j's purchases of newly issued medium-term ($i = 0$) and long-term ($i = 1$) SEQs in quarter q ($SEQ_{i,j,q}$) to account for time-varying factors affecting insurer j's demand for medium- and long-term CMOs in general. We include insurer and quarter fixed effects to control for fixed differences between insurers and aggregate trends. The coefficients in Columns (1) and (3) differ from those in Columns (1) and (4) of Table 3 because Table 6 examines the subsample of CMO deals with multiple PAC types (e.g., PAC-1 and PAC-2). We double cluster standard errors by quarter and insurer. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively.

	$\text{PAC-1}_{i,j,q}$	$\text{PAC-2}_{i,j,q}$	$\frac{\text{PAC-1}_{i,j,q}}{\text{AUM}_{j,y-1}}$	$\frac{\text{PAC-2}_{i,j,q}}{\text{AUM}_{j,y-1}}$
	(1)	(2)	(3)	(4)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	1.56**	-0.08	0.01**	-0.00
	(0.71)	(0.05)	(0.01)	(0.00)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{Post Period})_q$	0.53	-0.05	-0.00	-0.00
	(0.41)	(0.04)	(0.00)	(0.00)
$\mathbb{1}(\text{LT})_{i,j}$	0.06	-0.01	0.01***	-0.00
	(0.11)	(0.01)	(0.00)	(0.00)
$\text{SEQs}_{i,j,q}$	0.10**	-0.00		
	(0.04)	(0.00)		
$\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}} \times 100$			0.04***	0.00
			(0.01)	(0.00)
Constant	0.14	0.05***	0.00***	0.00***
	(0.24)	(0.01)	(0.00)	(0.00)
Firm FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
% Adjusted R^2	16.79	3.61	3.82	3.58
# Insurers	250	250	250	250
# Quarters	44	44	44	44
# Observations	19960	19960	19960	19960

Table 7: **Insurers with Prior CMO Experience Respond More.**
This table examines whether insurers with prior PAC or SEQ experience substituted more to PACs after the suspension of the 30-year UST bond than those without. The dependent variable is the aggregate value (in millions) of purchases of medium-term ($i = 0$) and long-term ($i = 1$) PACs by insurer j in quarter q, resulting in two observations i per quarter q for insurer j. Medium-term PACs have a WAL between 2 and 10 years, and long-term PACs have a WAL of over 10 years. Column (1) includes life insurers with at least one PAC or SEQ purchase between 1997 Q1 and 2001 Q3. Column (2) includes insurers without prior PAC or SEQ purchases by 2001 Q3. Columns (3) and (4) repeat Columns (1) and (2) after scaling by the insurer's fixed income portfolio size at year-end $y-1$. $\mathbb{1}(\text{LT})_{i,j}$ equals one for insurer j's aggregate purchases of long-term ($i = 1$) securities and zero for medium-term ($i = 0$) securities. $\mathbb{1}(\text{No Auction})_q$ equals one for quarters from 2001 Q4 (when the U.S. Treasury suspended 30-year UST bond auctions) to 2005 Q4 (Treasury resumed UST bond auctions in Feb. 2006). $\mathbb{1}(\text{Post Period})_q$ equals one for quarters from 2006 Q1 onwards. We control for insurer j's purchases of medium-term ($i = 0$) and long-term ($i = 1$) SEQs in quarter q ($SEQ_{i,j,q}$) to account for time-varying factors affecting insurer j's CMO demand in general. We include insurer and quarter fixed effects, and double-cluster standard errors by quarter and insurer. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively.

	$\text{PACs}_{i,j,q}$		$\frac{\text{PACs}_{i,j,q}}{\text{AUM}_{j,y-1}}$	
	(1)	(2)	(3)	(4)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	9.45**	-0.06	0.08***	-0.00
	(4.50)	(0.22)	(0.03)	(0.01)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{Post Period})_q$	0.40	-0.30*	-0.01	-0.01*
	(1.28)	(0.16)	(0.02)	(0.01)
$\mathbb{1}(\text{LT})_{i,j}$	0.34	0.00	0.01	0.00
	(0.72)	(0.00)	(0.01)	(0.00)
$\text{SEQs}_{i,j,q}$	0.45***	0.17**		
	(0.16)	(0.08)		
$\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}} \times 100$			0.28***	0.22***
			(0.04)	(0.07)
Constant	2.14	0.34***	0.06***	0.02***
	(1.32)	(0.05)	(0.01)	(0.00)
CMO Experience	Yes	No	Yes	No
Firm FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
% Adjusted R^2	23.60	7.90	12.00	9.87
# Insurers	170	61	170	61
# Quarters	44	44	44	44
# Observations	14352	5088	14352	5088

