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 starting in 2002. The suspension raised long-term UST prices and led to the issuance of safe, long-term collateralized mortgage obligations (CMOs) created by tranching mortgage pass-throughs to satisfy habitat-preference investor demand. The heterogeneity of UST 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 habitat-preference 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, preferred-habitat 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 habitat 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 and starting in 2002. 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 USTs with a maturity greater than 10 years. Around this suspension, we examine the extent to which preferred habitat 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 30-year mortgage pools, called pass-throughs, with credit guarantees from Fannie Mae, Freddie Mac, and the U.S. government (Ginnie Mae pass-throughs). Due to these credit guarantees, prepayment risk, rather than credit risk, is the primary concern for agency pass-throughs (Downing, Jaffee, and Wallace, 2009). PACs, by construction, have little exposure to prepayment risk; thus, agency-PACs have both low credit and prepayment risk, similar to USTs. Second, agency CMOs and PACs in particular are regularly issued in relatively large amounts. PACs are among the most common types of CMOs, comprising about 38% of agency-CMO issuance

[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).

amounts. According to SIFMA, 18% of the total outstanding agency mortgage-related securities between 2002 and 2018 consisted of CMOs. In contrast, Fleming (2000) notes that in the corporate bond market, despite its size, no single corporation can match the U.S. Treasury in issuance size and frequency.[2] Third, life insurers are considered habitat investors (e.g., Greenwood and Vissing-Jorgensen, 2018; Koijen, Koulischer, Nguyen, and Yogo, 2017, 2021; Chodorow-Reich, Ghent, and Haddad, 2021) and often purchase agency CMOs, particularly PACs.[3] Fourth, the targeted supply shock on the 30-year UST enables us to use the variation in PACs' and USTs' time-to-maturity for better identification. During the suspension period, investors had access to newly issued 10-year USTs. Thus, life insurers' purchases of PACs with medium average lives (under 10 years) act as a control group, as the PBM suggests their purchases remain unaffected by the 30-year UST supply shock. Lastly, the tranching of agency pass-throughs creates securities with varying exposure to prepayment. This heterogeneity allows for several controls and falsification tests to identify the PBM.

We test two PBM-related hypotheses. First, a decrease in long-term UST supply leads to a rise in the price of these bonds and long-term PACs. Second, a decrease in long-term UST supply leads to an increase in the volume of long-term PACs created to cater to the demand for long-term safe bonds from habitat-preference investors. We formalize these hypotheses with a model that builds on the gap filling theory in Greenwood, Hanson, and Stein (2010), which is 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). Additionally, without frictions, tranching—which sets rules for distributing cash flows from mortgage pools—adds no value. In contrast, in our model, limits to arbitrage render the supply of long-term safe assets not perfectly elastic. Thus, mortgage dealers add value by creating long-term PACs

[2] Agency debt issued by Fannie Mae and Freddie Mac can substitute for USTs in general but not for 30-year UST, as the 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."

as alternatives to long-term USTs.

We find strong support for the hypothesis that a decrease in the net supply of 30-year USTs leads to a rise in the price of 30-year USTs and 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). Moving beyond the direct effect on UST prices, the monthly return difference between long- and medium-duration PACs was 3.9% on announcement.

We find support for the second hypothesis that a decrease in UST supply increases the volume of long-term PACs created to cater to habitat-preference investors. Using a difference-in-difference analysis, we find life insurers increased purchases of new long-term PACs relative to medium-term PACs. 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 before and after the 30-year UST auction suspension. Another difference-in-difference analysis shows that long-term PAC issuances increased significantly compared to other long-term CMOs with prepayment risk during the suspension.

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 results hold for purchases of newly issued CMOs and USTs and secondary market purchases.

The PBM explains all of our findings, unlike the alternative signaling hypothesis. Although the 30-year UST suspension mainly affected UST sales patterns, not net government debt issuance (Bernanke, Reinhart, and Sack, 2004), it could indicate expected changes in interest rates and mortgage prepayment patterns, affecting UST and PAC prices. However, the 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 sizeable investments in other long-term CMOs with prepayment risk during the suspension. Thus, our findings – especially the diverse acquisition behaviors of CMOs by life insurers – result in an unambiguous identification of the PBM.

Our findings significantly contribute 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. In our model, mortgage dealers act similarly to corporations in Greenwood, Hanson, and Stein (2010). 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. We extend this literature by analyzing the acquisitions by preferred-habitat investors in addition to aggregate issuance. Our findings contribute to this literature by documenting a direct switch from 30-year UST bonds to newly issued PACs in life insurers' portfolios, clearly identifying the practice of catering to habitat-preference investors to fill the gap left by a UST supply shock.

Our results support the theory of the term structure based on habitat preference. The idea that the term structure of interest rates is partially driven by investors with preferences for specific maturities dates back to at least Culbertson (1957) and Modigliani and Sutch (1966). Recently, Greenwood and Vayanos (2014) and Vayanos and Vila (2021) formalized this idea in an arbitrage-free framework. Empirical support for these models has focused on government bond yields (e.g. Greenwood and Vayanos, 2010). We extend this empirical evidence by showing that investors typically classified as habitat-preference investors substitute 30-year UST bonds with other safe long-term bonds when 30-year bonds are scarce.

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 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 pre-crisis 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.

[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.

Our identification of the PBM supports the idea that the PBM played a role in the effect of QE. Breckenfelder and De Falco (2023) estimate the elasticity of demand for government bonds, confirming that life insurers are preferred habitat investors as their demand is far less elastic than mutual funds'. Several papers examine the spillover effects of QE. For example, Selgrad (2023) shows that mutual funds buy corporate bonds with the windfall from selling USTs during QE, prompting the issuance of corporate bonds. For identification, Selgrad (2023) uses the unexpected QE purchase amounts of individual UST CUSIPs. This method controls for overall supply shocks to USTs with similar maturities, making it unsuitable for studying preferred-habitat investors' reactions to specific maturity shocks. In contrast, we show that life insurers, besides their relatively inelastic UST demand, buy PACs when UST bonds face a long-term supply shock, prompting the creation of long-term PACs. For identification, we use a supply shock to UST bonds (over 10 years to maturity) and variation across maturities and CMO types, based on the PBM idea that preferred-habitat investors do not substitute long-term UST bonds with medium-term CMOs with prepayment risk. Our paper does not examine how the PBM interacts with other QE mechanisms. For example, QE purchases, paid with reserves, may reduce bank lending (Diamond, Jiang, and Ma, 2023). Thus, our findings do not address the PBM's importance relative to other QE mechanisms.

Section 1 develops the tested hypotheses; Section 2 describes the identification strategy; Section 3 describes the data; Section 4 describes the empirics; and Section 5 concludes.

