Tranching is Also Catering

Justin Balthrop, Jefferson Duarte, and Douglas A. McManus*

May 31, 2020

Abstract

The Financial Crisis literature (e.g., Caballero and Krishnamurthy (2009)) argues that demand for safe assets caused the pre-crisis growth in securitization, but empirical evidence for this theory is lacking. We provide the first evidence that securitization is "catering". We show that a 1% increase in excess demand for long-term U.S. Treasury bonds increases next month's issuance of long-term Collateralized Mortgage Obligations (CMOs) with low prepayment risk by 1.2%. This substitution effect does not exist for CMOs with characteristics that are very different from long-term government bonds, such as those with short duration or high prepayment sensitivity.

Keywords: Securitization, preferred habitat, financial crisis

*We thank seminar participants at Rice University for helpful comments. Balthrop is with University of Kansas. Duarte is with the Jesse H. Jones School of Business at Rice University. McManus is with Freddie Mac. E-mails: justin.balthrop@ku.edu, jefferson.duarte@rice.edu, and Douglas_McManus@freddiemac.com.

The creation of AAA-rated securities by pooling loans and forming tranches with a priority ordering for payments was remarkably high in the years preceding the 2007-2008 financial crisis. Even though many of the narratives about the financial crisis attribute this increase in tranching to a surge in the demand for safe assets (e.g. Caballero and Krishnamurthy (2009), Bernanke, Bertaut, DeMarco, and Kamin (2011), and Gennaioli, Shleifer, and Vishny (2012)), the securitization literature has no empirical evidence that tranching results from catering to investors with preferences for certain types of cash flows. In fact, the academic literature on securitization focuses on tranching as a mechanism for suppliers of securities to use to address a "lemons problem" when selling their loan portfolios (e.g. DeMarzo (2005), Downing, Jaffee, and Wallace (2009) and Begley and Purnanandam (2016)) instead of examining the extent that tranching is also catering for investors with preferences for specific types of securities. The objective of this paper is to fill this gap.

To do so, we analyze the issuance of Agency Collaterilized Mortgage Obligations (Agency-CMOs) and more specifically the issuance of Planned Amortization Class (PACs). Agency-CMOs are securities created by the tranching of cash flows from pools of mortgages guaranteed by the Agencies (Fannie-Mae, Freddie-Mac and Ginnie-Mae). There are many different types of Agency-CMOs. For instance, there are CMOs that receive only interest payments called IOs (Interest only) and CMOs that receive only principal payments called POs (Principal only). Different types of Agency-CMOs created from tranching a given pool of mortgages have similar credit quality because all the mortgages in Agency-CMOs are guaranteed by the Agencies. On the other hand, different types of CMOs have different exposure to the prepayment of the mortgages in the underlying pool. Specifically, PACs are CMOs with little exposure to prepayments and hence stable average life.

Focusing on agency CMOs has some advantages for establishing the existence of demand driven tranching. In particular, in our theoretical work we build on Vayanos and Vila (2009), Gromb and Vayanos (2010) and Greenwood and Vayanos (2014), and assume that there are investors with preferences for safe bonds with a certain time-to-maturity (habitat preference). Habitat preference is a well-established idea in the term structure literature (e.g. Culbertson (1957) and Modigliani and Sutch (1966)). In habitat preference models, there are investor clienteles with preferences for specific maturities. Our model builds on this hypothesis by assuming that tranching mortgage payoffs can be due to arbitrageurs catering to the preferences of these investor clienteles. In our empirical work, we explore the heterogeneity of CMOs in terms of their types and of PACs in terms of their time-to-maturity as a mean of falsification tests. Naturally, the focus of the financial crisis literature has been on the tranching of credit risk while our empirical and theoretical work is about the tranching of prepayment risk. Even though the types of risk are different, the economic mechanism is the same – tranching as catering for investor's preferences.

We start our examination of whether tranching is also catering with a stylized model. The model is an extension of the model in Greenwood, Hanson, and Stein (2010). In our model, there are two risk-averse arbitrageurs that use two distinct strategies to explore the shortage of government bonds to satisfy the demand from habitat-preference investors. The first arbitrageur issues long-term bonds and invest in short-term bills. This yield-curve arbitrageur earns a premium from the habitat-investors in exchange for assuming the risk of a drop in the short-term interest rate. The second arbitrageur issues long-term bonds with no possible prepayment and invest in long-term mortgages that can prepay in case interest rates drop. By doing so, the arbitrageur is earning a premium from the habitat-investors in exchanging for assuming the risk of mortgage prepayments. The long-term bonds issued by the mortgage arbitrageur are therefore similar to PACs, which are created to cater for habitat-preference investors.

The model has two empirical implications. First, provided there is a non-zero issuance of PACs, the amount of PACs with a given maturity grows with the excess demand for bonds with similar time-to-maturity. Second, in the model, each arbitrageur has a strategy to meet the excess demand for long-term bonds and they adopt their strategy only if its expected return is positive. That is, when the yield curve is steep and the term premium is positive the yield-curve arbitrageur does not issue "cheap" long-term bonds, instead the mortgage arbitrageur satisfy the demand for bond from preferred habitat investors alone. Generally speaking, arbitrageurs have at their disposal many different types of strategies to respond to the excess demand for bonds. For instance, AAA securities collateralized by commercial mortgages (AAA CMBS) may also serve as substitutes for high quality Treasury bonds. Hence, the second model implication is that the elasticity of PAC issuance to the excess demand of bonds depends on the the expected return of these alternative strategies.

Armed with the empirical implications from the model, we explore the richness of the PAC and CMO issuance data to test the hypothesis that PACs are created to cater to habitat-preference investors. We collect detailed data from all agency-CMOs issued between 1990 and 2016 from Bloomberg. The data include the estimated average lives of PACs issued every month along with the amount issued. The data also include the issued amount of other CMOs such as IOs and POs. In addition, we collect US Treasury issuance data that includes the amount that each auction was oversubscribed, which we call excess demand.

We then construct a series of tests of the first model implication that the amount of PACs with a given maturity grows with the excess demand for bonds with similar time-to-maturity. Specifically, we start by testing whether the relation between the growth of PAC issuance in month $t+1$ with the excess demand for Treasury securities at month t. As a placebo test, we also examine whether the relation between other types of CMOs (e.g. IOs) and excess demand for Treasuries is positive. While catering to long-term investors implies a positive relation between PACs issuance and excess demand for Treasuries, it does not have any implication for the relation between IOs issuance and Treasuries excess demand. Our second test explores the richness of the cross-section of PAC maturities. Specifically, short-term PACs substitute for short-term Treasuries but do not substitute long-term Treasury securities. Hence, we should find a relation between short-term PAC issuance and short-term Treasury excess demand, but not for long-term Treasury excess demand. Conversely, long-term PACs substitute for long-term Treasuries, but not short-term Treasuries. In this case we should find a relation between long-term PAC issuance and long-term Treasury excess demand, but not for short-term Treasury excess demand.

To test the second model implication, we examine whether the elasticity of PAC issuance to Treasury security excess demand depends on the slope of the term structure and on the quantity issuance of private label AAA securities. Specifically, when the yield curve is very steep, arbitrageurs prefer issuing PACs to attend to the excess demand of long-term Treasuries instead of engaging in the "costly" yield curve strategy. In addition, the issuance of PACs may have been less responsive to the excess demand for Treasuries during the period of record issuance of private-label AAA securities collateralized by different types of mortgages (e.g. subprime and commercial mortgages) preceding the 2007-2008 financial crisis.

Overall, our empirical findings indicate that tranching is also driven by catering to investors with preferences for specific types of cash flows. Specifically, we find that a one percent increase in Treasuries excess demand is followed by an increase in the PAC issuance of about 1%. The same type of relation is not present for CMOs that have significant exposure to prepayment risk. For instance, there is no significant relation between the issuance of IOs and the previous month excess demand for Treasuries. Interestingly, while the issuance of PACs with long average life (more than nine years) is related to the previous month's excess demand for Treasuries with time-to-maturity longer than nine years, it is not related to the excess demand for Treasuries with short time-to-maturity. Moreover, the relation between the growth in PAC issuance and lagged Treasury excess demand is stronger when the yield curve is steep. When the difference between 30-year Treasury yield and the 3-month Treasury rate is in the top quartile, the relation between PAC issuance growth and lagged excess demand for Treasuries is between 30 and 50% stronger.

Our paper links the securitization literature to "habitat preference" literature. In his seminal paper, DeMarzo (2005) shows that tranching addresses the adverse selection problem that the sellers of a portfolio of loans face because the sellers give a signal about the quality of the collateral portfolio by retaining the junior tranche. Downing, Jaffee, and Wallace (2009) show that the collateral in CMOs is subject to more efficient prepayment than the prepayment of pools of mortgages that are not used as CMO collateral. Hence, DeMarzo (2005) and Downing, Jaffee, and Wallace (2009) give both theoretical justification and empirical evidence of tranching being related to the need to the sellers of securities to address a lemon's problem. We take a complementary view in this securitization literature by focusing on the preferences of the buyers of securities. Gorton and Metrick (2012) recognized that the increase in demand for collateral may have been linked to the increase in the demand for securitized bonds. They also point out that "There is no direct evidence that these demands for collateral led to increased asset-backed security supply." We provide direct evidence that demand for certain types of payoffs drives securitization. Specifically, we build on Vayanos and Vila (2009) and Greenwood, Hanson, and Stein (2010) hypothesis that there are investors with "habitat preferences" to show that tranching also results from arbitragers catering to investors' preferences.