Table 8: **Halted UST Bond Auctions, PAC Purchases, & Insurer Size.**
This table shows that results in Table 3 Column (1) are robust to different samples of life insurers based on their 1999 AUM. The dependent variable is the aggregate value (in millions) of purchases of newly issued medium-term ($i = 0$) and long-term ($i = 1$) PACs by insurance company j in quarter q, resulting in two observations i per quarter q for insurer j. Medium-term PACs have a weighted-average life (WAL) between 2 and 10 years at issuance, and long-term PACs have a WAL of more than 10 years. Columns (1), (2), and (3) include insurers with a 1999 AUM rank of 1-75, 76-150, and 151-250, respectively. Columns (4) to (6) scale the outcome variable and controls by the lagged AUM of the insurer. $\mathbb{1}(\text{LT})_{i,j}$ is an indicator variable equal to one for insurer j's aggregate purchases of long-term ($i = 1$) securities and zero for medium-term ($i = 0$) securities. $\mathbb{1}(\text{No Auction})_q$ equals one for quarters from 2001 Q4 (when the U.S. Treasury suspended 30-year UST bond auctions) to 2005 Q4 (Treasury resumed UST bond auctions in Feb. 2006). $\mathbb{1}(\text{Post Period})_q$ equals one for quarters from 2006 Q1 onwards. We control for insurer j's purchases of newly issued medium-term ($i = 0$) and long-term ($i = 1$) SEQs in quarter q ($SEQ_{i,j,q}$) to account for time-varying firm-specific factors affecting insurer j's demand for medium- and long-term CMOs in general. We include insurance company and quarter fixed effects to control for fixed differences between insurers and aggregate trends in PAC purchases. Standard errors are double-clustered by quarter and insurer. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively.

	$\text{PACs}_{i,j,1}$			$\frac{\text{PACs}_{i,j,q}}{\text{AUM}_{j,y-1}}$		
Insurer Rank by AUM 1999	1-75	76-150	151-250	1-75	76-150	151-250
	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	17.69*	4.05*	0.47	0.07**	0.09**	0.02
	(10.22)	(2.16)	(0.52)	(0.03)	(0.05)	(0.02)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{Post Period})_q$	0.70	0.35	-0.23	-0.03	0.02	-0.01
	(2.79)	(0.55)	(0.18)	(0.02)	(0.03)	(0.02)
$\mathbb{1}(\text{LT})_{i,j}$	0.69	-0.06	0.10	0.02	-0.01	0.01
	(1.55)	(0.25)	(0.12)	(0.01)	(0.02)	(0.01)
$\text{SEQs}_{i,j,q}$	0.45***	0.39**	0.43**			
	(0.16)	(0.15)	(0.18)			
$\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}} \times 100$				0.28***	0.27***	0.30***
				(0.08)	(0.06)	(0.06)
Constant	3.49	1.25**	0.51***	0.03***	0.05***	0.05***
	(2.81)	(0.62)	(0.17)	(0.01)	(0.01)	(0.01)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes	Yes	Yes
% Adjusted R^2	24.00	14.40	13.74	12.43	12.51	11.62
# Insurers	75	75	100	75	75	100
# Years	44	44	44	44	44	44
# Observations	6200	6056	7704	6200	6056	7704

Internet Appendix to
Identifying the Portfolio Balance Mechanism

This Internet Appendix contains supplementary analyses. These include the following:

1. Appendix A.1 contains a brief explanation of the PSA standard.
2. Appendix A.2 contains model details
3. Figure A1 shows the number of life insurers and total AUM by year.
4. Figure A2 shows the principal cash flows of a mortgage pass-through under different prepayment speeds.
5. Figure A3 fully annotates Figure 5.
6. Figure A4 fully annotates Figure 6.
7. Table A1 shows the Table 3 results are robust to using a log transformation.
8. Table A2 shows the Table 3 results are robust to including secondary market purchases.
9. Table A3 shows the regressions used to generate the residual returns and daily yield changes in Figure 6.

A.1 PSA Standard

Prepayments have a significant effect on the cash flows of pass-through securities. Prepayment speeds are typically defined in terms of the Bond Market Association's prepayment speed standard (PSA). The PSA standard is commonly used as a simple metric to build different prepayment speed scenarios. Recently originated mortgages are less likely to prepay than seasoned mortgages. This seasoning effect on prepayments is captured in the PSA standard. This standard assumes that the annualized principal prepayment rate of a pool of mortgages is equal to 0.2% for one-month old mortgages, increases by 0.2% every month until it reaches 6% for mortgages 30-months old, remaining constant at 6% until the mortgages are paid in full. Figure A2 shows the principal cash flows of a pass-through under three different PSA scenarios.[31] In all three scenarios, the principal cash flows are at the maximum level when the underlying mortgage pool is 30-months old. This is a natural consequence of the PSA prepayment speeds. In addition, this creates the hump-shaped pattern that is common in all three scenarios. With 200% PSA, the principal cash flows of the underlying pool are much higher during the first 120 months of the mortgage pool, so the average life of the pool is shorter compared to that with 100% PSA. In contrast, in the 50% PSA scenario, the principal cash flows are spread more evenly over time. This results in an average life for the pool of mortgages that is longer than the one with 100% PSA due to the extension of the mortgage cash flows.

