Is the Market for Mortgage-Backed Securities a Market for Lemons?

Chris Downing
Barclays Global Investors

Dwight Jaffee and Nancy Wallace
University of California at Berkeley

This paper models and provides empirical evidence for the quality of assets that are securitized through bankruptcy remote special purpose vehicles (SPVs). The model predicts that assets sold to SPVs will be of lower quality ("lemons") compared to assets that are not sold to SPVs. We find strong empirical support for this prediction using a comprehensive data set of sales of mortgage-backed securities (Freddie Mac Participation Certificates, or PCs) to SPVs over the period 1991 through 2002. Valuation estimates based on a structural two-factor model indicate that PCs sold to SPVs are on average valued $0.39 lower per $100 of face value relative to PCs not so sold. For the four largest coupon groups in our full sample of Freddie Mac PCs, we find a "lemons spread" of 4–6 basis points in terms of yield-to-maturity, and this spread accounts for 13–45% of the overall prepayment spread of these securities. (*JEL* D82, G13, G14, G21)

The market for mortgage-backed securities (MBSs) carrying credit guarantees from the government-sponsored enterprises Fannie Mae and Freddie Mac (henceforth the GSEs) is one of the largest fixed-income markets in the world. At year-end 2006, the combined mortgage portfolios of Fannie Mae and Freddie Mac totaled $4.4 trillion, trailing only the corporate and Treasury bond markets in size.[1] The GSEs hold or guarantee close to 50% of all outstanding home mortgages in the United States, rendering the efficiency and perceived stability of the GSE mortgage market critical to the functioning of

---

[1] These figures are from Freddie Mac's 2006 Annual Report, Fannie Mae's 31 December 2006 Debt Activity report and April 2007 Monthly Summary, and the Federal Reserve Flow of Funds, Table L.2. The "mortgage portfolios" of Fannie Mae and Freddie Mac are defined as the sum of their on-balance sheet mortgage holdings and their outstanding MBSs held by third-party investors.

the U.S. financial system. The main risk affecting the value of MBSs backed by Fannie Mae and Freddie Mac is the timing of principal repayment, referred to as "termination risk," determined primarily by how mortgage borrowers prepay their mortgages. These securities carry virtually no default risk, since the GSEs guarantee immediate repayment of principal if a borrower defaults. However, defaults do affect overall termination risk because they affect the timing of principal repayments.

A mortgage borrower's option to prepay his or her mortgage can be modeled as a call option on the underlying mortgage (Schwartz and Torous 1989; Kau et al. 1995; Stanton 1995). Mortgage borrowers vary substantially in how they exercise their prepayment options, with some borrowers promptly and "efficiently" exercising when interest rates fall, while others inefficiently cancel their option by selling their home.[2] The variability in borrowers' prepayment efficiency reflects, in one form or another, heterogeneity in the transactions costs associated with refinancing mortgages. Mortgage market investors have widely varying information regarding these transactions costs, and therefore the expected prepayment efficiency of each MBS pool. The MBS pools for which borrowers tend to inefficiently exercise their prepayment options are more valuable from an investor's standpoint, so an asymmetry in information between informed and uninformed investors regarding prepayment efficiency should promote the use of signaling devices in the GSE MBS market.

We focus on a subset of GSE MBS that is structured in a two-stage process. In the first stage, individual loans are selected and pooled into a single-class, pass-through MBS where all investors receive a *pro rata* share of all cash flows. In the second stage, selected pools are resecuritized, or repooled, into a multiclass structure in which different classes of bonds have different priorities of claims on the underlying mortgage cash flows. These multiclass MBS deals are commonly referred to as REMICs, an acronym for Real Estate Mortgage Investment Conduit, their tax code designation.[3] As explained below, we expect REMICs to consist of the specific MBS pools that informed market participants anticipate will perform poorly because the borrowers will exercise their prepayment options relatively efficiently.

The structure of our main empirical tests is (i) to use sales to REMICs to identify those MBS pools that informed market participants expect *ex ante* to have unfavorable performance, and (ii) to verify *ex post* that, on average, these pools do in fact have inferior performance. We employ a comprehensive data set of MBSs issued by one GSE, Freddie Mac Gold Participation Certificates (PCs), over the period 1991 through 2002. The monthly termination rates published by Freddie Mac support a detailed examination of the *ex post* performance of PC pools used to create REMICs relative to the pools that remain in their

---

[2] In this paper, when we speak of "efficient" option exercise, we mean the degree to which the homeowner exercises the option in accordance with an option-theoretic model.

[3] An important benefit of the REMIC designation is tax exemption at the entity level.

original pass-through format. Our main empirical result is that, after controlling for all publicly available information about these pools, PCs converted to REMICS reveal a more efficient exercise of prepayment options on the part of the underlying mortgage borrowers. This analysis must take into account the associated interest rate environment, since an MBS instrument is more valuable to the investor if the principal is returned more slowly in a falling rate environment—the option is not efficiently exercised—or more rapidly in a rising rate environment—the option is exercised out of the money. Our results confirm that the options are exercised more efficiently for those PCs that were converted to REMICs. In other words, PCs that are restructured as part of a REMIC are lemons relative to PCs that remain in their original MBS pass-through format.