1 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 adept at capitalizing on 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 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. 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:[5]

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

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

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 long-term bonds, as outlined in Equation 3, is independent of their excess supply, which aligns with the expectation hypothesis. Moreover, in the scenario where the mortgage dealer's risk aversion approaches infinity ($\eta_f \to \infty$), they cease to issue any long-term PACs ($f^* = 0$), 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.[6]

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

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

[6] Dealers typically present hypothetical structures and pricing for agency CMOs to assess market interest. If investor demand for a proposed structure is lacking, alternative structures are offered. This iterative process of proposal and adjustment continues until the agency-CMO's structure final date, at which point the exact collateral and cash flow distribution rules among tranches are established.

arbitrage, the yield curve arbitrageur completely absorbs shocks to the excess supply of long-term bonds, and tranching is not observed ($f^* = 0$).[7] 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 $\eta_h > 0$), the model delivers the two PBM hypotheses that we examine:

Hypothesis 1 *The price of long-term bonds, such as long-term UST and long-term PACs, increases in response to negative supply shocks to long-term UST bonds.*

Hypothesis 2 *The issuance of long-term PACs increases when the excess supply of UST decreases, fulfilling the demand for long-term bonds from habitat-preference investors, such as life insurers.*

2 Identification Strategy

Our empirical analysis examines the suspension of the 30-year UST bond auctions (2002-2005) as a shock to long-term UST bond supply. 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 in Hypotheses 1 and 2. Furthermore, the diversity of CMO types regarding prepayment exposure allows for multiple controls and

[7] CMOs are structured as Real Estate Mortgage Investment Conduits (REMICs); as a result, there are no corporate tax advantages on the CMO issuance (Gorton and Metrick, 2013). The model justifies tranching to create long-term PACs by considering limits to arbitrage and the widely used assumption, central to the PBM, of investor habitat preference for long-term bonds (e.g., Culbertson, 1957; Modigliani and Sutch, 1966). More broadly, the model elucidates that the presence of various CMO types can be explained by assuming a segment of investors with an inelastic demand for specific securities that cannot be freely created by arbitrageurs. This rationale for tranching is commonly cited by practitioners to justify the existence of the hundreds of types of CMOs observed in reality (Davidson, Sanders, Wolff, and Ching, 2008).

falsification tests. Understanding this 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".[8] Prepayment speeds are typically defined in terms of the Bond Market Association's prepayment speed standard (PSA).[9] 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. 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 underlying mortgage pass-through prepayment risk. Indeed, Panel A shows that in the 250% PSA (100% PSA) 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 60 to 120, while the longer-term PAC receives principal from months 120 to 360.

[8] In the model, the long-term PACs do not have PAC bands, which implies that the dealers are completely assuming the risk of prepayment and not leaving any risk to the PAC buyers.

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

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.[10] Conversely, 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.[11]

We aim to identify the PBM by examining the effects of suspending the 30-year UST bond auction on prices and quantities (Hypotheses 1 and 2), exploring UST heterogeneity by time-to-maturity, PACs by weighted average lives, and heterogeneity in the issuance and acquisition of PACs and SEQs. Identifying the PBM poses challenges, as it requires attributing the changes in the portfolios of a preferred habitat investors during a UST supply shock to a substitution effect. Our identification strategy hinges on the assumption that the suspension of 30-year UST issuance results in an increase in the price of long-term bonds relative to the price of medium-term bonds, an increase in the demand for long-term PACs relative to medium-term PACs, and an increase in the issuance of PACs relative to SEQs, without affecting the demand for long-term SEQs relative to medium-term SEQs.[12]

[10]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-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."

[11]The mortgage dealer in the model assumes the prepayment risk associated with the mortgages financed through long-term PACs, emulating the roles played by dealers and hedge funds in the real world.

[12]Gabaix, Krishnamurthy, and Vigneron (2007) also explore CMO heterogeneity by analyzing prepayment risk pricing in Interest-only (IO) and Principal-only (PO) tranches. While common, IOs and POs are less

Our identification strategy addresses the two alternative hypotheses that often plague the identification of the PBM. The signaling hypothesis indicates that the suspension may 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 hypothesis implies an increase in life insurers' acquisitions of both newly issued long-term and medium-term PACs, as well as a decrease in their typical purchases of SEQs during the no-auction period.

Information frictions are another alternative theoretical justification for tranching.[13] 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.

3 Data

Our empirical analysis spans from 1998 to 2007, concluding in 2007 to ensure that our findings are not influenced by the financial crisis. Our data on UST notes and bonds come from the CRSP Treasury files. We gather data for all non-callable UST bonds and notes trading between 1998 and 2007 from CRSP. 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 1998 and 2007. 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

prevalent than PACs and SEQs. Unlike IOs and POs, PAC cash flows remain stable during refinancing waves due to the SUP tranche absorbing prepayment risk.

[13]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).

$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. 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.[14]

[Insert Figure 2 Here]

To examine Hypothesis 1, 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.[15] We collect data for PACs (CMOP and CMPZ indices), including 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.[16] 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 Hypothesis 1. See Galdi, Goldblatt, and Zhang (2006) for details on these indices. 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 the 10-year note (eight years) has a median of 12 constituents.

To evaluate Hypothesis 2, 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

[14]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.

[15]`https://www.ice.com/fixed-income-data-services/index-solutions/fixed-income-indices`

[16]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.

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 1998 and 2007. Specifically, we assemble a comprehensive panel of all agency-CMOs issued between 1998 and 2007 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 GNMA data disclosure web page.[17] The raw data consist of 3,107 individual CMO deals with 142,519 individual tranches. 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 2,984 deals and 85,035 CMO tranches, all falling within these three classes of tranches.[18] Table 1 provides summary statistics for our CMO data.

[Insert Table 1 Here]

Table 1, Panel A presents descriptive statistics for CMO deals in our sample. Each deal has on average $1.1 billion in principal and 40 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 59,456 tranches in this category and approximately 42% of the tranches issued in our raw sample and 38% of the dollar amount issued in the

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

[18] 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 and only if the term "PAC" type appeared in the type description. Likewise, a SEQ tranche only has "SEQ" in the type description from this set of types. 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.

raw sample. Table 1, Panel C shows descriptive statistics for SEQs. These SEQs represent the second largest class of CMOs with 25,579 tranches.

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 7.6 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 7.6 years.

Our life insurance companies' bond portfolios data are 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 1998 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.[19] Because some holdings are non-US and not denominated in dollars, we use the reported total AUM of the insurer, which is dollar-denominated.[20]

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 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

[19]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.

[20]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.

the creation of new bonds is motivated by the demand of preferred habitat investors. For instance, the NAIC data do not include the issuance date of the bonds, which is necessary to identify purchases of newly issued securities. In contrast, the CRSP Treasury data and the CMO data contain issuance dates. Hence, our merged dataset includes the issuance date and the amount that a given insurance company holds of a given bond at the end of the year. With this information, we can determine whether an insurance company acquired a newly issued bond in the quarter in which it was issued.[21] This, in turn, allows us to create a quarterly panel dataset that 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.[22] We use these purchases in Section 4 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 14.4% (1,292/8,988) of the 8,988 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 $43.9 million, or about 0.8% of an insurer's total fixed income portfolio. About 3.2% (287/8,988) of the observations involve the purchase of a 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 suspension. Conditional on an insurer purchasing newly issued UST bonds in a given quarter, the mean purchase amount is $42.6 million, or 0.4% of an insurer's total fixed income portfolio. In

[21]The assumption is that if an insurer reports in its annual filing a position in a security issued in that same year, the insurer purchased the security in the quarter of issuance. More than 40% of the purchases are of securities issued in the same year. In the Internet Appendix, we show that our results are robust when considering all purchases instead of only purchases of newly issued securities.

[22]The shortest (longest) UST note in CRSP has 1.98 (10.05) years at issuance. We use these cut-off points in our definition of medium- and long-term CMOs to perfectly match the UST maturities observed in the data.

addition, life insurers are also frequent purchasers of long-term SEQ tranches. Approximately 14.1% (1,264/8,988) of the observations involve the purchase of a new long-term SEQs, and the average purchase amount is $31.2 million, or 0.5% of an insurer's total fixed income portfolio.

[Insert Table 2 Here]

4 Empirical Results

4.1 Price Reactions to the 30-year UST Auction Suspension

Hypothesis 1 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. On Aug. 3, 2005, in a widely anticipated announcement, the U.S. Treasury confirmed that it would bring back the 30-year UST bond with the first auctions to be held in Feb. 2006. Consistent with this statement, 30-year UST bond issuances resumed in Feb. 2006.