Our results also give empirical support for the idea that the extreme increase in tranching preceding the financial crisis was in part a response to investors demand for securities with apparent good credit quality.[1] Even though the idea that the record level of tranching before the 2007-2008 financial crisis was due to increase demand for AAA bonds is pervasive in the financial crisis literature (e.g. Caballero and Krishnamurthy (2009), Bernanke, Bertaut, DeMarco, and Kamin (2011), and Gennaioli, Shleifer, and Vishny (2012)), it is very difficult to conclude from the record level of AAA securities created before the crisis that preference for certain types of securities drives tranching. Indeed, Begley and Purnanandam (2016) find evidence that the information-asymmetry between the sponsors of private-label residential mortgage-backed securities (RMBS) and the investors in RMBS credit-rated bonds drives the design of private-label RMBS. In light of the evidence in Begley and Purnanandam (2016), it is possible that the entire pre-crisis growth in tranching was driven by sponsors willingness to extend credit combined with the need to address the lemons problem in the sales of the created mortgages. On the other hand, our evidence indicates that tranching is also catering suggesting that at least part of the pre-crisis growth in tranching was satisfy the demand for investors in AAA securities.

The remainder of the paper is outlined as follows. Section 1 describes the most important types of CMOs along with their creation process. Section 2 describes the model and its testable implications. Section 3 tests the model predictions. Section 4 concludes.

1 CMOs

An agency pass-through security provides the investor with a pro-rata share of the monthly mortgage payments from a pool of mortgages held in a trust created by Freddie Mac or Fannie Mae. These are called pass through securities as the monthly payments of principal, interest, and prepayments from the mortgage pool are "passed through" to the security holder (and are also referred to as participation certificates).

A Collateralized Mortgage Obligation (CMO) is a type of debt security that repackages

[1] Data from Inside Mortgage Finance reveals that private-label securitization reached a record level in 2005 with a total issuance of about $1.6 trillion.

and directs mortgage principal, interest, and prepayments to different security 'tranches' through a defined set of rules. The collateral underlying a CMO are mortgage securities or whole mortgages. In CMOs, a tranche is one of several related securities offered as part of the same transaction using a set of pre-specified rules to redirect cash flows from the underlying pool of mortgage assets to the different bond tranches. The risk inherent in the underlying mortgage collateral are not created or destroyed by structuring, but instead are reallocated among the different tranches. For instance, the creation of tranches with more predictable cash flows necessitates the creation of tranches with less predictable cash flows. Similarly, the creation of tranches with shorter duration than the underlying collateral necessitates the creation of tranches of longer duration. CMOs were first created in the early 1980's but were treated as debt to the issuer and so remained on the issuer's balance sheet. The real estate mortgage investment conduit (REMIC) structure was created by the 1986 Tax Reform Act to avoid the potential for "double-taxation" and to allow REMIC CMOs to be removed from the issuer's balance sheet. Data from the SIFMA reveals that on average about 20% of the amount outstanding in agency mortgage-related securities between 2002 and 2018 was composed by CMOs while the remaining 80% was composed by agency pass-through securities.

Agency (Ginnie-Mae, Fannie-Mae, and Freddie-Mac) mortgages are insured against default risk, therefore Agency CMOs are created to redistribute duration and prepayment risk. In contrast, non-agency CMOs redistribute both credit and prepayment risk. Non-agency CMOs are generally paid sequentially from the most senior to most subordinate. The more senior rated tranches generally have higher bond credit ratings than the lower rated tranches. For example, senior tranches may be rated AAA, AA or A, while a junior tranche may be rated BB.

The most common agency-CMO tranche types are: sequential, planned amortization class, support, interest-only, and principle-only tranches. Floaters and inverse floaters are common Agency-CMOs but are not analyzed in this paper. Most collateral for Agency-REMIC securities is comprised of fixed-rate mortgages. There are REMICs that use ARM and Balloon mortgages for collateral, but these occur with a lower frequency. If the underlying collateral is floating rate, there is no need to create an inverse floater. However, for some customers, such as money market funds and European investors, a floating rate security is very attractive. To create a floating rate tranche from fixed-rate collateral requires the creation of an offsetting tranche to receive the difference between the fixed and floating rates, which is an inverse floater tranche. As the coupon for the floating rate tranche increases, the rate on the inverse floater decreases in a way that holds the total interest payment at the fixed-rate associated with the underlying collateral. Also, typically these tranches have coupon rate caps and floors that bound the range that the floating and inverse floating rates can move.

Sequential (Seq) tranches are considered a relatively simple design. In these structures, the first sequential tranche, frequently referred to as an 'A' tranche, receives all the principal payments until it has been paid off, then, in turn, the second sequential tranche, 'B,' receives all the principal payments until all the principal has been repaid to this tranche. This process continues until all the tranches are paid off. Interest is received on the principal remaining in the tranche. This sequential structure acts to create tranches that differ in expected duration.

Planned amortization classes (PAC) are tranches whose principal payments are perfectly determined if prepayment speeds stay within certain bands, typically defined in terms of the Bond Market Association's prepayment speed standard (PSA).[2]

Figure 1 shows the principal payments accruing to four PAC tranches if the prepayment speeds remain within the bands (in this example, from 100 to 250 PSA). The PAC tranches A, B, C, and D will receive the principal payments determined by the minimum of the 100 and 250 PSA lines. Because of the relative certainty of cash flows, PAC tranches are relatively easy to sell.

In order to create a PAC tranche, a complementary Support (SUP) tranche is created which takes on a disproportionate share of the prepayment risk. Because PAC tranches have lower volatility of principal payments, these SUP tranches must have greater volatility of principal payments. In Figure 1, should prepayment rates slow to 100 PSA, then the SUP tranches maturity would extend, receiving the principal payments only after about 100 months with these payments shown as the difference between the 100 and 250 PSA lines

[2]See, for example, Duarte and McManus (2016).

above the C and D PAC level principal payments. Alternatively, should prepayment rates rise to 250 PSA then the support tranches maturity will curtail, receiving all their principal repayments within about 100 months (specifically the wedge of principle payments between the 250 PSA line and the PAC tranches A, B, and C). Because of the additional prepayment risk, SUP bondholders are compensated by higher yields.

Targeted Amortization Classes (TAC) resemble PACs but with only one-sided prepayment protection. TAC redemption schedules are specified by a single prepayment rate schedule, typically the prepayment speed used for pricing the structure. At the specified rate, TACs always amortize first, and the TAC-Supports only amortize only after the TACs have paid down. For details see Kulason (2001).

Another set of paired tranche classes is interest-only (IO) and principal-only (PO) tranches. The value of these securities is more sensitive to prepayments than the underlying collateral. There are a number of investors, however, who find the cash-flows from IO and PO tranches can be used as an effective hedge against other business or fixed-income risks. For instance, a mortgage servicer is normally compensated with a percentage of the interest paid which vanishes in case of prepayment. Hence servicer's compensation resembles an IO. Hence traded IO/POs can be used by servicer for hedging their business exposure to prepayments.

Dealers cater to investors with different types of risk profile when creating CMOs. The creation of agency CMOs provides a mechanism for investors with different risk profiles to receive duration and prepayment risk exposure disproportionately, rather than pro-rata in the pass-through market. For instance, Mortgage passthroughs may not be interesting for investors with specific maturity preferences and no-appetite for prepayment risk. On other hand, a PAC may appeal for such investors.

The process of creating an agency CMO supports the idea that dealers are catering to investors with CMOs. The process for creating an agency REMIC security begins with a dealer contacting Freddie Mac and requesting that a 'shelf' be opened with a specified settlement date and a generic specification of the collateral, which the dealer is pledging for the transaction (for example, $200 million in 30-year Freddie Mac 4% coupon fixed rate mortgages). Freddie Mac assigns the shelf a series number, which the dealer uses to identify and market the REMIC bonds. The Dealer may not have the specific collateral available but may start to explore their inventories, securities actively trading in the market, and soon-to-be issued PCs as sources of collateral for the deal. Dealers then post hypothetical structures and corresponding prices to gauge market interest. If there is not sufficient investor demand for a proposed structuring, the dealer posts alternative structures. This process iterates, with refinements proposed and either accepted or rejected until the pre-specified REMIC's "structure final" date is reached. At this date, all parties know the exact collateral and how the cash flows from this collateral will be tranched. Two to four days prior to settlement, the Offering Circular Supplement is made available. On the settlement date the dealer exchanges the collateral with Freddie Mac or Fannie Mae in exchange for the REMIC bonds. Dealers would prefer to pre-sell tranches, especially the less liquid tranches, to reduce inventory risk. However, dealers typically only pre-sell a fraction of the offerings prior to settlement. This results in material risk to the dealer, should markets shift.

Generally, the multiple groups in a REMIC shelf cater to different investor risk appetite. For example, a Support/PAC is structure so that the Support tranche is marketed to investors with little aversion to prepayment such as hedge funds, while the PAC tranche is typically marketed to buyers with long-term liability and aversion to prepayments such as pension funds and insurance companies. Tranche categories are not mutually exclusive, as, for example, a sequential tranche can be further refined into principal and interest tranches. It is also common to see different structures mixed within a group to satisfy more complex investor demands.

2 Model and testable implications

Our model is an extension of Greenwood, Hanson, and Stein (2010) for the case where there is a mortgage arbitrageur. As in Greenwood, Hanson, and Stein (2010), assume a three period world. In time 1, interest rate is known and equal to r_1. Interest rate in period 2 is r_2 and it has mean μ_r and variance σ_r^2. There are five agents in the model. First, homeowners who borrow through fixed-rate mortgages with maturity at $t = 3$. Homeowners can prepay their mortgages at time $t = 2$ without any prepayment penalty. The mortgage rate is set in the passthrough market which is exogenous to the model. Second, preferred habitat investors who do not invest in mortgage passthroughs because of mortgage prepayments, instead they demand B dollars of bonds with maturity at $t = 3$ and no possible prepayments. Third, the government that issues G dollars of these long-term bonds. Hence the excess demand for bonds is $g = B - G$.[3]

The forth agent is a yield-curve arbitrageur. The yield-curve arbitrageur specializes in exploring arbitrage opportunities between long-term bonds and short-term interest rates created by the excess demand for long-term bonds from preferred habitat investors. The arbitrageur satisfies the excess demand ($g > 0$) for long-term bonds by selling long-term bonds at price P and investing the proceeds at the short-term rate. We call this the yield-curve strategy. Assume that the arbitrageur sells \$$h$ of the long-term bond. The yield-curve arbitrageur's wealth at time $t = 3$ is $Z = h \times [(1 + r_1)(1 + r_2) - 1/P]$. The yield-curve arbitrageur maximizes the mean variance utility of terminal wealth, $E[Z] - \sigma_Z^2/(2\lambda)$, subject to the constraint that $h \geq 0$. Where λ is the yield-curve arbitrageur's risk tolerance, $E[Z] = h \times [(1 + r_1)(1 + \mu_r) - 1/P]$, and $\sigma_Z^2 = h^2(1 + r_1)^2\sigma_r^2$.