Because transaction prices for MBS are not available, the pricing implications of these results are examined using an extension of a structural two-factor valuation model developed by Downing, Stanton, and Wallace (2005). The structure of the model identifies hazard rates for mortgage terminations and distributions of transactions costs for PCs sold to REMICs and for those not sold. We again find strong support for the prediction that REMIC PCs exhibit systematically more efficient exercise of the prepayment option than non-REMIC PCs. The parameter differentials estimated under the structural model translate into pricing differentials for REMIC PCs that are, on average, $0.39 lower per $100 of face value than non-REMIC PCs. For the four largest coupon groups in our full sample of Freddie Mac PCs, we find a "lemons spread" of 4–6 basis points in terms of yield-to-maturity, and this spread accounts for 13–45% of the overall prepayment spread of these securities. Given the huge size and central importance of the GSE MBS market, these differences are clearly economically significant.

To our knowledge, this is the first paper to document that at least one important class of securitized assets is traded in a market for lemons, compared to a set of superficially similar assests that do not enter this market. This conclusion rests in large part on the institutional structure of the PC market, which precludes *ex ante* revelation of pool-specific information known to informed participants, since PCs largely trade through an anonymous forward contracting market. Hence, we interpret our finding of statistically and economically significant *ex post* performance differentials between REMIC PCs and non-REMIC PCS as evidence that the REMIC structure acts as a market signal to identify lower value MBS pools.

This paper is organized as follows. In Section 1, we review the institutional structure of the market for GSE MBS, and indicate how a model of asymmetric information between originators and investors can generate empirical predictions concerning the quality of assets transferred into the REMIC market. Section 2 lays out the empirical strategy we use to test the key proposition that MBS pools that are resecuritized as REMICs are lemons. The results of our reduced-form empirical analysis are also reported in Section 2, along with a

battery of robustness tests on the cross-sectional and time-series stability of the performance differentials found between REMIC and non-REMIC pools. The pricing implications of these differentials are reported in Section 3, and the economic relevance of the empirical findings is reported in Section 4. Section 5 concludes.

1. Asymmetric Information in the GSE MBS Market

Adverse selection arises in the GSE MBS market as a result of the hold or sell decisions by a sequence of informed market participants. The first part of this section traces this sequence of decisions in order to identify the informed and uninformed agents in the market and the likely nature of each agent's private information. The second part of the section applies a theory of asymmetric information to decisions by originators to sell pools into this market, and provides our testable hypotheses and a simple theoretical framework in which to interpret the results.

1.1 The sequence of hold or sell decisions

Figure 1 provides a flow diagram of the two-stage process that is used to create multiclass REMIC securities and the sequence of hold or sell decisions that are made by informed mortgage market participants over the course of this process. The process begins in Cell 1 with an originator creating a new mortgage. We assume that this is a "conforming mortgage," meaning that it satisfies the size limits and other criteria that allow one of the two GSEs to hold or securitize the loan.[4] We also assume that the borrower has the option to prepay at any time without penalty, as is generally the case with conforming mortgages.[5]

The presence of the prepayment option gives mortgage originators an incentive to separate highly mobile borrowers—who must inefficiently cancel their prepayment option when they move—from those with an expected long tenure—who may efficiently exercise the option to refinance. Stanton and Wallace (1996) show that lenders use a points–contract rate trade-off to induce mobile borrowers to self-select into low-point, high-rate contracts.[6] Points are kept by the lender and not explicitly disclosed to any other market participants, an important source of private information for originators. Lenders are also

---

[4] Conforming loans as a share of total mortgage originations were 62.3% in 2003, 41.4% in 2004, 35.0% in 2005, and 34.0% in 2006 (*Inside Mortgage Finance*, 17 August 2007). The declining conforming loan share is likely the combined result of GSE accounting problems and greater demand for nonconforming mortgages, particularly in regions experiencing rapid house price appreciation.

[5] State laws often require mortgage lenders to provide borrowers the option to prepay fixed-rate mortgages without penalty. The state of California, for example, imposes this condition on all fixed-rate mortgages made for home purchase. Fannie Mae and Freddie Mac also require this condition for their main MBS products.