Figure 3 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 medium-term UST notes (with 9 to 10 years to maturity), was approximately 2.1%.[23] This marks the largest positive daily difference in long-term UST bond and 10-year note returns within the sample period from 1998 to 2007. This pronounced reaction suggests that the market was taken by surprise by the discontinuation of the 30-year bond issuance.[24]

[23]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 3 during the suspension period.

[24]Although Gary Gensler, the Under Secretary of the Treasury for Domestic Finance, hinted in Feb. 2000 that the ten-year note might replace the thirty-year bond as the benchmark long-term security, the announcement's coverage suggested the suspension was largely unexpected. Coverage of this "surprise move" can be found in the Wall Street Journal at `https://www.wsj.com/articles/SB1004548380881711360`, CNN at `https://money.cnn.com/2001/10/31/markets/longbond/`, and the Economist at `https://www.economist.com/finance-and-economics/2001/11/01/cut-short`.

This significant announcement return 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.[25] 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.[26]

[Insert Figure 3 Here]

Table 3 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 to 10 years to maturity) in the period January 1, 1998 to August 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 7.7 for UST bonds on Oct. 31, 2001 when the suspension is announced, and the t-statistic is -4.5 on May 4, 2005 when the possible reversal of the suspension is announced.

[Insert Table 3 Here]

Now, we turn our attention to the prices of long-duration PACs, around the announcement of the suspension. Table 3 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.[27] The difference in monthly returns on the day of the announcement was 3.9% (t-statistic of 4.5). Figure 4 plots this difference in monthly returns for the sample period, showing that the price move in Oct. 2001 was atypical.[28]

[25]It is insightful to compare the effect shown in Figure 3 with the outcomes of QE. Wiliams (2014) notes that the impact estimates of QE suggest that $600 billion in asset purchases lead to a reduction in the yield of 10-year notes by approximately 15 to 25 basis points.

[26]The figure also indicates the largest negative return occurred on Sept. 21, 2001, the day markets reopened after the Sept. 11, 2001 terrorist attacks.

[27]In fact, 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.

[28]Figure A3 shows that the returns of the agency SUP tranches decrease slightly on the announcement of the suspension of the 30-year UST bond auctions. During our sample period, SUP tranches have an 49bp higher effective yield than long-term PACs which is consistent with their higher exposure to prepayment.

[Insert Figure 4 Here]

The price movements that we observe align with Hypothesis 1. 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 UST leads to adjustments in the term premium as depicted in Equation 3. The impact on PAC prices aligns with the UST bond supply shock increasing demand for alternative safe assets among habitat-preference investors.

The alternative signaling hypothesis may rationalize the price reactions presented in Figures 3 and 4, as well as in Table 3. Those findings may be indicative that the suspension and subsequent resumption of UST bond auctions convey information about the anticipated interest rate trajectory over the next 30 years. To address this alternative explanation, we investigate whether PACs serve as substitutes for UST bonds in the next section.

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

We now examine Hypothesis 2, which predicts that a negative shock to the excess supply of 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 issuances of long-term PACs relative to SEQs during the suspension period. The U.S. Treasury announced on Oct. 31, 2001 (2001 Q4) that UST bond auctions were indefinitely suspended. In May 2005 (2005 Q2), the U.S. Treasury announced the possible resumption of UST bond auctions. We call this period when UST bonds are suspended indefinitely the *No Auction* 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:

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

The dependent variable is the amount of purchases of newly issued medium- or long-term PACs by the insurance company j in quarter q. 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). $\mathbb{1}(\text{LT})_{i,j}$ 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 Q2 when UST bond auctions were indefinitely suspended. 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 (absorbs β_3). 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 5 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 $16.5 million per life insurer in 2002 Q4. PAC purchases remained significantly elevated through 2004. On May 4, 2005, the U.S. Treasury announced its intention to resume UST bond auctions, and PAC purchases returned to normal in 2005 Q2 when it became clear that the suspension of UST bond auctions was ending.

[Insert Figure 5 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 4 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 $7.3 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 0.07 percentage points of an insurer's total fixed income portfolio.

[Insert Table 4 Here]

The identification of the PBM requires attributing changes in the portfolios of life insurers to a substitution from long-term UST bonds to long-term PACs. To assess the extent to which the $7.3 million quarterly increase in PAC purchases during the *No Auction* period substitutes for UST bonds, we estimate the volume of newly-issued UST bonds that life insurance companies would have bought had auctions taken place. To do so, we estimate 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).

Column (2) shows that life insurers reduce the purchases of UST bonds by $6.1 million. The increase in long-term PAC purchases of $7.3 million in Column (1) is similar in magnitude to the $6.1 million decrease in UST bond purchases in Column (2). Examining the quantities scaled by the size of the insurer, the increase in long-term PAC purchases relative to the insurer's AUM of 0.07 percentage points in Column (4) constitutes about 78% of the decrease in UST bond purchases of 0.09 percentage points in Column (5). Together, these results suggest a strong substitution between UST bonds and long-term agency PACs, which is consistent with the PBM and anecdotal evidence described in Footnote 3.

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, life insurance companies did not increase the amount of long-term SEQs relative to medium-term SEQs in their portfolios during the period of indefinite suspension of UST bond auctions. The coefficient β_1 in Columns (3) and (6) of Table 4 indicates that the insurance companies did not increase their long-term SEQ purchases during the *No Auction* period. Insurers' purchases of long-term SEQs remain unchanged, even though Table 2 shows they regularly buy newly issued SEQs in amounts similar to PACs.[29]

[29] 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.

Motivated by the significant price increase of long-term PACs on the announcement of the suspension and the strong substitution by insurers to long-term PACs, we examine whether mortgage dealers responded by issuing more long-term PACs with the following panel regression:

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

The outcome is either the total amount of security i (long-term PACs or long-term SEQs) issued in quarter q or the total amount of pass-through tranched to create security i 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 total PAC issuances (or total collateral tranched to create PACs) and equal to zero for the time series of total SEQ issuances (or 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 Q2 when UST bond auctions were indefinitely suspended. The sample is limited to long-term tranches with a weighted average life that exceeds ten years at issuance.

[Insert Table 5 Here]

In Column (1) of Table 5, the β_1 coefficient on the interaction term shows that long-term PAC issuance increased on average for the entire suspension period by about \$2.34 billion per quarter relative to long-term SEQ issuance. Note that in this analysis, we cannot control for medium-term PAC issuance because, as Panel B of Figure 1 shows, the creation of long-term PACs is mechanically tied to the creation of medium-term PACs due to the sequential structure of PACs.

In Column (2), the interaction term shows that the amount of collateral tranched to create PACs increased on average for the entire suspension period by about \$22.3 billion per quarter relative to the amount of pass-through used to create long-term SEQs. 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, the fraction of long-term PACs to the amount of pass-through to create them is 12.1%. Using this fraction, we calculate that the increase in the amount of pass-throughs to create PACs of \$22.3 billion per quarter results in an average increase of \$2.7 billion of long-term PACs, which is about the same as the point estimate of β_1 in Column (1).

Figure 6 shows the dynamics of Equation 5. 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 Q4. The amount of collateral for PACs returned to normal in 2006 when the UST bond auctions resumed.

[Insert Figure 6 Here]

The PBM states that a decrease in UST 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 4 and 5. Our results indicate that, during the no-auction period, a segment of the preferred-habitat investors (life insurers) increased their PAC purchases by \$7.25 billion per year ($4 \times 250 \times$ \$7.25 million from Table 4) to substitute for \$6.06 billion per year of UST bonds that they would have bought without the suspension ($4 \times 250 \times$ \$6.06 million from Table 4). At the same time, the issuance of long-term PACs relative to long-term SEQs increased by \$9.36 billion per year ($4 \times$ \$2.34 billion from Table 5). 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.