[Insert Figure A2 Here]

A.2 Model Details

Our model expands on the framework presented in Greenwood, Hanson, and Stein (2010), adapting it to a scenario with a mortgage dealer. As in Greenwood, Hanson, and Stein (2010), we consider a three-period world. In the first period, the known short-term interest rate is r_1. The interest rate for the second period is r_2 with mean μ_r and variance σ_r^2. Preferred-habitat investors exhibit an inelastic demand for bonds maturing at $t = 3$. The excess supply of bonds with maturity at $t = 3$ is represented by g, which is equal to the amount of bonds the government issues minus the demand from inelastic preferred habitat investors.

Drawing parallels to Greenwood, Hanson, and Stein (2010), our model incorporates a yield curve arbitrageur adept at capitalizing on arbitrage opportunities within the yield curve. This term-structure arbitrageur addresses the excess demand for long-term bonds by selling long-term bonds at a price P and reallocating the proceeds at the short-term interest rate. The arbitrageur maximizes the mean variance utility of terminal wealth:

$$\max_h h[(1 + r_1)(1 + \mu_r) - \frac{1}{P}] - \frac{h^2}{2} \frac{(1 + r_1)^2 \sigma_r^2}{\lambda}$$

where λ is the yield curve arbitrageur's risk tolerance. The first order condition of this

[31] See https://www.sifma.org/wp-content/uploads/2017/08/chsf.pdf for the formulas used to calculate these cash flows.

problem implies:

$$h^* = \frac{(1+r_1)(1+\mu_r) - 1/P}{\eta_h} \tag{7}$$

where $\eta_h = (r_1+1)^2\sigma_r^2/\lambda$ is the risk penalty associated with the yield-curve arbitrageur's problem.

The mortgage dealer addresses the excess demand from preferred habitat investors for bonds maturing at time 3 by issuing Planned Amortization Class (PAC) securities. Specifically, the dealer acquires f dollars worth of mortgage pass-through securities, financed by bonds maturing at time $t = 3$.[32] These bonds, being devoid of prepayment risk, are akin to PACs. The mortgage dealer assumes the prepayment risk for the mortgages financed by these PACs, similar to how a hedge fund would retain a support tranche. The prepayment amount, denoted as (Π_2), is reinvested at the interest rate r_2, while the non-prepaid portion $(1-\Pi_2)$ accrues interest at rate c. Consequently, the mortgage dealer's profit at time t_3, derived from financing mortgages with PACs, is calculated as $f \times (1 + M_I - 1/P)$, where P represents the price of the zero-coupon bond maturing at time 3. Here, $M_I = (1-\Pi_2)c + \Pi_2 r_2 + (1+r_2)c$ signifies the value at time 3 of the interest paid on \$1 of mortgage principal from time 1 to 3. The term M_I has a mean of μ_M and a variance of σ_M^2. Accordingly, the mortgage dealer's wealth at time 3 is expressed as $W = f \times (1 + M_I - 1/P)$. The mortgage dealer's objective is to maximize the mean-variance utility of terminal wealth:

$$\max_f E[W] - \frac{1}{2\theta}\sigma_W^2 \tag{8}$$

Here, θ symbolizes the mortgage dealer's risk tolerance. The primary condition for optimization yields $f = (1 + \mu_M - 1/P)/\eta_f$, with $\eta_f = \sigma_I^2/\theta$ representing the risk penalty inherent to the mortgage dealer's problem. The mortgage interest rate c is exogenous to our model.

$$f^* = \frac{1 + \mu_M - 1/P}{\eta_f} \tag{9}$$

The first order conditions of the arbitrageurs' and mortgage dealer's problems along with the market clearing condition $(f^* + h^* = -g)$ and result in the following solutions for f^*, h^*:

$$f^* = \frac{1 + \mu_M - (1+\mu_r)(1+r_1)}{\eta_f + \eta_h} - \frac{\eta_h}{\eta_f + \eta_h} g \tag{10}$$

$$h^* = \frac{(1+r_1)(1+\mu_r) - (1+\mu_M)}{\eta_f + \eta_h} - \frac{\eta_f}{\eta_f + \eta_h} g \tag{11}$$

For simplicity, and without loss of generality, we assume that the mortgage rate is determined in the pass-through market in a manner that does not price prepayment, i.e., $1 + \mu_M =$

[32] For the sake of simplicity, our model does not incorporate short-selling constraints. That is, when the excess supply of bonds is positive ($g > 0$), mortgage dealers are allowed to short sell mortgage pass-throughs for investing in long-term bonds. Our primary focus, however, remains on scenarios where there is a negative excess supply for bonds.