The fifth agent is a mortgage arbitrageur that caters to the excess the demand from preferred habitat investors for bonds maturing at time 3 by issuing PACs. Specifically, the mortgage arbitrageur buys f dollars of mortgage passthroughs financed with bonds that mature at time $t = 3$. These bonds have no prepayment risk, they are therefore similar to PACs (or TACs). The mortgage arbitrageur retains the prepayment risk of the mortgages financed with PACs (analogous to a hedge fund retaining a support tranche). Let Int be the value at time 3 of the amount of interest paid between time 1 and 3 on \$1 of mortgage principal.[4] Int has mean μ_I and variance σ_I^2. As a result, the mortgage arbitrager wealth at time 3 is $W = f \times (1 + Int - 1/P)$. As the yield-curve arbitrageur, the mortgage arbitrageur maximizes the mean variance utility of terminal wealth $E[W] - \sigma_W^2/(2\theta)$, with the constraint

[3] In Greenwood, Hanson, and Stein (2010), g is excess supply of government bonds, in our case g is the excess demand. We chose to frame the model in terms of excess demand because our model does not apply to the case when there excess supply of long-term bonds since only homeowners can borrow through mortgages. The model solution when there is excess supply of government bonds is the same as the one in Greenwood, Hanson, and Stein (2010).

[4] Our definition of Int is general and does not depend on the structure of mortgages. However, for purpose of an example, we can assume that the mortgages are non-amortizing and pay a constant interest rate c in each period, while the amount that is prepaid (Π_2) is reinvested at the interest rate r_2. In this case, $Int = (1 - \Pi_2)c + (\Pi_2 + c)r_2$.

that $f > 0$. Where θ is the mortgage arbitrageur risk tolerance, $E[W] = (1 + \mu_I - 1/P)$, and $\sigma_W^2 = f^2\sigma_I^2$. Therefore both arbitrageurs may respond to the excess demand for long-term bonds, hence the market clearing condition is $f^* + h^* = g$.

The model has three possible solutions that we briefly discuss herein (details are in the appendix). The first solution is when the constraint $f > 0$ binds and $f^* = 0$. In this solution, only the yield-curve arbitrageur issues bonds with maturity at time 3 to arbitrage away the excess demand for bonds. In this case, the market clearing condition implies that $h^* = g$. Moreover, we find that in this case:

$$1 + \mu_I - \frac{1}{P} < 0. \tag{1}$$

That is, when the expected return of the mortgage strategy is negative, only the term-structure arbitrageur responds to the excess demand for bonds with maturity at time 3. As a result, the price of the long-term bond is set with respect to the short-term rate as in Greenwood, Hanson, and Stein (2010):

$$\frac{1}{P} = (1 + r_1)(1 + \mu_r) - \eta_h g. \tag{2}$$

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

The second possible solution is when the constraint $h > 0$ binds and $h^* = 0$. In this solution, only the mortgage arbitrageur issues bonds with maturity at time 3 to arbitrage away the excess demand for bonds. In this case, the market clearing condition implies that $f^* = g$ and $\partial f^*/\partial g = 1$. The yield of the long-term bond is set with respect to the expected interest rate paid on mortgages:

$$\frac{1}{P} = 1 + \mu_I - \eta_f g \tag{3}$$

where $\eta_f = \sigma_I^2/\theta$ is the risk penalty associated with the mortgage arbitrageur problem. Moreover, we find that in this case that:

$$\frac{1}{P} - (1 + r_1)(1 + \mu_r) > 0. \tag{4}$$

That is, when the term-structure is very steep and the term premium is greater than zero, only the mortgage arbitrageur responds to the excess demand for long-term bonds.

In the case of an interior solution, $f^* > 0$, $h^* > 0$. In this case both arbitrageurs issue bonds to preferred habitat investors and ,

$$\frac{\partial f^*}{\partial g} = \frac{\eta_h}{\eta_f + \eta_h} \tag{5}$$

which is greater than zero and smaller than one. Moreover, the share of any increase on the excess demand for bonds that is captured by the mortgage arbitrageur 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 arbitrageur captures $\partial f^*/\partial g$ of each dollar increase in g, the yield curve arbitrageur captures $1 - \partial f^*/\partial g$. The yield of the long-term bond is set based on the short-term rate and on the mortgage rates and is given by:

$$\frac{1}{P} = \frac{(1 + r_1)(1 + \mu_r)\eta_f + (1 + \mu_I)\eta_h}{\eta_f + \eta_h} - \frac{\eta_f \eta_h}{\eta_f + \eta_h} g \tag{6}$$

Even though the implications of the model to the yield of the long-term bond are not used in our empirical tests, these implications are somewhat interesting. Specifically, Equations 3 and 6 reveal that the prices of long-term bonds are set not only with respect to $(1 + r_1)(1 + \mu_r)$ as in the expectation hypothesis literature, but also with respect to the mortgage rates (μ_I). Specifically, Equation 6 reveals that the effect of increases in short-term rates $(1 + r_1)(1 + \mu_r)$ on $1/P$ is dampened if the risk penalty of the mortgage arbitrageurs is small (small η_f). The implication that an alternative arbitrage strategy to the yield-curve strategy could dampen the relation between the price of long term-bond and $(1 + r_1)(1 + \mu_r)$ is particularly interesting because of the 2004 and 2005 term-structure conundrum described by the former Fed Chairman Alan Greenspan. In this period, the long-term interest rates remained remarkably low despite rising short-term interest rates. The economic rational for the conundrum in our model is that arbitrageurs have access to a strategy to issue bonds to satisfy the preferred habitat investors' demand, such as issuing AAA bonds collaterilized by sub-prime mortgages. Naturally, our model is not a general equilibrium model hence this explanation to the conundrum has the caveat that both μ_r and μ_I are exogenous to the model. Therefore, instead of focusing on the implications of the model to the yield of long-term bonds, we focus on the implications of the model to the relation between the issuance of PACs and the excess demand for long-term bonds. Specifically in Section 3 we test two propositions of the model.

Proposition 1 *When the issuance of PACs is greater than zero ($f > 0$), it increases with the excess demand for Treasuries (g). That is, the issuance of PACs is a direct response to the excess demand for bonds with maturity at time $t = 3$.*

Proof. An inspection of Equations 18 and 20 reveals that when $f > 0$ an increase in the excess demand for bonds with maturity at time $t = 3$ causes an increase the issuance of PACs that also have maturity at time $t = 3$. ■

The intuition for Proposition 1 is simple. Provided the mortgage arbitrageur can make a profit by catering for the preferred habitat investors, that is $E[W] > 0$, as the demand for long-term bonds increases, issuance of PACs increases.

Proposition 2 *When the yield curve is steepest, the substitution effect between PAC tranches and excess demand for bonds maturing at time 3 is stronger.*

Proof. Equation 4 reveals that when the term premium is greater than zero and hence the yield curve is steepest, only the mortgage arbitrageur engages in arbitraging the excess demand for bonds. In this case, $\partial f^* / \partial g$ has the maximum value of one which implies that the substitution effect between PAC tranches and excess demand for bonds is stronger. ■

The idea of Proposition 2 is similar to the idea of Proposition 1. The yield-curve arbitrageur does not respond to the excess demand for long-term bonds from habitat investors when $E[Z] < 0$. That is, when the term premium, $1/P - (1 + r_1)(1 + \mu_r)$, is greater than zero, the yield curve arbitrageur has no reason to issue bonds that mature at time 3 financed with short-term rates. Therefore, when the term structure slope is steep only the mortgage arbitrageurs respond to the excess demand for long-term bonds and, in turn, PAC issuance is more sensitive to the excess demand for bonds.

An implication of Proposition 2 related to the sharp increase in collateralized finance in the 2004-2006 period is that PAC issuance should be less sensitive to Treasury excess demand in this period. If we view other forms of securitized financial instruments (e.g. AAA securities backed by subprime mortgages) as other potential substitutes that might take the place of PAC issuance to meet excess demand for government bonds, a logical implication of Proposition 2 is that the substitution effect is attenuated in times where investors have other outside securitization options.

We test Propositions 1 and 2 in Section 3. For these empirical tests, it is also important to note that the relations between the issuance of PACs and the excess demand for bonds are very specific. For instance, and increase for the demand in *short-term* Treasury securities should not be related to an increase in the issuance of *long-term* PACs. Moreover, while the model has direct implications about the issuance of PACs and the excess demand for bonds of the same maturity, the model has no implications about the relation between the issuance of other types of CMOs (e.g. IOs/POs) and the excess demand for bonds.

3 Testing the model implications

3.1 Data

The primary dependent variable of interest in this study is the change in collateralized mortgage obligation (CMO) issuance for a given month. We observe a comprehensive monthly panel of all CMOs from 1990 to 2016 issued by The Federal Home Loan Mortgage Company (FHLMC), or "Freddie Mac". This data was downloaded from Bloomberg and consists of 4,611 individual CMO deals totaling 164,446 individual tranches. For each observation, we have an exhaustive array of characteristics calculated at the time of issuance including the issue size, duration, weighted average life (WAL), and other features. A unit of observation for this original data set is a CMO tranche.