4.3 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 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 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. By contrast, Columns (2) and (4) show no change in purchases of PAC-2 tranche types. These findings exploiting the degree of prepayment protection PACs provide, along with the results in Table 4 that insurers do not increase purchases of SEQs but do increase purchases of long-term PACs relative to medium-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 1998 Q1 to 2001 Q3, which predates the announcement of the suspension in 2001 Q4. Then, we repeat Column (1) of Table 4 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 $10.3 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, we show that our results in Table 4 showing that insurers substitute UST bonds with long-term PACs are robust to various sub-samples and specifications. First, Table 8 shows that the results are not driven by the largest or smallest insurers in the sample. Instead, Columns (1)-(2) and (4)-(5) show a significant increase in PAC purchases for insurers with ranks based on 1999 AUM of 1-50 and 51-100. Although the coefficients for insurers of ranks 101 to 250 are not statistically significant, the coefficients are positive and economically meaningful. Second, Table A1 shows that the results are robust to using the log transformation to reduce the possible influence of skewness. Third, Table A2 shows that the results are robust to examining *all* purchases of PACs and USTs, not only purchases of newly issued PACs.

[Insert Table 8 Here]

5 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 and the connection between the purchases by the Global Savings Glut (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 of 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.

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 CMOs with prepayment risk (SEQs) during the no-auction period, and the increase in issuance of long-term PACs relative to long-term 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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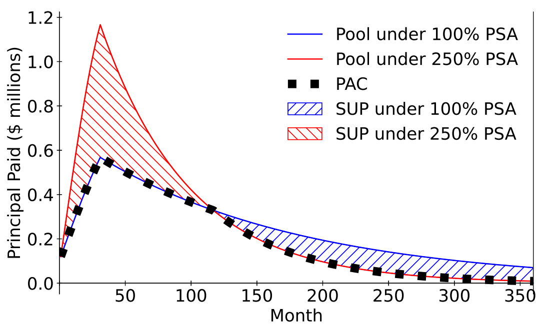
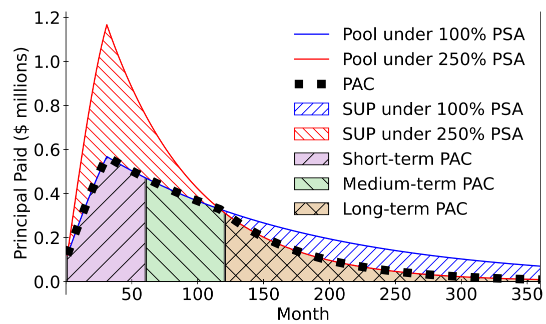
Figure 1: **Principal Cash Flows for PACs, SUPs, and SEQs.**
Panel A shows the cash flows of a PAC with 100% to 250% PSA bands and its SUP under 100% and 250% PSA prepayment scenarios. Panel B displays the cash flows of three PACs with different average lives and with bands equal to 100% to 250% PSA. These PACs pay the principal amount at the top of each colored area. Panel C illustrates the cash flows of three SEQs under a 250% PSA scenario, with the line above the colored 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 areas indicating each SEQ's principal cash flows. All figures assume a $100 million unpaid principal at time zero.

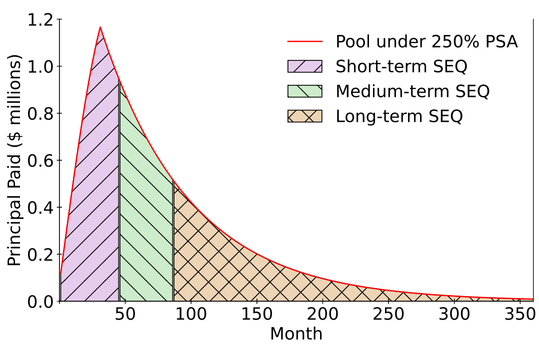
(a) PAC and SUP Tranches



(b) Varied Life PACs



(c) Varied Life SEQs (250% PSA)



(d) Varied Life SEQs (100% PSA)

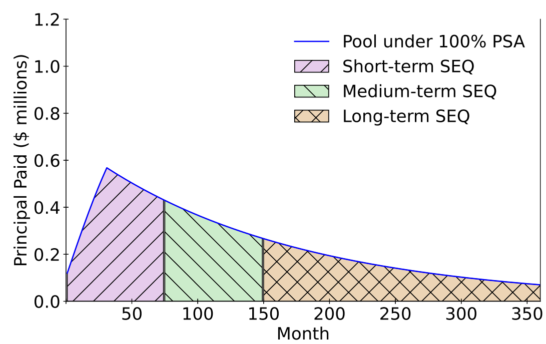


Figure 2: **Total amount of UST Notes and Bonds Issued by Year.**
Panel A shows the yearly total issuance of UST notes (maturity 2 to 10 years) and bonds (maturity over 10 years). Panel B shows the yearly bond issuance as a fraction of total notes and bonds. No UST bonds were issued from 2002 to 2005. The 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.

Figure 3: **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), May 4, 2005 (possible resumption of UST bond auctions), and Sept. 21, 2001 (UST market reopening after Sept. 11, 2001).

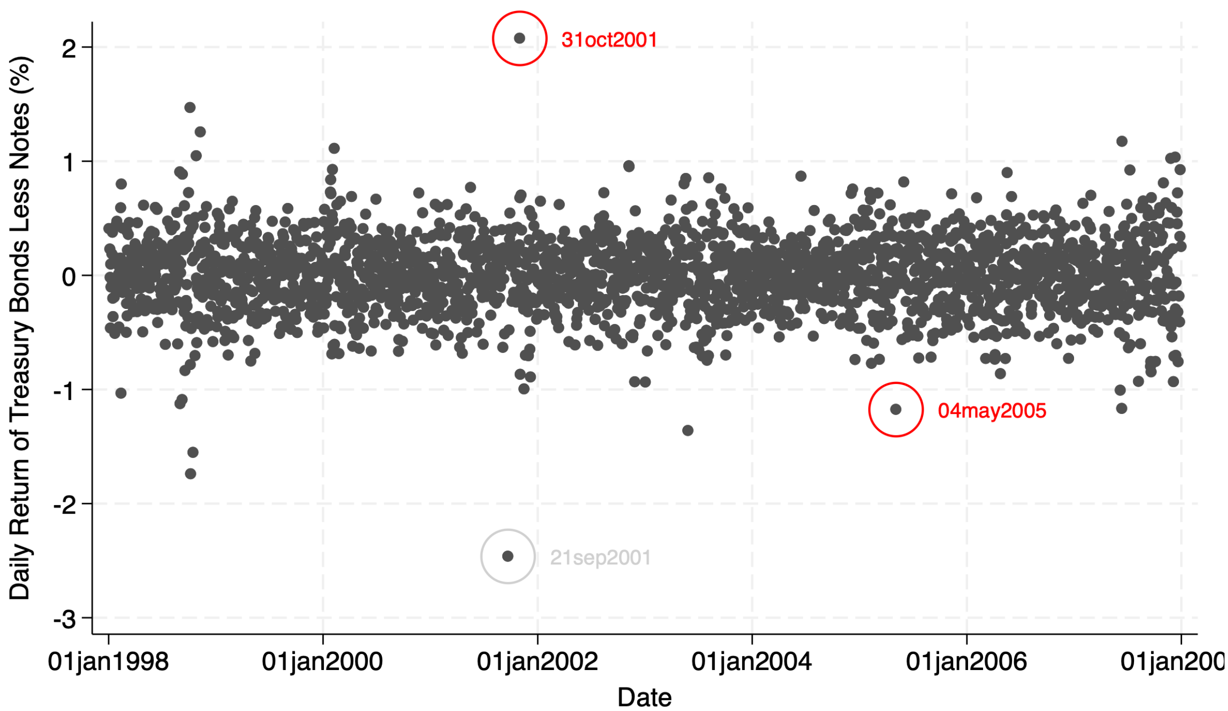


Figure 4: **Monthly PAC Returns and the Suspension.**
This figure shows the monthly difference in returns for long-duration (duration greater than 9 years) and medium-duration (duration of 7-8 years) agency PAC bonds. Medium-duration PAC bonds have a duration similar to that of the 10-year UST note. We circled Oct. 2001 (suspension of 30-year UST bond auctions), May 2005 (possible resumption of UST bond auctions), and Sept. 2001 (Sept. 11 attacks).