$(1+\mu_r)(1+r_1)$, and

$$f^* = -\frac{\eta_h}{\eta_f + \eta_h} g \text{ and } h^* = -\frac{\eta_f}{\eta_f + \eta_h} g \tag{12}$$

This solution implies that

$$\frac{\partial f^*}{\partial g} = -\frac{\eta_h}{\eta_f + \eta_h} \tag{13}$$

This implies that the share of any increase on the excess demand for bonds that is captured by the mortgage dealer decreases with her risk penalty ($\eta_f = \sigma_I^2/\theta$), and increases with the risk penalty of the yield-curve arbitrageur, $\eta_h = (1+r_1)\sigma_r^2/\lambda$. Indeed, while the mortgage dealer captures $\partial f^*/\partial g$ of each dollar increase in g, the yield curve arbitrageur captures $1 - \partial f^*/\partial g$. The 2-period expected excess return of the long-term bond is:

$$\frac{1}{P} - (1+r_1)(1+\mu_r) = \frac{\eta_f \eta_h}{\eta_f + \eta_h} g \tag{14}$$

Figure A1: **Life Insurer AUM and Count by Year in the Sample.**
We sample the top 250 U.S. life insurers by fixed income portfolio size at the end of 1999. We plot their aggregate AUM from 1997 to 2007 and the number of insurers each year. The number of insurers decreases over time, reflecting national trends in life insurance (American Council of Life Insurers *Life Insurers Fact Book 2022*, Table 1.7 (ACLI, 2022)).

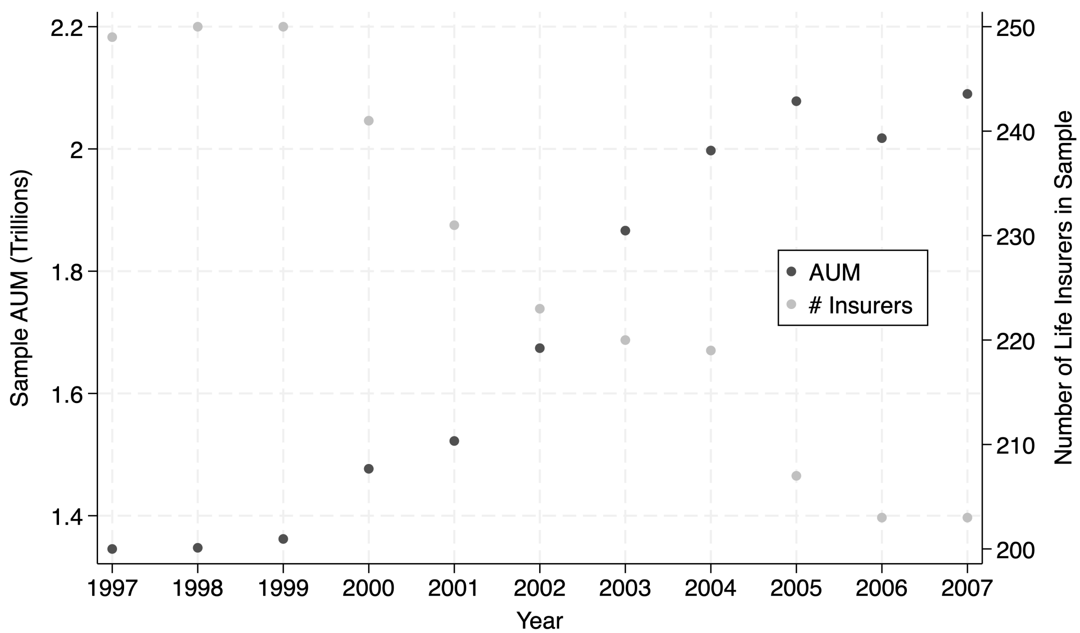


Figure A2: **Principal Cash Flows of a Mortgage Pass-through under Different Prepayment Speeds.**
This figure shows the principal cash flows of a 5% coupon pass-through security under different PSA scenarios. The initial principal is $100 million. The x-axis has the weighted average loan age (months) of the loans backing the mortgage pass-through. The PSA standard is a metric for prepayment speed scenarios, accounting for mortgage seasoning. It assumes an annual prepayment rate of 0.2% for one-month-old loans, increasing by 0.2% monthly until 6% at 30 months, then remaining constant. The 100% PSA scenario follows the PSA standard, 200% PSA is double, and 50% PSA is half. The figure is build with a $100 million unpaid principal at time zero.