CMO tranches have variable characteristics and are broadly classified into the following categories: planned amortization class (PAC), targeted amortization class (TAC), sequential pay securities, interest only strips (IO), and principle only strips (PO). There is significant variation across CMO issues in terms of the composition of each tranche type. We take these tranche-level data and aggregate them each month to create a new panel in which a unit of observation is monthly tranche-type issuance. Table 1 provides summary statistics for this panel.

The top five rows of Table 1 show full-sample descriptive statistics for total monthly CMO issuance (of all tranche types), and each section below restricts the sample to only issuance of a specific type. For example, the mean monthly PAC issuance for our sample is $8.22 billion. Using these data, we construct a simple monthly percentage change variable for each type:

$$\Delta CMO_{i,t} = \frac{CMO_{i,t} - CMO_{i,t-1}}{CMO_{i,t-1}} \tag{7}$$

where t indexes months and i indexes tranche types (PAC, TAC, Seq, and IOs/POs). In our empirical work, we also take advantage of the average lives at issuance of PACs, TACs and SEQs. For this purpose, we also calculate series such as $\Delta PAC_{j,t}$, which is the percentage change in the issuance of PACs with a weighted average life (at issuance) of tenor j where $j \in \{< 3 \text{ years}, 3 \text{ years to } 9 \text{ years}, 10 \text{ years to } 30 \text{ years}\}$.

The primary independent variable of interest in our study is a measure of excess demand for US Treasury securities. To understand how we arrive at a measure of this, it is important to briefly describe the process of auctioning off US Treasuries to investors.

After the announcement of a Treasury issuance, investors can submit either a competitive or non-competitive bid. Non-competitive bids are limited to a maximum purchase of \$5 million per investor per auction, and therefore typically constitute a trivial fraction of the overall issue. Non-competitive bidders receive the full amount of their bid guaranteed but agree to accept the high discount rate, yield, or margin that is set at the auction. This subset of UST demand is dominated by individual investors. Conversely, the vast majority of UST issuance is governed by the competitive bidding process and is where virtually all institutional investors operate. The only size restriction for competitive bidders is that a single bidder may not be awarded more than 35% of the total issuance. Subject to the 35% maximum rule, customer bids are binding.

To test hypotheses related to the role of gap-filling by CMO issuance we gather data on government bond issuance directly from the US Treasury through Treasury Direct. This database is an exhaustive panel of all US Treasury auctions from 1990-2016 that includes detailed results for 5,654 US Treasury auctions.

An example of the data is in Figure 2 which shows the results of a 30-year Treasury auction from November 12, 2015. The relative size of the competitive and non-competitive bids is evident, with over \$38 billion in competitive bids and approximately \$16 million in non-competitive bids. The bottom three rows are what we use to construct our measure of excess UST demand. These data aggregate all competitive tendered offers for a given UST issuance and also show the level of acceptance, broken down by investor type. For example, in this auction total competitive bids by all investors totalled \$38.53 billion but accepted bids only sum to \$15.98 billion. It is this difference, aggregated across all investors, that we define as excess UST demand on a per-auction basis. We then create a monthly measure for excess demand by summing the individual auction results, which is then used to create our percentage change measures. Formally, we define the following percentage change measure:

$$\Delta g_{j,t} = \frac{g_{j,t} - g_{j,t-1}}{g_{j,t-1}} \tag{8}$$

where g represents excess demand for government bonds as in the model above, t again indexes months and j indexes different maturity buckets of US Treasuries. In much of the analysis that follows, we divide all UST issuance into three buckets based on the term of the bonds: short-term (all maturities less than 3 years), medium-term (all maturities between 3 and 9 years), and long-term (all maturities 10 years or greater). Summary statistics for UST demand within each maturity bucket are in Table 2. The final CMO and UST excess demand data set consists of 27 years, or 324 months of observations for both CMO issuance and UST excess demand.

We also compile data for a detailed list of control variables for each regression. A table of all control variables and definitions can be found in Table 3. We divide controls into three categories: yield curve, MBS market, and swaption. Yield curve controls such as the slope of the yield curve (in levels) and changes in the slope are collected from the St. Louis Federal Reserve Economic Data source (FRED). We also compile several measures of the MBS market including mortgage rates, changes in rates and prepayment speeds. These data are collected from the Mortgage Bankers Association database. As a measure of interest rate volatility, we collect at-the-money swaption volatility figures from Bloomberg.

3.2 Empirical Design

Our empirical methodology is designed to capture the relationship between excess demand for US Treasury securities and subsequent CMO tranche issuance. We use percentage changes in monthly issuance to avoid any potentially non-stationary time series. To capture these effects we use a baseline OLS specification:

$$\Delta CMO_{i,t} = \alpha + \beta \times \Delta g_{j,t-1} + \gamma' F_{t-1} + \epsilon_{i,j,t} \tag{9}$$

g_j represents the net government bond excess demand of type j where $j \in$ <3y, 3y-9y, or 10y-30y bonds. $CMO_{i,t}$ represents the face value of tranche type i issuance of all tenors, aggregated each month. The coefficient of interest, β, is hypothesized to have a positive sign if excess demand is related to increases in future CMO issuance. The intuition is as follows: large investors submit bids (demand) for US Treasuries in month $t-1$, and some of that demand is not satisfied. CMO issuers see this excess demand and cater their month t issuance to meet this excess demand.

This regression equation is intentionally general. It allows us to examine a number of related hypothesis by pooling either the CMO issuance variable or the government demand variable (or both) by different types of bonds or different maturity characteristics. For example, by pooling all monthly CMO issuance by tranche type (where type $\in$ (PAC, TAC, Sequential, IO/PO) but aggregating US government bond issuance of any maturity, we are able to test the hypothesis of a relationship between government bond demand and *any* type of CMO issuance.

In most of the analysis below, we do this pooling at the CMO tranche level to generate both robustness checks on our main result and placebo tests. As mentioned above, the primary hypothesis relies on the similarity of government bonds and certain types of CMO tranches, specifically those that have a stable maturity structure (those that are not sensitive to prepayment speeds). The least sensitive bonds are PACs and TACs, with PAC issuance being significantly higher historically. As such, we use PAC issuance as our main dependent variable of interest but also use TACs as a robustness check. Even though the tests for TAC issuance will have lower power, if our hypothesized relationship is true, we would expect that it holds for both types of tranches.

This specification also allows for the creation of two related falsification tests using Sequential and IO/PO tranche issuance as the dependent variable. Because these tranche types are very dissimilar to a typical US government bond, we would not expect the excess demand relationship to have any bearing on the issuance of these tranche types.

Specification 9 above relied on a pooling of all tranches of a given type and all government bonds, regardless of maturity characteristics. Those tests by construction were not concerned with whether the excess demand for UST in a given month was primarily short-term T-bills or 30-year bonds. The granularity of both the CMO and UST auction data, however, allow us to construct more specific measures of both issuance and demand and run regressions of the following form:

$$\Delta PAC_{k,t} = \alpha + \beta \times \Delta g_{j,t-1} + \gamma' F_{t-1} + \epsilon_{k,j,t}. \tag{10}$$

Here, g_j represents the net government bond excess demand of type j where $j \in$ <3y, 3y-9y, or 10y-30y bonds. Specifically, PAC_k is calculated as the aggregate monthly issuance of PAC bonds with a weighted average life (at issuance) of tenor k where $k \in$ <3y, 3y-9y, or 10y-30y bonds.

Now we have for each type of CMO tranche (e.g. PAC) an estimate of the relationship between CMO issuance and excess UST demand for bonds of different maturity characteristics. We can combine all of possible relation into a 3x3 substitution matrix. Specifically, the relationship between excess demand for short-term US Treasuries and subsequent short-term PAC issuance can be estimated separately from long-term PACs and long-term Treasury bonds. When the maturity structure of both types of securities is the same, that is when $j = k$ (e.g. PAC issuance with <3y weighted average life and UST with maturity <3y), we label it an "on-diagonal" estimate. Similarly, when the maturity groupings of the CMO tranche and UST demand are different $j \neq k$, we call the resulting estimate "off-diagonal".

Because we hypothesize that CMO issuers cater their future issuance to as closely as possible match the excess demand for a specific type of US government bond, we expect a positive and significant relationship between on-diagonal pairs and a muted or non-existent relationship for off-diagonal. The underlying intuition here is that investors will seek out the closest substitute available to meet their excess demand for government bonds, and the maturity characteristics of the CMO tranches are an important determinant of how similar the bonds are. As before, the data allow us to create these substitution matrices for all CMO tranche types and the same placebo tests follow. Specifically, we do not expect any significant relationship between sequential or IO/PO tranche types for either on or off-diagonal regressions.

Proposition 2 implies that a possible mitigating factor to the issuance of PACs is the existence other strategies for arbitrageurs to respond to excess demand for bonds. Specifically, our model predicts that when the yield curve is *steepest*, the substitution effect between PAC tranches and excess demand should be stronger. We test this prediction with the following regression:

$$\Delta PAC_{j,t} = \alpha + \beta_1 * \Delta g_{j,t-1} + \beta_2 * I_{slope,t-1} + \beta_3 * (\Delta g_{j,t-1} \times I_{slope,t-1}) + \gamma' F_{t-1} + \epsilon_t \quad (11)$$

As before, PAC_j is calculated as the aggregate monthly issuance of PAC bonds with a weighted average life (at issuance) of tenor j where $j \in$ <3y, 3y-9y, or 10y-30y bonds. These binned monthly issuance figures are regressed only against excess demand (g) for the same tenor j of government excess demand, g. I_{Slope} is an indicator equal to one if the given yield curve spread is in the top quartile of steepness for the period preceding time t. β_3 is the coefficient of interest, and we interpret a positive and significant coefficient as evidence consistent with a stronger substitution effect when there is a lack of short-term versus long-term government bond arbitrage.