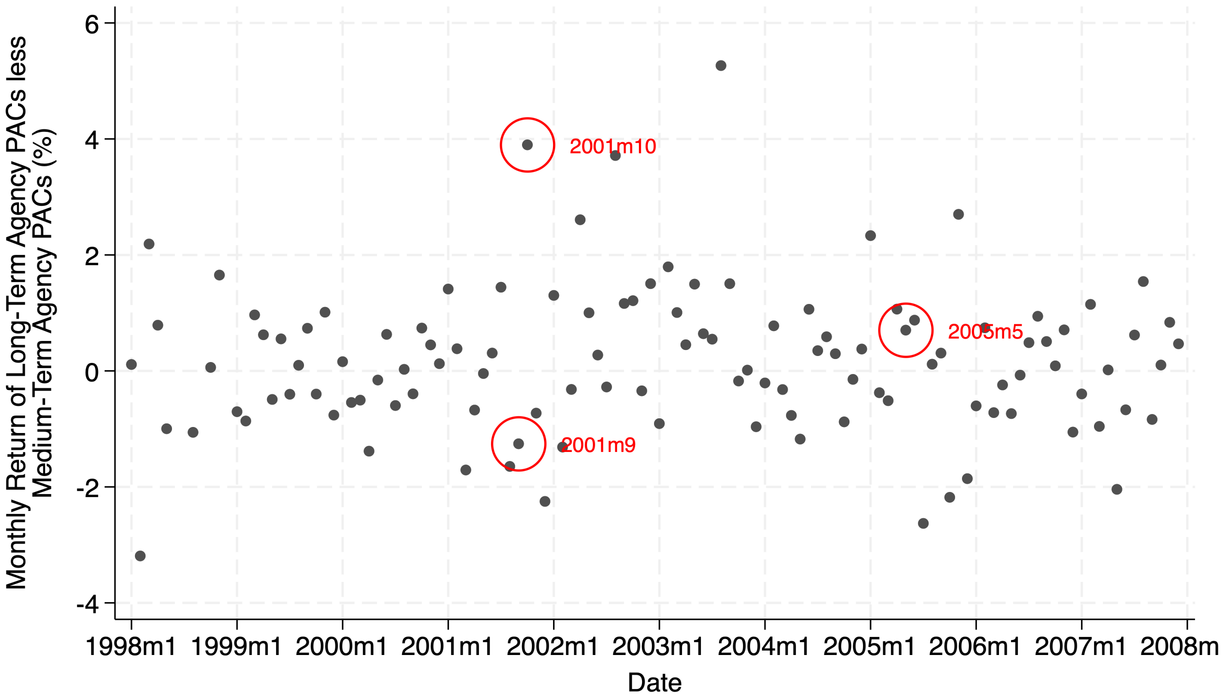


Figure 5: **Effect of UST Bond Auction Interruption on CMO & UST Purchases.** This figure shows that life insurers purchased more newly issued long-term PACs compared to medium-term PACs when 30-year UST bond auctions were suspended. It plots the dynamics of column (1) in Table 4. The dependent variable 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. 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 coefficient of 16.5 in 2002 Q4 indicates an average increase of $16.5 million in quarterly purchases of newly issued long-term PACs relative to medium-term PACs, accounting for SEQs and fixed effects. We winsorize purchases and double cluster standard errors by year and insurer. We show the 90% confidence intervals.

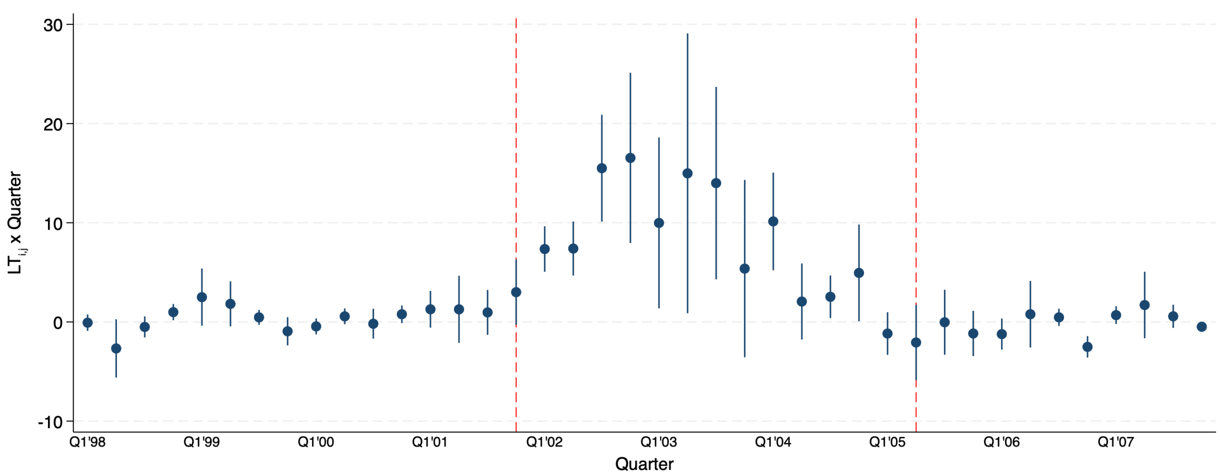


Figure 6: **UST Bond Auction Suspension & Collateral Supporting PAC Issuance.** This figure shows that the pass-through collateral supporting groups of tranches with PACs increased relative to SEQs. The dependent variable is the difference in the aggregate value (in billions) of collateral backing PACs in quarter q and the aggregate collateral backing SEQs. The red lines denote the $\mathbb{1}(\text{No Auction})_q$ period from 2001 Q4 (30-year UST suspension) to 2005 Q2 (resumption announcement). The sample includes collateral groups supporting PACs or SEQs, not both.