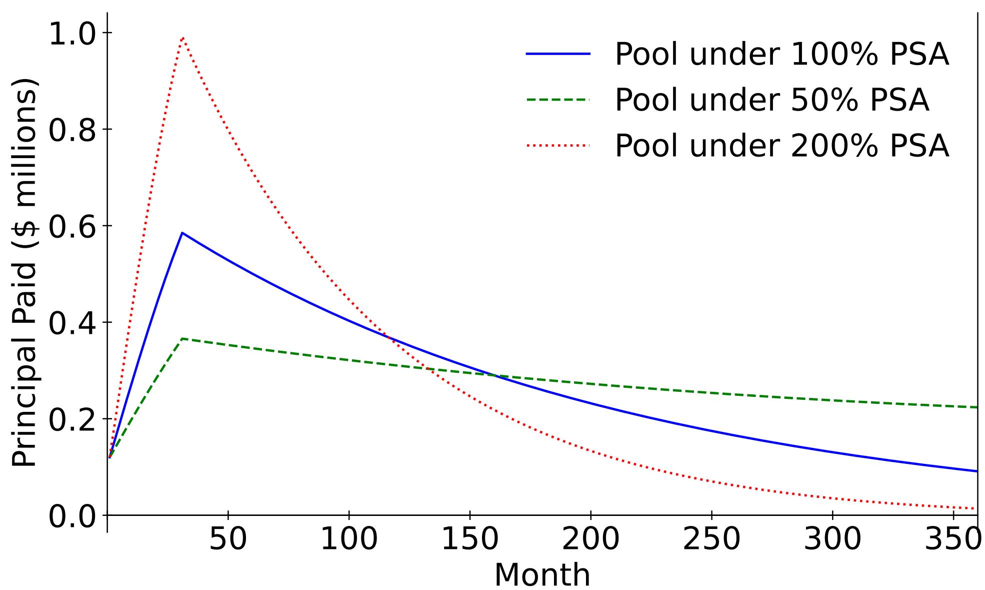


Figure A3: **Daily UST Returns & the Suspension Announcement.**
The figure shows the daily difference in returns for UST bonds (25-30 years maturity) and 10-year UST notes (9-10 years maturity). Daily returns are calculated as the price change plus accrued and paid interest, divided by the previous day's price plus accrued interest (TDRETNUA in CRSP). We calculate the principal-weighted average of daily returns for UST bonds and notes. Red circles mark key events: LTCM meltdown (Sept. 23, 1998), Gesler predicts 30-year UST loses benchmark status (Feb. 2, 2000), suspension announcement of 30-year UST auctions (Oct. 31, 2001), possible resumption announcement (May 4, 2005), confirmation of resumption (Aug. 3, 2005) and first auction after suspension (Feb. 9, 2006).