The model also predicts that PAC issuance is less responsive to the excess demand for Treasuries when alternative strategies such as the issuance of AAA bonds backed by subprime loans are available. To test this prediction, we use the same regression format as in Equation 11 but we replace the yield curve dummy variable with a dummy for months between January 2004 and December 2006, inclusive. These months are identified as coincident with a sharp peak in total securitizations as reported by the Inside Mortgage Finance statistics. We interact this dummy variable with our excess demand measure and the theory predicts a negative coefficient, consistent with a *decrease* in the substitution effect for PAC bonds when investors have other securitizations from which to choose.

3.3 Empirical Results

Table 4 presents the baseline OLS regression results for the pooled specification. Specifically, we regress percent changes in total monthly CMO issuance on percent changes in total excess US Treasury demand. This is done separately for each type of tranche. Columns 1 and 2 show the baseline results for PAC tranches, where we estimate that a one percent increase in excess UST demand of any tenor corresponds with between 0.889% and 1.08% increase in PAC issuance in the following month. A positive and significant coefficient here is consistent with the catering or gap-filling hypothesis as the PAC cash flow schedule most closely resembles that of a typical government bond.

Columns 3 and 4 in Table 4 report results using only TAC tranches, which are similar to PAC in terms of the characteristics of their cash flows. We also find positive and statistically significant coefficients on the excess UST demand variable. The slightly lower coefficients and t-statistics are likely the result of a much smaller TAC panel as compared with PACs, and therefore are the result of a lower power test.

To ensure that we are finding evidence consistent with the substitution hypothesis, we also run a placebo test using CMO tranche types with cash flows that are nothing like a typical US Treasury bond. As described above, sequential tranches (Seq) and interest-only or principal-only tranches have average lives that are highly sensitive to prepayment speeds and are therefore unlikely to be seen by bond investors as a direct substitute for government bonds. Given this, our hypotheses predict that the excess demand for government bonds is unrelated to future issuance of these specialized tranches. Columns 5-8 in Table 4 show this to be the case, with inconsistent signs on the coefficient and no statistical significance for either sequential or IO/PO tranches.

Table 4 assumes that issuance of (and therefore excess demand for) all government bonds is homogeneous. However, the dynamics driving excess demand for very short-term securities (T-bills) could be very different than that of long-term T-bonds. If CMO issuers are truly catering their issuance in response to excess demand for high credit quality bonds with stable cash flows, we reason that the relation between these two types of securities would depend on the duration or average lives of the bonds in question. Table 5 tests this hypothesis directly.

Table 5 repeats the above analysis but instead of grouping all government bond issuance in a given month together, we separate (bin) government issuance into three tenor categories: less than three years, three to nine years, and ten or greater years to maturity. We then regress the total PAC issuance for a given month on the binned government issuance. The first and second columns show the results for long-term government bond excess demand and we find results that are qualitatively similar to our pooled regression. A one percent increase in excess demand in month t is associated with a 1-1.2% increase in PAC issuance. This result is robust to the inclusion of controls for changes in the shape/slope of the yield curve and changes in average mortgage rates in the US. Columns 3 and 4 repeat the analysis using medium-term government debt and find that the relationship remains positive and significant, albeit with smaller coefficients. Columns 5 and 6, using the shortest-term government issuance show no significant relationship with pooled PAC issuance.

This last result is perhaps not surprising in light of the difference between the average life of a PAC bond and the fact that much of short-term Treasury issuance comes from extremely short-term financing, much of which is made up of Treasury bills of three months or less in tenor. Also, given that the average life of PAC bonds exhibits considerable variation, the substitution hypothesis is most rigorously tested by binning both government bond and PAC issuance into groups of identical expected life. The result would be similar to a "substitution matrix" and is presented in Table 6.

Panel A of Table 6 represents the on diagonal results of this dual binning process. That is, we regress monthly long-term (10-30 years) PAC issuance on long-term government bond issuance and repeat the analysis for medium and short-term issuances. We hypothesize that the relation between these binned issuances will be stronger than the pooled results, suggesting a very specific substitution pattern: namely, excess long-term government bond demand should be most closely related to future long-term PAC issuance. We find results consistent with this hypothesis. Columns 1 and 2 in Table 6 shows a larger coefficient estimate with greater statistical significance compared to the pooled approaches above. We estimate a one percent increase in excess long-term demand is associated with a 1.2-1.3% increase in next month's long-term PAC issuance. This pattern remains consistent for medium-term issuance, with coefficient estimates of approximately 1% and a high degree of statistical significance (p-values $< .01$). Additionally, whereas the pooled results for short-term government bond issuance were insignificant and of inconsistent sign, we find weak evidence of a positive short-term bond substitution effect as well. However, the sign remains positive but loses statistical significance when controlling for yield curve and mortgage market variables. This is still likely the result of a low number of very short-term PACs and a large amount of shot-term US Treasury issuance.

In addition to the on diagonal hypothesis, we examine the relationship between off diagonal issuance. That is, we regress PAC issuance of one maturity group on excess demand for US Treasury issuance of a *different* group. These results are found in Panel B of Table 6. To the extent that, for example, 20-year PAC bonds are not substitutes for <3 year government bonds, we would expect no significant relationship to emerge. The results in Panel B show that there is no off-diagonal relationship between any of the cross pairs of issuance groups. Columns 1 and 2 show that long-term PAC issuance is unrelated to short and medium-term excess Treasury demand. Columns 3 through 6 confirm no significant relationship between groups of different maturities.

To further test this specialized substitution hypothesis, we run a horse race between all monthly Treasury issuance amounts and include them in the same regression for each tenor of PAC tranches. The results, shown in Table 7, are consistent with the on/off diagonal results. Specifically, for each maturity group of PACs, the strongest relationship exists for the maturity bucket that matches the PAC issuance. For example, Columns 1 and 2 show that short-term PAC issuance is positively and significantly related to short-term government bond excess demand, there is some residual relationship with medium term demand, and no relationship with long-term demand. The reason for multiple buckets with some significance here is that for issuance very near the cutoff points, the true substitution relationship is likely identical, but the issuance must be classified into only one maturity bucket. A similar pattern emerges for medium and long-term PACs: the maturity bucket with the most significant coefficient is the one with the closest match in maturity.

The middle panel of Table 7 repeats the exact analysis in the placebo case of sequential tranches. As before, there is no significant relationship between the demand for any group of government bonds and the issuance of sequentials of any kind. In all specifications for sequentials we cannot reject the null hypothesis of a zero coefficient. The bottom panel repeats the analysis for TAC issuance, the closest substitute for PAC issuance, and a similar pattern to PACs emerges. We find considerable evidence of "on-diagonal" significance and very little "off-diagonal".

The first two columns of Table 8 show evidence consistent with a stronger substitution effect when there is a lack of short-term versus long-term government bond arbitrage. In the long-term sample, we show that when the yield curve is at its steepest level (top quartile), a one percent increase in excess long-term government demand is associated with an *additional* 0.2-0.3% increase in PAC issuance in month $t+1$. This coefficient suggest that when excess demand increases and it is relatively expensive to arbitrage the excess demand for long-term U.S. Treasury bonds by issuing long-term debt and investing in short-term Treasury bills, the relationship is much stronger. A similar pattern emerges for medium-term and short-term PAC issuance.

The coefficient on the slope term is also of interest. The lack of significance and inconsistent sign in all specifications suggests that the presence of a steep yield curve does not in itself generate an increase in PAC issuance. It is only when a steep yield curve slope coincides with an increase in excess demand that has an impact on PAC issuance.

Table 9 displays the results of the regression examining the increase in the AAA securities during the 2004-2006 period affected the issuance of PACs. The negative and insignificant coefficient on the 2004-2006 dummy is consistent with a small decline in CMO issuance during that time period, but the negative and significant (for PACs and TACs) coefficient on the interaction directly relates to model prediction in Proposition 2. We interpret the economic magnitude of the interaction coefficient as being significant when compared to the baseline estimates. In the pooled sample, a one percent increase in excess demand results in an increase of 0.3-0.4% in PAC issuance, but an interaction term coefficient of -.09% indicates that this substitution effect decreases by approximately one-third in the peak subprime mortgage time period. As before, we confirm this effect in the market for TAC issuance (Columns 3 and 4 of Table 9) and find similar results. Also, Columns 5-8 show that while the issuance of sequential and IO/PO tranches also fell in general during the 2004-2006 period, there is no significant relationship between either the time period itself or its interaction with excess demand, once again suggesting that the issuance of these imperfect substitutes for government bonds is not driven by demand for long-term bonds. Overall, are consistent with the model predictions.

4 Conclusion

Our findings indicate that the creation of securities through tranching is also the result of catering to investors with preferences for specific types of cash flows. We find that a one percent increase in the excess demand for Treasuries is followed by about one percent increase in the issuance of PACs. Moreover, we build a series of falsification tests which help assign the relation between PAC issuance and Treasury excess demand to catering to investors preferences. Specifically, there is no relation between the issuance of other types of CMOs (e.g. IOs, Sequentials) and lagged Treasury excess demand. In addition, the relation between PAC issuance and lagged Treasury excess demand is specific to their time-to-maturity. That is, only the excess demand for long-term Treasury securities is related to the issuance of long-term PACs. We also find that the elasticity of PACs issuance to Treasury excess demand is higher when the term structure is steeper. This is consistent with the idea that arbitrageurs use the most efficient strategy available to respond to the excess demand that investors may have for certain types of securities.

Even though our findings are related to PACs, the economic mechanism for tranching that we examine is similar to the one in some of the narratives about the 2007-2008 financial crisis. For instance, Bernanke, Bertaut, DeMarco, and Kamin (2011) point out that "The strong demand for apparently safe assets ... provided additional incentives for the U.S. financial services industry to develop structured investment products that "transformed" risky loans into highly-rated securities." In our case, the excess demand for bonds of a specific maturity incentivizes arbitrageurs to create PACs. We therefore show that one important point in some of the narratives of the financial crisis (e.g. Caballero and Krishnamurthy (2009) and Gennaioli, Shleifer, and Vishny (2012)) have strong empirical support.