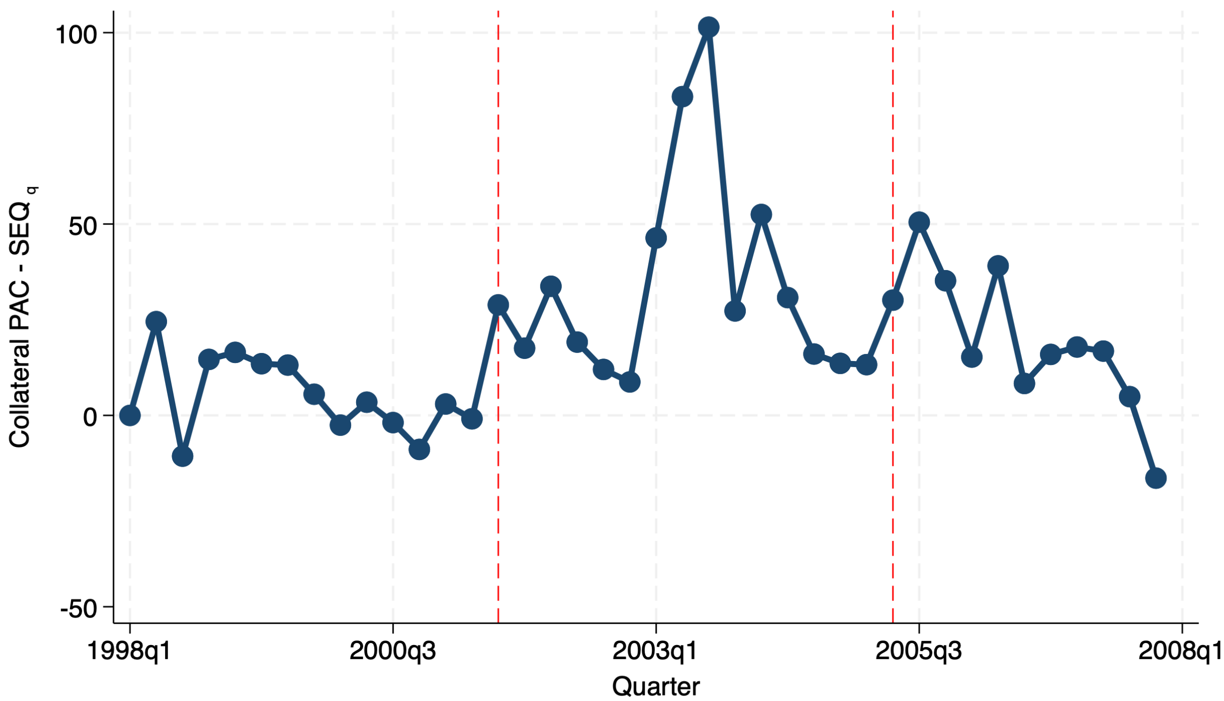


Table 1: **Summary Statistics.**
This table summarizes CMO issuances from 1998 to 2007. Panel A combines all CMO tranche issuances by deal. Panels B and C provide summary statistics for PAC/SUP and SEQ tranche types. Winsorized at 1%.

	N	Mean	St. Dev.	Q1	Median	Q3
A - CMO Deals						
Total Issuance (Million $)	2,984	1,137	1,089	408	772	1,468
Number of Tranches	2,984	40	35	15	31	54
B - PAC/SUP Tranches						
Tranche Amount (Million $)	59,456	47	63	8	25	57
Weighted Average Life at Issuance	59,456	7.6	5.8	3.3	6.0	11.0
Tranches by Deal	2,428	24	22	9	19	33
C - SEQ Tranches						
Tranche Amount (Million $)	25,579	74	96	13	36	100
Weighted Average Life at Issuance	25,579	7.6	5.2	3.6	5.3	10.9
Tranches by Deal	2,227	11	12	4	8	15

Table 2: **Summary Statistics of Insurers' Purchases of USTs and CMOs.**
This table summarizes quarterly purchases of newly issued USTs and CMOs by the 250 largest life insurers (as of 1999) from 1998 to 2007. Medium-term U.S. Treasuries 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. N reflects the number of firm-quarters with purchases of newly issued bonds. There are 8,988 firm-quarters in the final sample. For example, insurers purchased newly issued long-term PACs in 14.4% (1,292/8,988) of firm-quarters.

Panel A: PAC						
	N	Mean	St. Dev.	Q1	Median	Q3
Medium Term	936	30.9	60.0	5.0	11.4	27.7
Long Term	1,292	43.9	76.4	7.5	16.7	43.0
% Medium Term	936	0.6	0.9	0.1	0.3	0.7
% Long Term	1,292	0.8	1.0	0.1	0.4	0.9

Panel B: U.S. Treasuries						
	N	Mean	St. Dev.	Q1	Median	Q3
Medium Term	1,984	40.3	91.1	1.8	7.1	28.6
Long Term	287	42.6	85.3	2.7	9.7	35.0
% Medium Term	1,984	0.6	1.0	0.0	0.2	0.6
% Long Term	287	0.4	0.8	0.0	0.2	0.5

Panel C: SEQ						
	N	Mean	St. Dev.	Q1	Median	Q3
Medium Term	962	24.3	39.4	5.0	11.2	24.9
Long Term	1,264	31.2	47.4	6.1	13.7	33.3
% Medium Term	962	0.4	0.5	0.1	0.2	0.5
% Long Term	1,264	0.5	0.6	0.1	0.3	0.7

Table 3: **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, 1998 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***	7.7	-1.17***	-4.4
Long Less Medium PAC Returns (Monthly)	3.90***	4.5	0.70	0.83

Table 4: **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 Q2 (when the U.S. Treasury announced their likely resumption). 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 winsorize the data and double cluster standard errors by year 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)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	7.25**	-6.06*	-0.71	0.07**	-0.09***	0.02
	(3.25)	(3.19)	(1.75)	(0.03)	(0.03)	(0.02)
$\mathbb{1}(\text{LT})_{i,j}$	0.20	-6.23***	2.00***	0.01	-0.08***	0.03***
	(0.36)	(2.08)	(0.68)	(0.01)	(0.02)	(0.01)
$\text{SEQs}_{i,j,q}$	0.50**					
	(0.21)					
$\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}} \times 100$				0.30***		
				(0.05)		
Constant	1.83	9.81***	2.89***	0.05***	0.13***	0.04***
	(1.18)	(1.09)	(0.46)	(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	24.14	18.99	22.55	12.64	9.79	10.77
# Insurers	250	250	250	250	250	250
# Quarters	40	40	40	40	40	40
# Observations	17968	17968	17968	17968	17968	17968

Table 5: **Halted UST Bond Auctions and CMO Issuances.**
Column (1) shows that long-term PAC issuances increased during the 30-year UST suspension period, relative to SEQs. The sample includes total issuances of security i (long-term PACs or long-term SEQs) by quarter q, resulting in two observations per quarter. $\mathbb{1}(\text{PAC})_i$ is an indicator variable for PAC issuances (1) and SEQ issuances (0). The sample is limited to tranches with a weighted average life over ten years at issuance. $\mathbb{1}(\text{No Auction})_q$ equals one for quarters from 2001 Q4 (30-year UST suspension) to 2005 Q2 (resumption announcement). Column (2) shows 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. Standard errors are clustered at the quarter level, and quarter fixed effects are included, absorbing the standalone $\mathbb{1}(\text{No Auction})_q$ variable. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively.