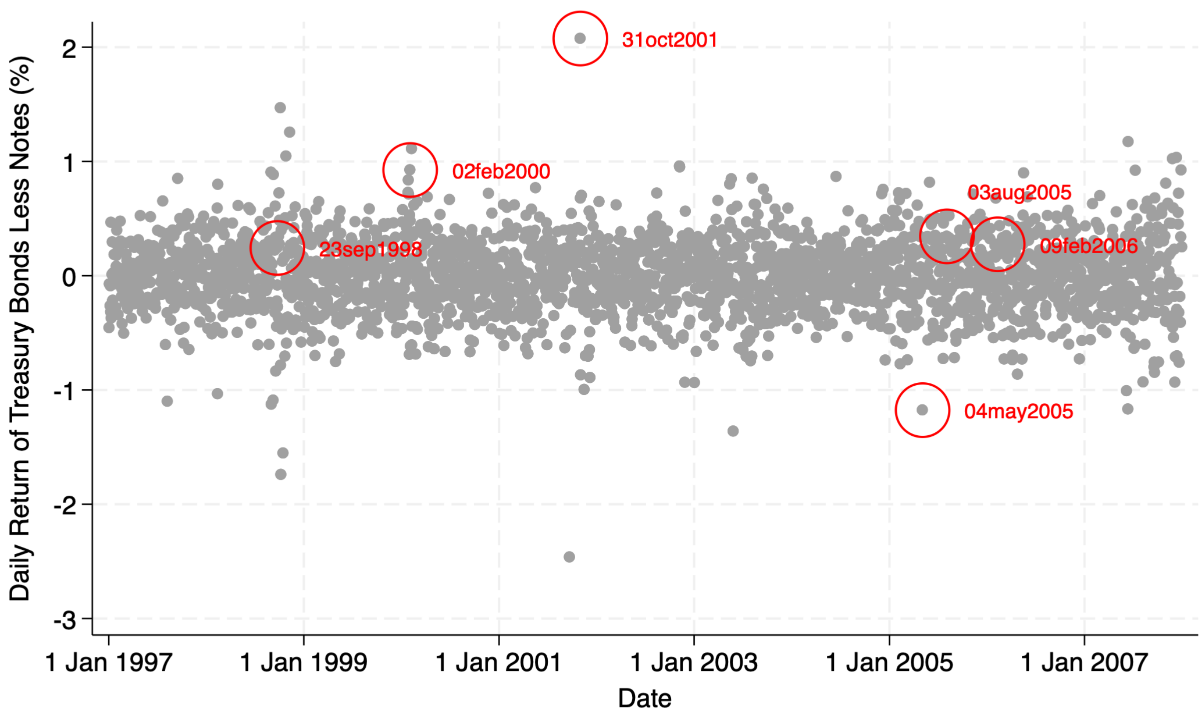
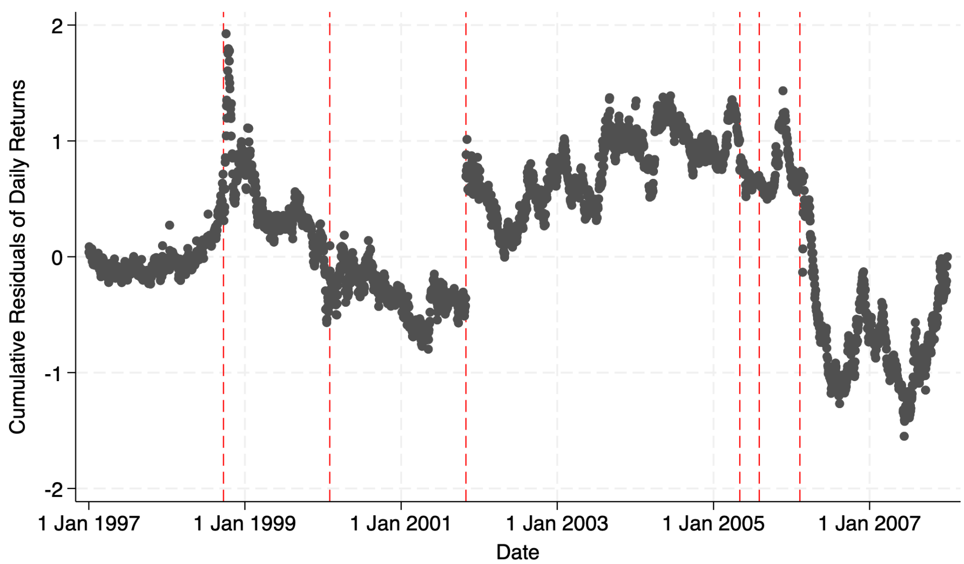
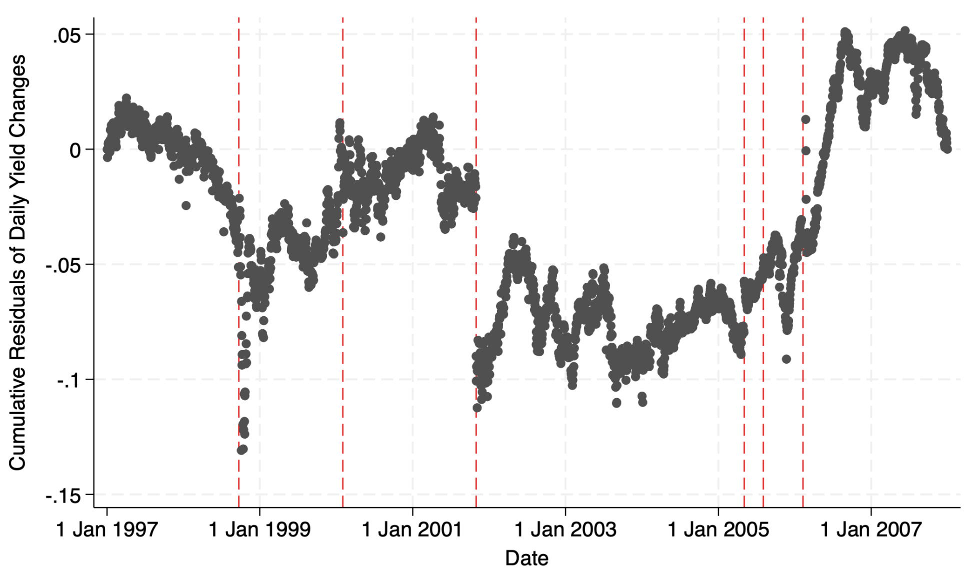


Figure A4: **Cumulative Residual Returns & Changes in Yields.**
Panel A shows the cumulative residual daily return of the 30-year UST. This is calculated by regressing the daily returns of UST bonds with maturities of 25-30 years on those with maturities of less than 1 year, 1-2 years, 2-3 years, 3-5 years, 5-7 years, 7-15 years, 15-20 years, and 20-25 years. Vertical red (dashed) lines mark key events: LTCM meltdown (Sept. 23, 1998), Gesler predicts 30-year UST loses benchmark status (Feb. 2, 2000), suspension announcement of 30-year UST auctions (Oct. 31, 2001), possible resumption announcement (May 4, 2005), confirmation of resumption (Aug. 3, 2005) and first auction after suspension (Feb. 9, 2006). Panel B shows the residual daily change in YTMs, calculated similarly to Panel A.