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Figure 1: **Principal Cash Flows for PACs.** This figure shows the principal payments of four PACs (A, B, C, and D). In this example, if the underlying pool of mortgages have prepayments between 100 and 250 PSAs, the four PACs receive the principal amount each month according to this figure and the SUP tranche receives the difference between the underlying pool prepayment and the PAC payments. If the underlying pool prepays at a speed below 100 PSA, the prepayments go in the order of tranches A, B, C, D, and SUP. If the underlying pool prepays at a speed above 250 PSA, once the SUPs are extinguished, any prepayment above 250 PSAs go in the order of tranches A, B, C, and D.

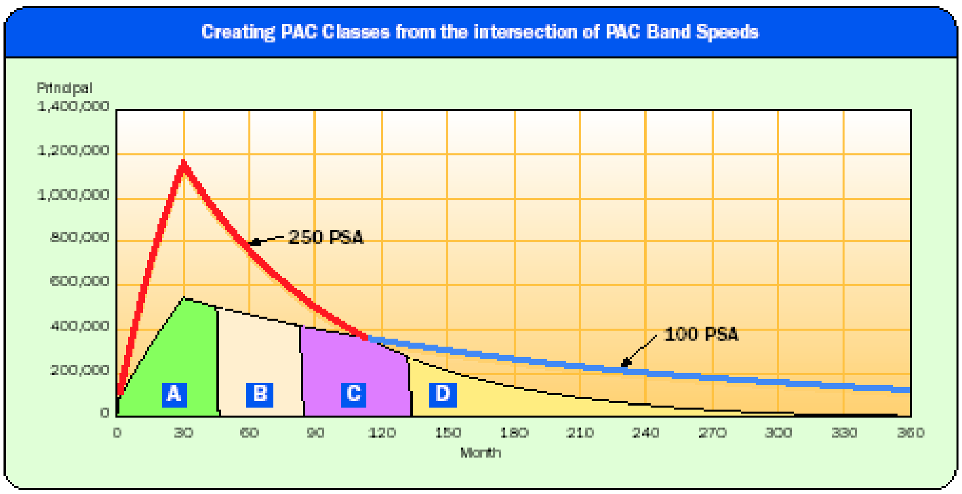

Figure 2: **Example of U.S. Treasury auction results.** This figure shows an example of the U.S. Treasury auction results used to build the excess demand for Treasury bills, notes and bonds.

TREASURY NEWS

Department of the Treasury • Bureau of the Fiscal Service

For Immediate Release
November 12, 2015

CONTACT: Treasury Securities Services
202-504-3550

TREASURY AUCTION RESULTS

Term and Type of Security	30-Year Bond
CUSIP Number	912810RP5
Series	Bonds of November 2045
Interest Rate	3%
High Yield [1]	3.070%
Allotted at High	95.55%
Price	98.633963
Accrued Interest per $1,000	$0.08242
Median Yield [2]	3.030%
Low Yield [3]	2.936%
Issue Date	November 16, 2015
Maturity Date	November 15, 2045
Original Issue Date	November 16, 2015
Dated Date	November 15, 2015

	Tendered	Accepted
Competitive	$38,528,920,000	$15,984,180,000
Noncompetitive	$15,822,700	$15,822,700
FIMA (Noncompetitive)	$0	$0
Subtotal [4]	**$38,544,742,700**	**$16,000,002,700[5]**
SOMA	$81,521,500	$81,521,500
Total	**$38,626,264,200**	**$16,081,524,200**

	Tendered	Accepted
Primary Dealer [6]	$24,174,200,000	$4,728,746,500
Direct Bidder [7]	$3,299,000,000	$1,624,688,500
Indirect Bidder [8]	$11,055,720,000	$9,630,745,000
Total Competitive	**$38,528,920,000**	**$15,984,180,000**

Table 1: **Summary Statistics.** This table summarizes the monthly for CMO issuance from 1990 to 2016. The top panel describes the monthly data for all types of CMO issuance combined, and the bottom panel breaks out the summary statistics by specific CMO tranche types.

	Mean	St Dev	Min	1Q	Median	3Q	Max
Total CMO Issuance (Billion $)	101	108	2.24	23.9	69.1	133	648
Total tranche issuance (Billion $)	4.96	8.28	0.001	.042	1.56	5.65	63.5
Effective Duration	1.71	12.81	-59.81	2.04	3.98	8.45	62.81
Number of Tranches	120	133	1	26	93	131	656
Maturity WAL	6.078	3.221	0.958	3.954	5.211	7.462	17.32
PAC							
Total tranche issuance (Billion $)	8.22	9.75	0	1.39	4.75	10.80	62.61
Tranche type percentage	0.094	0.087	0.000	0.0347	0.068	0.125	0.427
Effective Duration	3.07	0.98	-0.28	2.59	3.21	3.78	4.94
Maturity WAL	5.602	1.298	1.524	3.932	5.589	8.601	16.893
TAC							
Total tranche issuance (Billion $)	1.11	0.91	0	0	2.19	3.99	13.55
Tranche type percentage	0.013	0.022	0.000	0.000	0.019	0.092	0.222
Effective Duration	2.98	0.96	-0.41	2.01	2.99	3.28	5.09
Maturity WAL	5.330	0.997	1.137	3.667	5.037	8.003	14.303
Sequential (Seq)							
Total tranche issuance (Billion $)	6.35	7.72	.0338	1.64	3.93	7.52	54.4
Tranche type percentage	0.085	0.080	0.000	0.038	0.062	0.102	0.565
Effective Duration	2.61	1.11	-0.21	1.88	2.65	3.37	4.98
Maturity WAL	3.820	1.182	1.219	2.927	3.872	4.576	6.464
IO							
Total tranche issuance (Billion $)	12.12	12.10	.0592	3.10	8.46	17.67	63.51
Tranche type percentage	0.134	0.088	0.007	0.079	0.110	0.156	0.561
Effective Duration	-23.19	11.14	-59.80	-29.13	-20.51	-14.11	-7.28
Maturity WAL	5.912	1.860	2.534	4.152	5.425	7.494	10.970
PO							
Total tranche issuance (Billion $)	1.49	2.09	.001	.144	.586	2.19	14.70
Tranche type percentage	0.016	0.017	0.000	0.004	0.012	0.022	0.125
Effective Duration	12.94	6.77	3.81	9.09	12.12	13.46	62.81
Maturity Weighted Average Life	5.752	3.107	1.892	3.940	4.872	6.269	17.320

Table 2: **U.S. Treasury Issuance.** This table summarizes the monthly data by U.S. Treasury Issuance Type.

	Mean	St Dev	Min	1Q	Median	3Q	Max
$UST_{<3y}$							
UST issuance (Billion $)	411	162	99.9	291	393	519	993
Bid-to-cover Ratio	3.87	0.83	0.93	2.88	3.77	4.57	6.36
Excess Demand (g, Billion $)	85.1	20.6	-0.98	73.2	86.5	101	143
UST_{3y-9y}							
UST issuance (Billion $)	120	88.0	0	55.6	81.9	172	345
Bid-to-cover Ratio	2.82	0.45	2.11	2.52	2.67	3.09	4.69
Excess Demand (g, Billion $)	47.3	21.2	0.061	33.0	45.3	60.1	100
$UST_{10y-30y}$							
UST issuance (Billion $)	9.82	8.37	0	0	12.3	16.0	38.4
Bid-to-cover Ratio	2.45	0.25	1.58	2.26	2.41	2.67	3.05
Excess Demand (g, Billion $)	19.2	4.70	3.55	17.2	19.0	22.2	28.3

Table 3: **List of Control Variables by Category.** The sources of the data are U.S. Treasury (UST), Mortgage Bankers Association (MBA) and Bloomberg.

Category	**Data**	**Source**	**Notes**
Yield Curve Controls			
	Slope (30y-3m)	US Treasury	30 year UST rate minus 3m T-bill rate
	Slope (10y-3m)	US Treasury	10 year UST rate minus 3m T-bill rate
	Slope (3y-3m)	US Treasury	3 year UST rate minus 3m T-bill rate
	Δ Slope (30y-10y)	US Treasury	Monthly change in 30-year minus 10-year UST rates
	Δ Slope (10y-5y)	US Treasury	Monthly change in 10-year minus 5-year UST rates
	Δ Slope (5y-1y)	US Treasury	Monthly change in 5-year minus 1-year UST rates
MBS Market Controls			
	Mortgage Rate Level	MBA	30y fixed mortgage rate
	Δ Mortgage Rate	MBA	Monthly change in mortgage rate
	Prepayment Level	MBA Refinancing Index	Monthly refinance index level
	Δ Prepayment	MBA Refinancing Index	Changes in refinance index
Swaption Controls			
	ATM swaption volatility	Bloomberg	Monthly ATM average swaption volatility

Table 4: **CMO issuance, Excess UST Demand: Univariate Results.** This table presents OLS regression results for the following specification: $\Delta CMO_{i,t} = \alpha + \beta \times \Delta g_{t-1} + \gamma' F_{t-1} + \epsilon_{i,t}$. g_t represents the net government bond excess demand of all types j where $j \in$ <3y, 3y-9y, or 10y-30y bonds, aggregated monthly. CMO_{it} represents the face value of CMO issuance of type i at time t where $i \in$ PAC, TAC, Sequantials, IO, PO. F'_{t-1} is a vector of one-month lagged control variables. Coefficients with standard denotations for statistical significance are reported with t-statistics in parenthesis. In all specifications, standard errors are robust to heteroskedasticity and clustered in time and across CMO types. Coefficients are reported in percentage points, i.e. a one percent increase in excess demand for Treasurys corresponds with a future 1.08% increase in PAC CMO issuance (column 1). PAC stands for Planned Amortization Class, TAC for Targeted Amortization Class, Seq for Sequential Pay tranche, and IO/PO for interest only/principal-only strips.