	CMO Amt. Issued$_{i,q}$ (Billions) (1)	Collateral Amt$_{i,q}$ (Billions) (2)
$\mathbb{1}(\text{No Auction})_q \times \text{PAC}_i$	2.34**	22.30***
	(0.95)	(7.64)
PAC_i	1.14	11.43***
	(0.43)	(3.19)
Constant	3.13***	25.58***
	(0.21)	(1.64)
Quarter FE	Yes	Yes
% Adjusted R^2	52.40	70.60
# Observations	80	80

Table 6: **Falsification using Heterogeneity in PAC Types.**
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. We only examine CMO deals with multiple PAC types (e.g., PAC-1 and PAC-2). 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 to 2005 Q2, when the U.S. Treasury suspended and then resumed 30-year UST bond auctions. 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. We winsorize purchases and 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)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	1.50**	-0.04	0.01**	-0.00
	(0.61)	(0.05)	(0.01)	(0.00)
$\mathbb{1}(\text{LT})_{i,j}$	0.14	-0.04*	0.01***	-0.00
	(0.12)	(0.02)	(0.00)	(0.00)
$\text{SEQs}_{i,j,q}$	0.11**	-0.00		
	(0.05)	(0.00)		
$\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}} \times 100$			0.05***	0.00
			(0.02)	(0.00)
Constant	0.51***	0.06***	0.01***	0.00***
	(0.17)	(0.01)	(0.00)	(0.00)
Firm FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
% Adjusted R^2	11.65	4.53	3.83	3.26
# Insurers	250	250	250	250
# Quarters	40	40	40	40
# Observations	17968	17968	17968	17968

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 1998 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 to 2005 Q2, marking the suspension and resumption announcements of the 30-year UST bond auctions. 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, winsorize purchases, 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)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	10.33**	0.67	0.11***	0.00
	(4.72)	(0.41)	(0.04)	(0.01)
$\mathbb{1}(\text{LT})_{i,j}$	0.29	0.02	0.02	-0.01*
	(0.54)	(0.15)	(0.01)	(0.00)
$\text{SEQs}_{i,j,q}$	0.51**	0.02		
	(0.21)	(0.02)		
$\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}} \times 100$			0.31***	0.10***
			(0.06)	(0.03)
Constant	2.59	0.46***	0.07***	0.02***
	(1.70)	(0.12)	(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	24.48	5.25	12.63	7.30
# Insurers	159	72	159	72
# Quarters	40	40	40	40
# Observations	12088	5504	12088	5504

Table 8: **Halted UST Bond Auctions, PAC Purchases, & Insurer Size.**
This table shows that results in Table 4 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 1-50, 51-100, and 101-250, 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 Q2 (when resumption was announced). 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. Purchases are winsorized. 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	1-50	56-100	101-250	1-50	56-100	101
	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	23.27*	6.55*	1.23	0.08*	0.13*	0.05
	(13.66)	(3.37)	(0.93)	(0.04)	(0.07)	(0.03)
$\mathbb{1}(\text{LT})_{i,j}$	0.92	0.47	-0.03	0.02*	0.01	0.00
	(1.47)	(0.51)	(0.14)	(0.01)	(0.02)	(0.01)
$\text{SEQs}_{i,j,q}$	0.51**	0.12***	0.49***			
	(0.23)	(0.04)	(0.12)			
$\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}} \times 100$				0.25***	0.27***	0.31***
				(0.05)	(0.09)	(0.07)
Constant	4.19	3.19***	0.85***	0.03***	0.06***	0.06***
	(4.59)	(0.78)	(0.28)	(0.01)	(0.02)	(0.01)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes	Yes	Yes
% Adjusted R^2	25.97	8.44	17.44	12.28	13.63	12.12
# Insurers	50	50	150	50	50	150
# Years	40	40	40	40	40	40
# Observations	3872	3600	10496	3872	3600	10496

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 shows that the returns of the agency Support tranches do not change with the announcement of the suspension of the 30-year UST bond auctions.
6. Table A1 shows that the results of Table 4 are robust to using a log transformation.
7. Table A2 shows that the results of Table 4 are robust to examining all purchases of PACs and USTs, not only newly issued PACs and USTs.

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 cash flows of a pass-through under three different PSA scenarios. 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 problem implies:

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

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 $t = 3$.[30] 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., $1 + \mu_M = (1+\mu_r)(1+r_1)$, and

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

[30] 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.

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 1998 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)).

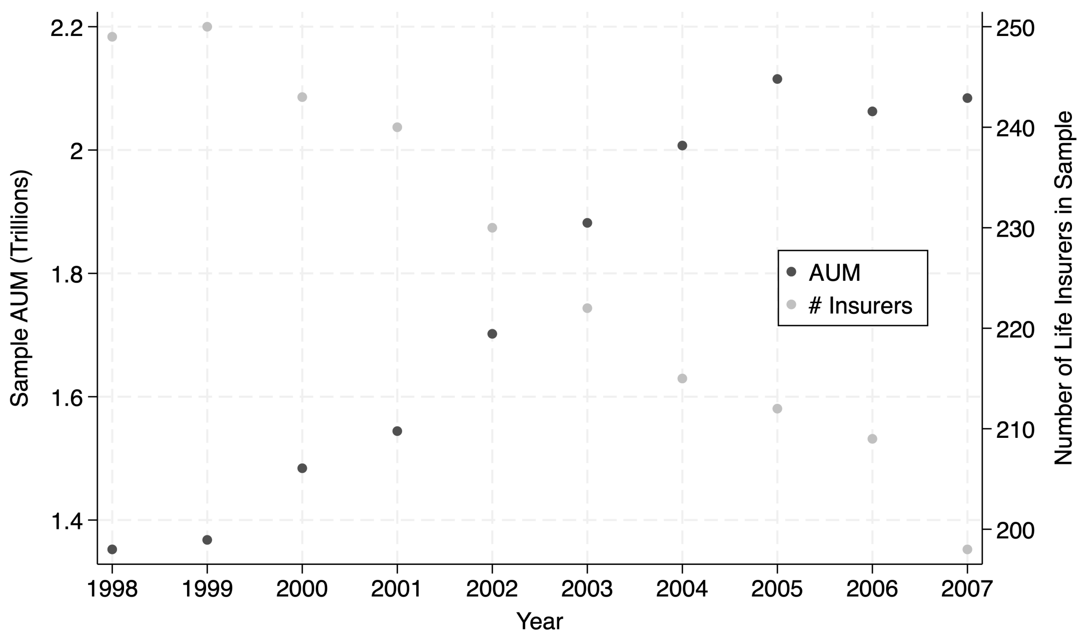


Figure A2: **Principal Cash Flows of a Mortgage Pass-through under Different Prepayment Speeds.**
This figure shows the principal cash flows of a 5% coupon pass-through security under different PSA scenarios. The initial principal is $100 million. The x-axis has the weighted average loan age (months) 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.

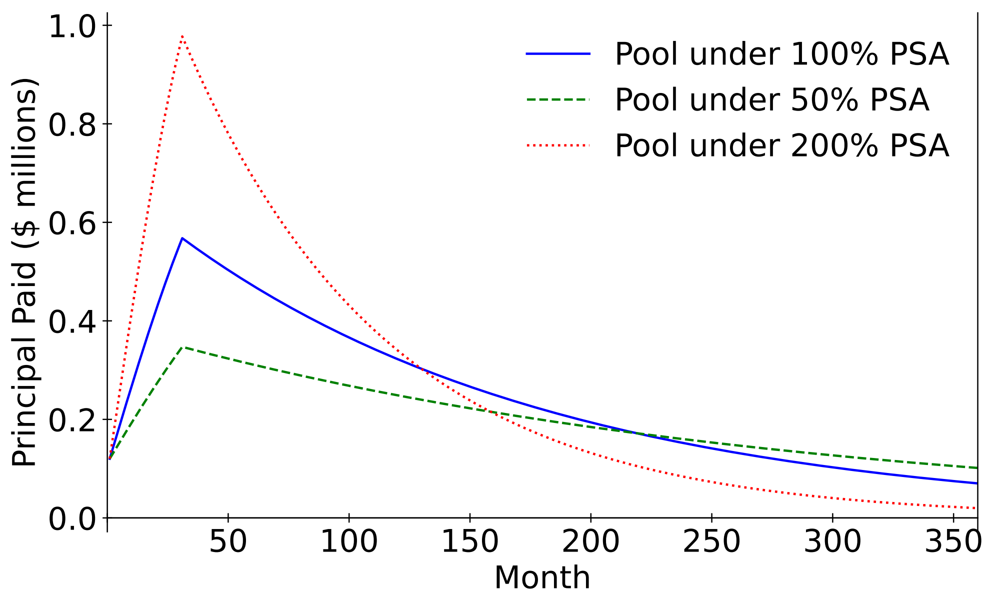


Figure A3: **Monthly Agency Support Tranche Returns.** This figure shows the monthly weighted average returns for agency Support (SUP) bonds from the ICE Bank of America - Merrill Lynch CMSZ index. Key dates circled are October 31, 2001 (end of 30-year UST bond auctions) and May 4, 2005 (possible resumption of UST bond auctions).