(a) Cumulative residual daily 30-year UST returns



(b) Cumulative residual daily changes in 30-year UST YTM

Table A1: **Robustness of Table 3 to log transformations.** This table shows that the results in Table 3 are robust to log transformations addressing data skewness. In column (1), the dependent variable is log(1 + X), where X is the aggregate value (in millions) of purchases of newly issued medium-term and long-term PACs by insurance company j in quarter q. We aggregate purchases of medium-term and long-term PACs separately, resulting in two observations i per quarter q for insurer company j. Medium-term PACs have a weighted-average life (WAL) between 2 and 10 years, and long-term PACs have a WAL of more than 10 years. In column (2), we use a similar outcome variable for the maturity of newly-issued medium-term and long-term USTs purchased by life insurers. Medium-term USTs have a time-to-maturity between 2 and 10 years, and long-term USTs have a time-to-maturity of more than 10 years. In columns (3) and (4), we repeat columns (1) and (2) after scaling X by the dollar size of the insurer's fixed income portfolio at the end of year $y-1$. $\mathbb{1}(\text{LT})_{i,j}$ is an indicator variable equal to one for insurer j's aggregate purchases of long-term (i=1) securities and zero for medium-term (i=0) securities. $\mathbb{1}(\text{No Auction})_q$ equals one for quarters from 2001 Q4 (when the U.S. Treasury suspended 30-year UST bond auctions) to 2005 Q4. The Treasury resumed UST bond auctions in Feb. 2006, and $\mathbb{1}(\text{Post Period})_q$ equals one for quarters from 2006 Q1 to 2007 Q4. We control for insurer j's purchases of newly issued medium-term (i=0) and long-term (i=1) sequential tranches in quarter q ($SEQ_{i,j,q}$) to account for time-varying firm-specific factors affecting insurer j's demand for medium- and long-term CMOs in general. We include insurance company fixed effects to control for fixed differences between insurers and quarter fixed effects to control for aggregate trends. Standard errors are double-clustered by quarter and insurer. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively.

	$\ln(1+\text{PACs}_{i,j,y})$	$\ln(1+\text{UST}_{i,j,y})$	$\ln(1+\frac{\text{PACs}_{i,j,y}}{\text{AUM}_{j,y-1}})$	$\ln(1+\frac{\text{UST}_{i,j,y}}{\text{AUM}_{j,y-1}})$
	(1)	(2)	(3)	(4)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	0.18***	-0.23**	0.06***	-0.07*
	(0.06)	(0.10)	(0.02)	(0.04)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{Post Period})_q$	0.05	-0.03	-0.01	0.00
	(0.04)	(0.06)	(0.01)	(0.02)
$\mathbb{1}(\text{LT})_{i,j}$	0.03	-0.28***	0.01	-0.08***
	(0.02)	(0.05)	(0.01)	(0.02)
$\ln(1+\text{SEQs}_{i,j,q})\times 100$	0.24***			
	(0.03)			
$\ln(1+\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}}) \times 100$			0.29***	
			(0.04)	
Constant	0.19***	0.46***	0.05***	0.12***
	(0.02)	(0.02)	(0.01)	(0.01)
Firm FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
% Adjusted R^2	23.99	25.52	12.25	11.86
# Insurers	250	250	250	250
# Years	44	44	44	44
# Observations	19960	19960	19960	19960