	(PAC)		**(TAC)**		**(Seq)**		**(IO/PO)**	
Excess UST Demand (Δg_{t-1})	1.081***	0.889**	0.779***	0.604**	-0.104	0.003	-0.112	-0.008
	(3.05)	(2.19)	(2.89)	(2.04)	(-0.77)	(0.10)	(-0.61)	(-0.39)
Yield Curve controls	N	Y	N	Y	N	Y	N	Y
MBS Market controls	N	Y	N	Y	N	Y	N	Y

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 5: **Placebo: PAC substitutes by Granular Treasury WAL.** This table presents OLS regression results for the following specification: $\Delta PAC_t = \alpha + \beta \times \Delta g_{j,t-1} + \gamma' F_{t-1} + \epsilon_t$. g_i represents the net net government bond excess demand of type i where $i \in$ <3y, 3y-9y, or 10y-30y bonds. CMO_t represents the face value of PAC issuance of all tenors, aggregated each month. F'_{t-1} is a vector of one-month lagged control variables: δ30-10 is defined as the one-period absolute change in the 30-year US Treasury Yield minus 10-year US Treasury yield spread, and similarly for 10-5 and 5-1. Coefficients on the UST variables correspond to percentages, i.e. 1.50 = 1.5%. In all specifications, standard errors are robust to heteroskedasticity and clustered in time.

	All PAC Issuance					
Δg_{10-30}	1.205***	0.997**				
	(3.84)	(2.23)				
Δg_{3-9}			0.816**	0.642**		
			(1.99)	(2.00)		
$\Delta g_{<3y}$					-0.114	0.049
					(-0.21)	(0.10)
δ 30-10		-13.093		-44.408		-49.812
		(-0.06)		(-0.20)		(-0.22)
δ 10-5		-178.816		-60.049		-74.399
		(-0.87)		(-0.28)		(-0.33)
δ 5-1		88.467		61.725		70.071
		(0.95)		(0.63)		(0.71)
δ mortgage rate		-74.029		-57.505		-68.007
		(-1.05)		(-0.75)		(-0.91)

***** $p < 0.1$**; **** $p < 0.05$**; ***** $p < 0.01$

Table 6: **Placebo: PAC by WAL substitutes by Granular Treasury WAL.** This table presents OLS regression results for the following specification: $\Delta PAC_{k,t} = \alpha + \beta \times \Delta g_{j,t-1} + \gamma' F_{t-1} + \epsilon_{k,j,t}$. g_i represents the net net government bond excess demand of type i where $i \in$ <3y, 3y-9y, or 10y-30y bonds. Specifically, PAC_k is calculated as the aggregate monthly issuance of PAC bonds with a weighted average life (at issuance) of tenor k where $k \in$ <3y, 3y-9y, or 10y-30y bonds. Panel A represents "on-diagonal" results (j=k). For example, column 1 of Panel A is interpreted as a one percent increase in excess demand for 10-30 year UST corresponds with a subsequent 1.339% increase in 10-30y PAC issuance in the following month. Panel B repeats the analysis by comparing "off diagonal" bins of excess demand and PAC issuance ($j \neq k$). F'_{t-1} is a vector of one-month lagged control variables: δ30-10 is defined as the one-period absolute change in the 30-year US Treasury Yield minus 10-year US Treasury yield spread, and similarly for 10-5 and 5-1. Coefficients on the UST variables correspond to percentages, i.e. 1.50 = 1.5%. In all specifications, standard errors are robust to heteroskedasticity and clustered in time.

Panel A: Grouped PAC Issuance-"On-Diagonal"						
	10-30 PAC		**3-9 PAC**		**<3 PAC**	
Δg_{10-30}	1.339***	1.201***				
	(4.63)	(3.08)				
Δg_{3-9}			0.994***	0.918***		
			(2.99)	(2.84)		
$\Delta g_{<3y}$					0.605*	0.219
					(1.69)	(0.88)
δ 30-10		-6.980		-5.005		-9.616
		(-0.16)		(-0.03)		(-0.44)
δ 10-5		-13.834		-19.377		-26.805
		(-0.66)		(-0.81)		(-0.33)
δ 5-1		71.501		44.587		79.984
		(0.88)		(0.61)		(0.80)
δ mortgage rate		-22.202*		-18.117		-14.674
		(-1.65)		(-1.27)		(-0.33)
market controls	Y	Y	Y	Y	Y	Y
Panel B: Grouped PAC Issuance "Off-Diagonal"						
Δg_{10-30}			0.012	0.019	0.022	-0.009
			(0.56)	(0.23)	(0.44)	(-0.52)
Δg_{3-9}	-0.141	-0.077			0.092	-0.046
	(-0.20)	(-0.14)			(0.19)	(-0.56)
$\Delta g_{<3y}$	0.152	-0.092	-0.066	-0.157		
	(0.01)	(-0.21)	(-0.57)	(-0.48)		
MBS Market controls	Y	Y	Y	Y	Y	Y
Yield Curve controls	Y	Y	Y	Y	Y	Y

*** $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$**

Table 7: **Horse Race: PAC substitutes by Granular Treasury WAL.** This table presents OLS regression results for the following specification: $\Delta CMO_{i,t} = \alpha + \sum_{j=1}^{3} \beta_j \times \Delta g_{j,t-1} + \gamma' F_{t-1} + \epsilon_{k,j,t}$. $CMO_{i,t}$ denotes CMO of type i where $- \in PAC, TAC, Seq$ and $g_{j,t}$ represents the month t net government bond excess demand of type j where $j \in$ <3y, 3y-9y, or 10y-30y bonds. For each regression, the excess demand for all government bond types (j) is included. F'_{t-1} is a vector of one-month lagged control variables. Coefficients with standard denotations for statistical significance are reported with t-statistics in parenthesis. In all specifications, standard errors are robust to heteroskedasticity and clustered in time and across CMO types. Coefficients on g_{jt} correspond to percentages, i.e. 1.50 = 1.5%.

	<3 PAC		**3-9 PAC**		**10-30 PAC**	
$\Delta g_{<3y}$	0.238*	0.202*	-0.058	0.033	0.008	0.014
	(1.82)	(1.73)	(-0.19)	(0.22)	(0.10)	(0.09)
Δg_{3-9}	0.119*	0.058	0.789**	0.663**	0.201*	0.199
	(1.68)	(0.95)	(2.31)	(2.03)	(1.69)	(1.53)
Δg_{10-30}	-0.002	-0.314	0.291*	0.186*	1.092***	1.003***
	(-0.38)	(-0.22)	(1.81)	(1.70)	(3.06)	(2.81)
Yield Curve Controls	Y	Y	Y	Y	Y	Y
Market return controls	N	Y	N	Y	N	Y
	<3 Seq		**3-9 Seq**		**10-30 Seq**	
$\Delta g_{<3y}$	0.008	-0.003	0.010	0.007	0.007	0.011
	(0.16)	(-0.27)	(0.22)	(0.20)	(0.11)	(0.10)
Δg_{3-9}	0.104	0.009	0.008	0.009	0.009	0.004
	(0.37)	(0.36)	(0.27)	(0.27)	(0.64)	(0.33)
Δg_{10-30}	0.174	0.133	0.094	0.088	0.101	0.075
	(1.03)	(0.84)	(0.58)	(0.44)	(0.99)	(0.90)
Yield Curve Controls	Y	Y	Y	Y	Y	Y
Market return controls	N	Y	N	Y	N	Y
	<3 TAC		**3-9 TAC**		**10-30 TAC**	
$\Delta g_{<3y}$	0.915**	0.888*	0.312	0.117	0.110	0.009
	(2.01)	(1.83)	(0.61)	(0.43)	(0.24)	(0.19)
Δg_{3-9}	0.129	0.204	0.984**	0.775*	0.418*	0.195
	(0.77)	(0.65)	(2.11)	(1.90)	(-1.91)	(1.57)
Δg_{10-30}	0.206	-0.112	0.288	0.301	1.045***	0.966**
	(0.23)	(-0.38)	(0.81)	(0.76)	(3.01)	(2.31)
Yield Curve Controls	Y	Y	Y	Y	Y	Y
MBS Market controls	N	Y	N	Y	N	Y

***** $p < 0.1$**; **** $p < 0.05$**; ***** $p < 0.01$

Table 8: **PAC Issuance, Excess UST Demand and Yield Curve Slope: On-Diagonal.** This table presents OLS regression results for the following specification: $\Delta PAC_{j,t} = \alpha + \beta_1 * \Delta g_{j,t-1} + \beta_2 * I_{slope,t-1} + \beta_3 * (\Delta g_{j,t-1} \times I_{slope,t-1}) + \gamma' F_{t-1} + \epsilon_t$. g_j represents the net government bond excess demand of type j where $j \in$ <3y, 3y-9y, or 10y-30y bonds. PAC_j is calculated as the aggregate monthly issuance of PAC bonds with a weighted average life (at issuance) of tenor j. F'_{t-1} is a vector of one-month lagged control variables. This table presents "on-diagonal" results (j=k). $I_{slope,t-1}$ is a one-month lagged indicator equal to one if the given yield curve spread is in the top quartile of steepness for the period preceding time $t-1$. Coefficients with standard denotations for statistical significance are reported with t-statistics in parenthesis. In all specifications, standard errors are robust to heteroskedasticity and clustered in time and across CMO types.