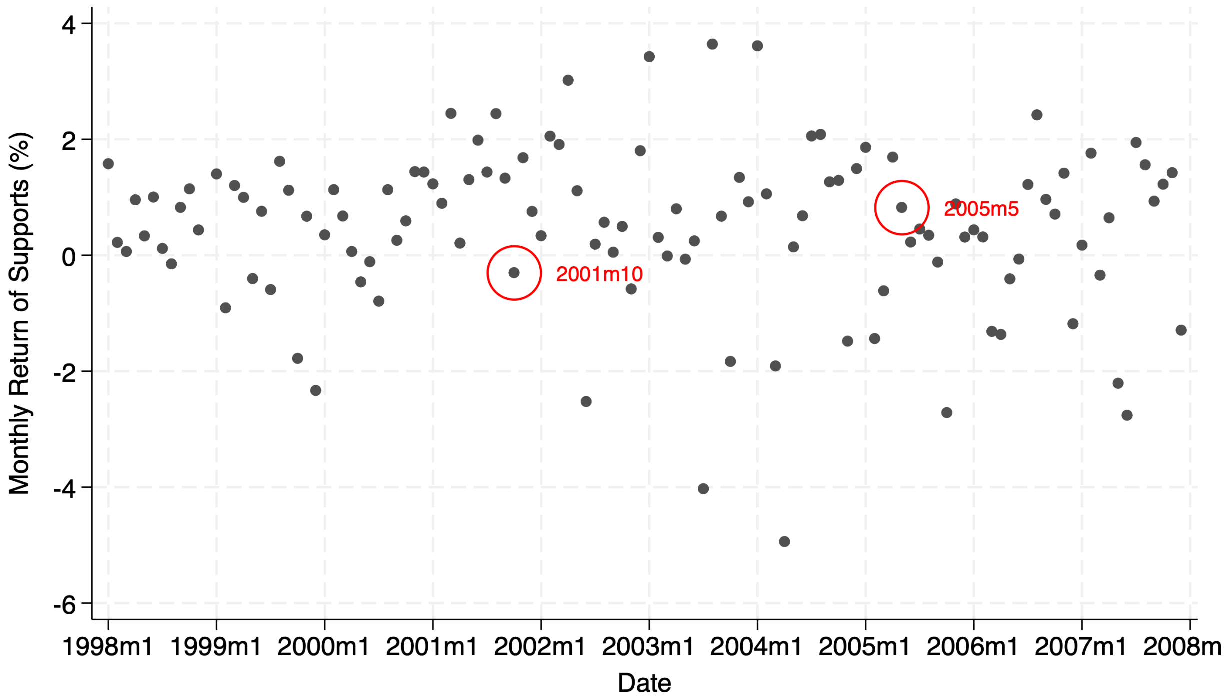


Table A1: **Robustness of Table 4 to log transformations.** This table shows that the results in Table 4 are robust to log transformations addressing data skewness. In column (1), the dependent variable is log(1 + X), where X is the aggregate value (in millions) of purchases of newly issued medium-term 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 Q2, when the auctions resumed. 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'2 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. Purchases are winsorized. 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)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_q$	0.16**	-0.27***	0.07**	-0.09***
	(0.06)	(0.08)	(0.03)	(0.03)
$\mathbb{1}(\text{LT})_{i,j}$	0.07***	-0.33***	0.01	-0.08***
	(0.02)	(0.07)	(0.01)	(0.02)
$\ln(1+\text{SEQs}_{i,j,q})\times 100$	0.25***			
	(0.03)			
$\ln(1+\frac{\text{SEQs}_{i,j,q}}{\text{AUM}_{j,y-1}}) \times 100$			0.30***	
			(0.05)	
Constant	0.21***	0.51***	0.05***	0.13***
	(0.02)	(0.03)	(0.01)	(0.01)
Firm FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
% Adjusted R^2	25.74	26.79	12.72	9.86
# Insurers	250	250	250	250
# Years	40	40	40	40
# Observations	17968	17968	17968	17968

Table A2: **Robustness of Table 4 to examining all PAC purchases, not just purchases of newly issued PACs.** This table shows that the results in Table 4 are robust to examining all PAC purchases, not only purchases of newly issued PACs. However, this table uses the annual purchases of securities because purchases outside of the issuance year cannot be assigned to a specific quarter. In column (1), the dependent variable is the aggregate value (in millions) of purchases of medium-term and long-term PACs by insurance company j in fiscal year y. Specifically, we aggregate the purchases of medium-term PACs and long-term PACs separately, resulting in two observations i per year y for each insurance company j. Medium-term PACs have a remaining weighted-average life (WAL) between 2 and 10 years, and long-term PACs have a remaining WAL of more than 10 years. In column (2), we construct a similar outcome variable using the remaining time to maturity of USTs that life insurers purchase. Medium-term USTs are notes with time-to-maturity between 2 and 10 years, and long-term USTs are bonds with a time-to-maturity of more than 10 years. In columns (3) and (4), we repeat columns (1) and (2) after scaling the variables by the dollar size of the insurer's fixed income portfolio at the end of the year $y-1$. $\mathbb{1}(\text{LT})_{i,j}$ 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. $\mathbb{1}(\text{No Auction})_y$ is an indicator that equals one for all years starting in 2002, which is when the U.S. Treasury suspended the 30-year UST bond auctions, and ending in 2004, which is the year before the U.S. Treasury announced it would resume 30-year UST bond auctions. We control for insurer j's purchases of medium-term ($i=0$) and long-term ($i=1$) sequential tranches in year y ($SEQ_{i,j,y}$) to account for time-varying firm-specific factors affecting demand for medium- and long-term CMOs in general. We include insurance company fixed effects to control for fixed differences between insurers that determine purchases. We also include year fixed effects to control for aggregate trends determining insurers' purchases. We winsorize purchases. We double cluster standard errors by year and insurer. ***, ** and * denote statistical significance at the levels 1%, 5%, and 10%, respectively.

	$\text{PACs}_{i,j,y}$	$\text{UST}_{i,j,y}$	$\frac{\text{PACs}_{i,j,y}}{\text{AUM}_{j,y-1}}$	$\frac{\text{UST}_{i,j,y}}{\text{AUM}_{j,y-1}}$
	(1)	(2)	(3)	(4)
$\mathbb{1}(\text{LT})_{i,j} \times \mathbb{1}(\text{No Auction})_y$	36.18**	-25.84***	0.34**	-0.36**
	(12.68)	(6.79)	(0.12)	(0.13)
$\mathbb{1}(\text{LT})_{i,j}$	1.32	-6.28***	0.06	-0.25***
	(2.04)	(1.56)	(0.04)	(0.04)
$\text{SEQs}_{i,j,y}$	0.58**			
	(0.19)			
$\frac{\text{SEQs}_{i,j,y}}{\text{AUM}_{j,y-1}} \times 100$			0.45***	
			(0.08)	
Constant	3.74	25.70***	0.13***	0.53***
	(3.89)	(0.59)	(0.03)	(0.01)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
% Adjusted R^2	24.52	15.58	21.39	16.10
# Insurers	250	250	250	250
# Years	10	10	10	10
# Observations	4492	4492	4492	4492