Table A2: **Repeating Table 3 with secondary market purchases**

This table repeats Table 3 after including secondary market purchases. The table again shows that life insurers purchased more long-term PACs relative to medium-term PACs during the suspension of 30-year UST bond auctions. When examining secondary market purchases, the periodicity of our data is a year (instead of a quarter) because insurers' position amounts are reported annually. By contrast, when examining new issuances, we can use the precise purchase date and issuance date to construct a quarterly panel of newly-issued bond purchases. In Column (1), the dependent variable is the aggregate value (in millions) of purchases of medium-term ($i = 0$) and long-term ($i = 1$) PACs by insurer j in year y, resulting in two observations i per year y for insurer j. Medium-term PACs have a weighted-average life (WAL) between 2 and 10 years, and long-term PACs have a WAL of more than 10 years. When examining the secondary market purchases of CMOs, we adjust the WAL at origination to the year of acquisition. In Column (2), we aggregate purchases of medium-term and long-term USTs, where a UST's WAL is its time to maturity. In Column (3), we aggregate purchases of medium-term and long-term Sequential CMOs (SEQs). In Columns (4) to (6), we repeat Columns (1) to (3) after scaling by the insurer's fixed income portfolio size at the end of year $y - 1$. $\mathbb{1}(\text{LT})_{i,j}$ is an indicator variable equal to one for insurer j's aggregate purchases of long-term ($i = 1$) securities and zero for medium-term ($i = 0$) securities. $\mathbb{1}(\text{No Auction})_y$ equals one for years from 2002 (when the U.S. Treasury suspended 30-year UST bond auctions) to 2005. The Treasury resumed UST bond auctions in Feb. 2006. We control for insurer j's purchases of medium-term ($i = 0$) and long-term ($i = 1$) SEQs in year y ($SEQ_{i,j,y}$) to account for time-varying firm-specific factors affecting insurer j's demand for medium- and long-term CMOs. We include insurance company and year fixed effects to control for insurer-specific and aggregate trends. We double cluster standard errors by year and insurer. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively.

	$\text{PACs}_{i,j,y}$	$\text{UST}_{i,j,y}$	$\text{SEQs}_{i,j,y}$	$\frac{\text{PACs}_{i,j,y}}{\text{AUM}_{j,y-1}}$	$\frac{\text{UST}_{i,j,y}}{\text{AUM}_{j,y-1}}$	$\frac{\text{SEQs}_{i,j,y}}{\text{AUM}_{j,y-1}}$
	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_y$	30.74*	-34.53***	-9.16	0.24**	-0.36***	-0.06
	(16.38)	(9.03)	(5.92)	(0.10)	(0.10)	(0.05)
$\mathbb{1}(\text{LT})_{i,j}$	2.20	-21.77***	2.66	0.03	-0.32***	0.03**
	(1.71)	(5.29)	(1.64)	(0.03)	(0.06)	(0.01)
$\text{SEQs}_{i,j,y}$	0.72*					
	(0.38)					
$\frac{\text{SEQs}_{i,j,y}}{\text{AUM}_{j,y-1}} \times 100$				0.45***		
				(0.08)		
Constant	4.26	39.97***	11.36***	0.17***	0.51***	0.16***
	(6.38)	(3.40)	(1.42)	(0.03)	(0.02)	(0.01)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
% Adjusted R^2	26.67	39.49	30.72	21.35	21.69	20.35
# Insurers	250	250	250	250	250	250
# Years	11	11	11	11	11	11
# Observations	4990	4990	4990	4990	4990	4990

Table A3: **Model for Residual Returns & Changes in Yields**
The dependent variable in Column (1) is the weighted average daily return (*TDRETNUA*) of USTs with 25-30 years to maturity. We weight returns by the amount outstanding of a security. We separately control for the weighted average daily returns of USTs with maturities less than 1 year, in 1-2 years, in 2-3 years, in 3-5 years, in 5-7 years, in 7-15 years, in 15-20 years, and in 20-25 years. In Column (2), the dependent variable is the weighted average daily change in the YTM (*TDYTM*) of USTs with 25-30 years to maturity. The sample period is Jan. 1, 1997 to Dec. 31, 2007. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively.

	30-Year USTs	
	Ret_d	$dYTM_d$
	(1)	(2)
Ret_d (mat. 0-1yr)	0.2103	
	(0.1448)	
Ret_d (mat. 1-2yr)	0.0144	
	(0.0792)	
Ret_d (mat. 2-3yr)	-0.1964*	
	(0.1187)	
Ret_d (mat. 3-5yr)	-0.0582	
	(0.1361)	
Ret_d (mat. 5-7yr)	0.1333**	
	(0.0566)	
Ret_d (mat. 7-15yr)	-0.0656	
	(0.0449)	
Ret_d (mat. 15-20yr)	-0.2149***	
	(0.0533)	
Ret_d (mat. 20-25yr)	1.3254***	
	(0.0505)	
ΔYTM_d (mat. 0-1yr)		-0.0003
		(0.0004)
ΔYTM_d (mat. 1-2yr)		-0.0009
		(0.0060)
ΔYTM_d (mat. 2-3yr)		-0.0388*
		(0.0213)
ΔYTM_d (mat. 3-5yr)		0.0231
		(0.0393)
ΔYTM_d (mat. 5-7yr)		-0.0401*
		(0.0213)
ΔYTM_d (mat. 7-15yr)		0.0526**
		(0.0248)
ΔYTM_d (mat. 15-20yr)		-0.1422***
		(0.0369)
ΔYTM_d (mat. 20-25yr)		1.1167***
		(0.0410)
Constant	-0.0041**	0.0001
	(0.0020)	(0.0001)
% Adjusted R^2	98.85	99.02
# Observations	2744	2744