Dep. Variable: % change in PAC issuance						
	10-30 PAC		**3-9 PAC**		**<3 PAC**	
$\Delta g_{10-30,t-1}$	0.918***	0.668**				
	(3.02)	(2.03)				
$\Delta g_{3-9,t-1}$			0.812**	0.800*		
			(1.98)	(1.85)		
$\Delta g_{<3y,t-1}$					0.792*	0.614
					(1.77)	(1.29)
$I_{slope,30y-3m,t-1}$	0.118	0.101				
	(0.81)	(0.30)				
$I_{slope,10y-3m,t-1}$			0.111	-0.005		
			(0.16)	(-0.24)		
$I_{slope,3y-3m,t-1}$					-0.084	-0.090
					(-0.55)	(-0.20)
$\Delta g_{10-30,t-1} \times I_{slope,30y-3m,t-1}$	0.338**	0.222**				
	(2.01)	(1.93)				
$\Delta g_{3-9,t-1} \times I_{slope,10y-3m,t-1}$			0.404*	0.400*		
			(1.85)	(1.75)		
$\Delta g_{<3y,t-1} \times I_{slope,3y-3m,t-1}$					0.302*	0.119
					(1.66)	(1.00)
Swapton controls	N	Y	N	Y	N	Y
MBS Market controls	N	Y	N	Y	N	Y

***** $p < 0.1$**; **** $p < 0.05$**; ***** $p < 0.01$

Table 9: **CMO issuance, Excess UST Demand and Yield Curve- PAC Specifications.** This table presents OLS regression results for the following specification: $\Delta CMO_{i,t} = \alpha + \beta_g * \Delta g_{t-1} + \beta_{slope} \times I_{slope,t-1} + \beta_{2004-2006} \times I_{2004-2006,t-1} + \gamma' F_{t-1} + \epsilon_t$. g_t represents the pooled net government bond excess demand of all types j where $j \in$ <3y, 3y-9y, or 10y-30y bonds, aggregated monthly. $CMO_{i,t}$ represents the face value of CMO issuance of type i at time t where $i \in$ PAC, TAC, Sequantials, IO, PO. F'_{t-1} is a vector of one-month lagged control variables. PAC stands for Planned Amortization Class, TAC for Targeted Amortization Class, Seq for Sequential Pay tranche, and IO/PO for interest only/principal-only strips. $I_{t-1,slope}$ is an indicator equal to one if the given yield curve spread is in the top quartile of steepness for the period preceding time $t-1$ and $I_{t-1,2004-2006}$ equals one for months between January 2004 and December 2006, inclusive. Coefficients with standard denotations for statistical significance are reported with t-statistics in parenthesis. In all specifications, standard errors are robust to heteroskedasticity and clustered in time and across CMO types. Coefficients are reported in percentage points, i.e. a one percent increase in excess demand for Treasurys corresponds with a future 0.36% increase in PAC CMO issuance (column 1).

	(PAC)		**(TAC)**		**(Seq)**		**(IO/PO)**	
Δg_{t-1}	0.361***	0.308**	0.227**	0.205**	0.080	-0.002	0.001	0.001
	(3.01)	(2.22)	(2.04)	(2.01)	(0.56)	(-0.11)	(0.94)	(0.89)
$I_{slope,30y-3m,t-1}$	0.001		0.001		0.000		0.001	
	(0.83)		(0.43)		(0.20)		(0.34)	
$\Delta g_{t-1} \times I_{slope,30y-3m,t-1}$	0.191**		0.099*		0.002		0.001	
	(1.99)		(1.80)					
$I_{2004-2006,t-1}$		-0.002		-0.001		-0.000		-0.001
		(-0.65)		(-0.71)		(-0.28)		(-0.13)
$\Delta g_{t-1} \times I_{2004-2006,t-1}$		-0.099*		-0.086*		0.003		-0.001
		(-1.72)		(-1.70)		(0.61)		(-0.55)
Yield Curve controls	Y	Y	Y	Y	Y	Y	Y	Y
MBS Market controls	Y	Y	Y	Y	Y	Y	Y	Y

***** $p < 0.1$**; **** $p < 0.05$**; ***** $p < 0.01$

A Appendix - Model Details

The term-structure arbitrageur satisfies the excess demand ($g > 0$) for long-term bonds by selling long-term bonds at price P and investing the proceeds at the short-term rate. We call this the yield-curve strategy. Assume that the arbitrageur sells \$$h$ of the long-term bond. The profit from this strategy at time $t = 3$ is equal to $h[(1 + r_1)(1 + r_2) - 1/P]$, and her wealth is $Z = h \times [(1 + r_1)(1 + r_2) - 1/P]$. The term-structure arbitrageur maximizes the mean variance utility of terminal wealth:

$$\max_h E[Z] - \frac{1}{2\lambda}\sigma_Z^2 \tag{12}$$
$$h \geq 0$$

Where λ is the term-structure arbitrageur's risk tolerance. The first order condition of this problem implies:

$$h^* = \frac{\lambda_h + (1 + r_1)(1 + \mu_r) - 1/P}{\eta_h} \tag{13}$$

where λ_h is the Lagrange multiplier associated with the constraint that $h \geq 0$ and $\eta_h = (r_1 + 1)^2\sigma_r^2/\lambda$ is the risk penalty associated with the yield-curve arbitrageur's problem. The slackness condition is $\lambda_h h = 0$.

The mortgage arbitrageur caters to the excess the demand from preferred habitat investors for bonds maturing at time 3 by issuing PACs. Specifically, the mortgage arbitrageur buys f dollars of mortgage passthroughs financed with bonds that mature at time $t = 3$. These bonds have no prepayment risk, they are therefore similar to PACs (or TACs). The mortgage arbitrageur retains the prepayment risk of the mortgages financed with PACs (analogous to a hedge fund retaining a support tranche). The amount that is prepaid (Π_2) is reinvested at the interest rate r_2, while the amount that is not prepaid $(1 - \Pi_2)$ pays interest rate c. So the profit of the mortgage arbitrageur at time t_3 from financing mortgages with PACs is $f \times (1 + Int - 1/P)$ where P is the price of the zero-coupon bond maturing at time 3 and $Int = (1 - \Pi_2)c + (\Pi_2 + c)r_2$ is the value at time 3 of the amount of interest paid on the \$1 of mortgage principal between time 1 and 3. Int has mean μ_I and variance σ_I^2. As a result, the mortgage sector wealth at time 3 is $W = f \times (1 + Int - 1/P)$. As the term-structure arbitrageur, the mortgage arbitrageur maximizes the mean variance utility of terminal wealth:

$$\max_{f} E[W] - \frac{1}{2\theta}\sigma_W^2 \qquad (14)$$
$$f \geq 0$$

where θ is the mortgage arbitrageur risk tolerance. The first order condition of this problem leads to:

$$f^* = \frac{\lambda_f + 1 + \mu_I - 1/P}{\eta_f} \qquad (15)$$

where $\eta_f = \sigma_I^2/\theta$ is the risk penalty associated with the mortgage arbitrageurs' problem and λ_f is the Lagrange multiplier associated with the constraint that $f \geq 0$. The slackness condition is $\lambda_f f = 0$.

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

$$f^* = \frac{1 + \mu_I - (1+\mu_r)(1+r_1) + \lambda_f - \lambda_h}{\eta_f + \eta_h} + \frac{\eta_h}{\eta_f + \eta_h} g \qquad (16)$$

$$h^* = \frac{(1+r_1)(1+\mu_r) - (1+\mu_I) + \lambda_h - \lambda_f}{\eta_f + \eta_h} + \frac{\eta_f}{\eta_f + \eta_h} g \qquad (17)$$

In the case of an interior solution, $f^* > 0$, $h^* > 0$, $\lambda_h = \lambda_f = 0$. In this case,

$$\frac{\partial f^*}{\partial g} = \frac{\eta_h}{\eta_f + \eta_h} \qquad (18)$$

which is greater than zero and smaller than one. Moreover, the share of any increase on the excess demand for bonds that is captured by the mortgage arbitrageur 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 arbitrageur captures $\partial f^*/\partial g$ of each dollar increase in g, the yield curve arbitrageur captures $1 - \partial f^*/\partial g$. Even though, the implications of the model to the yield of the long-term bond are not used in our empirical test. For completeness, we present these yields herein. The yield of the long-term bond is set based on the short-term rate and on the mortgage rates and is given by:

$$\frac{1}{P} = \frac{(1+r_1)(1+\mu_r)\eta_f + (1+\mu_I)\eta_h}{\eta_f + \eta_h} - \frac{\eta_f \eta_h}{\eta_f + \eta_h} g \qquad (19)$$

The second possible solution for the problem above is when the constraint $h > 0$ binds and $h^* = 0$. In this solution, only the mortgage arbitrageur issues bonds with maturity at time 3 to arbitrage away the excess demand for bonds. In this case, the market clearing condition implies that $f^* = g$. Therefore

$$\frac{\partial f^*}{\partial g} = 1. \tag{20}$$

Moreover, the yield of the long-term bond is set with respect to the expected interest rate paid on mortgages:

$$\frac{1}{P} = 1 + \mu_I - \eta_f g \tag{21}$$

which implies that the yield of the long-term bond is set with respect to the expected interest rate paid on mortgages. Substituting the conditions that $\lambda_h > 0$ and $\lambda_f = 0$ in Equations 16 and 17 we find that in this case that:

$$\frac{1}{P} - (1 + r_1)(1 + \mu_r) > 0. \tag{22}$$

That is, when the term-structure is very steep and the term premium is greater than zero, only the mortgage arbitrageur responds to the excess demand for bonds with maturity at time 3.

The third solution for the problem above is when the constraint $f > 0$ binds and $f^* = 0$. In this solution, only the term-structure arbitrageur issues bonds with maturity at time 3 to arbitrage away the excess demand for bonds. In this case, the market clearing condition implies that $h^* = g$. Therefore, the yield of the long-term bond is set with respect to the short-term rate as in Greenwood, Hanson, and Stein (2010):

$$\frac{1}{P} = (1 + r_1)(1 + \mu_r) - \eta_h g. \tag{23}$$

Substituting the conditions that $\lambda_f > 0$ and $\lambda_h = 0$ in Equations 16 and 17 we find that in this case that:

$$1 + \mu_I - \frac{1}{P} < 0. \tag{24}$$

That is, when the expected payments from mortgages are smaller than the expected payments in the long-term bond, only the term-structure arbitrageur responds to the excess demand for bonds with maturity at time 3.