[6] Points refer to a front-end fee, stated as a percentage of the loan amount, that the borrower is required to pay at the time the loan is made. Lenders provide menus of choices ranging from low-point, high-rate to high-point, low-rate contracts as a self-selection device.
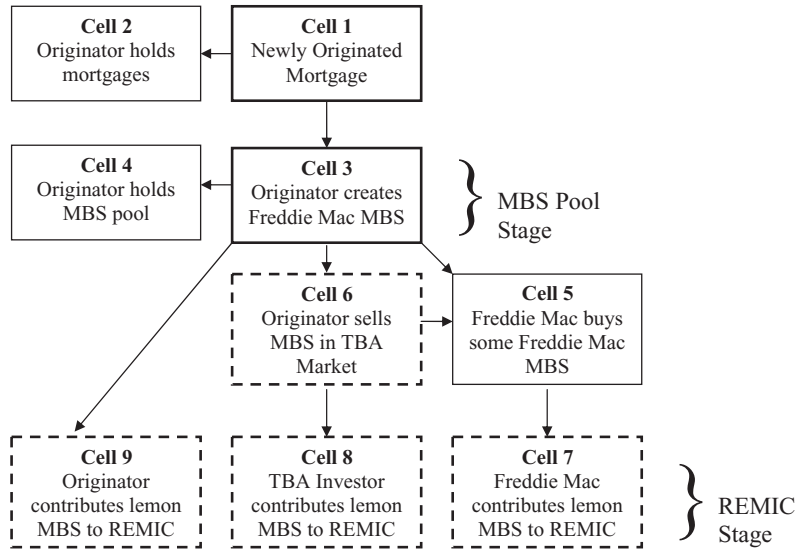
Figure 1
Hold or sell decisions in the market for GSE MBS
The figure illustrates the sequence of hold or sell decisions in the two stages of the securitization process for GSE MBS. Transactions involving low-quality pools are indicated by a dashed outline. The "MBS Pool Stage" begins with a newly originated mortgage in Cell 1. Originators hold about 20% of newly originated conforming mortgages (Cell 2) and securitize the remainder into GSE MBS (Cell 3). In our data, Freddie Mac is the GSE creating the MBS. The originator either holds the MBS or sells in the TBA market (Cell 6), and in some cases directly to Freddie Mac (Cell 5). The primary MBS sales channel is through the TBA market on a cheapest-to-deliver basis. The "REMIC Stage" occurs when MBS pools are contributed to REMIC resecuritization through three channels: Freddie Mac (Cell 7); TBA investors (Cell 8); and originators (Cell 9). The MBS pool is contributed through a cheapest-to-deliver transaction where the MBS pool principal is swapped for an equivalent REMIC principal, so there is no advantage to high-quality pool contributions.

likely to have other undisclosed information that will allow them to separate borrowers based on the efficiency with which they are expected to exercise their prepayment and default options, such as personal financial information and the borrower's history of payment behavior on previous mortgages and other loans. Armed with such information, the originator decides whether to hold the mortgage or securitize it as a pass-through MBS, as shown in Cells 2 and 3 of Figure 1.

In Cell 2 of Figure 1, the originating institution holds the mortgage in its own portfolio.[7] This choice is open mainly to banks and thrift institutions who use deposits to fund their mortgage portfolios. We expect the depositories to hold mortgages with higher expected returns, based on the private information that they develop in the lending process. In 2005, about 20% of conforming mortgages were held in originators' portfolios, with the remaining share being

---

[7] Held mortgages will most likely be retained in an originator's portfolio until maturity because the market requires that the mortgages placed in each MBS pool be homogeneous in terms of their issue date, coupon, and maturity.

securitized with pass-through MBSs (Cell 3).[8] It is important to note that, in our data set, we do not have any information about the whole loans held on originators' balance sheets. Hence, we cannot test the relative performance of these mortgages against those securitized through the GSEs.

As shown in Cell 3 of Figure 1, the mortgage securitization process begins with an originator converting an accumulated pool of mortgages into a GSE MBS pass-through instrument, obtaining a specific CUSIP designation in the process.[9] At this step, all of the mortgage default risk is shifted to the GSE and, as a result, defaults produce an early return of principal to MBS investors. The pass-through pools typically contain between 25 and 125 mortgages. Importantly, the mortgages backing a given MBS CUSIP are from one lender's origination pipeline, and are not commingled with the mortgages of other originators. Hence, the private information that an originator might have on his mortgages carries over to the pool of mortgages backing the MBS; the usefulness of this information for predicting pool performance is not diluted by the presence of other originator's mortgages in the pool.

Following the creation of the pass-through MBS with the GSE, the originator has three possible courses of action: hold the MBS in its portfolio (Cell 4); sell the MBS (Cells 5 and 6); or exchange the MBS for an equivalent principal position in a multiclass REMIC (Cell 9).[10] The TBA ("to be announced") market (shown in Cell 6) is the primary market where originators can sell their MBS pass-through pools. According to the Bond Market Association, the TBA market has average daily trading volume in excess of $200 billion, thus providing an organized, active, and liquid market for forward delivery of newly created MBSs. Originators use the TBA market to lock in a price for forthcoming MBSs as they are originating the mortgages.[11] The TBA contract defines the MBS to be delivered only by the average maturity and coupon of the underlying mortgage pool, and by the GSE backing the MBS.[12] Hence the TBA contract embeds a valuable cheapest-to-deliver option. The pools that are

---

[8] See *Inside MBS & ABS*, 1 December 2006.

[9] Originators must securitize either 100% of a given mortgage or none of it under the "true sale" requirements of FAS 140. (See The Financial Accounting Standard No. 140 (FAS 140) "Accounting for Transfers and Servicing of Financial Assets and Extinguishment of Liabilities," September 2000.) True sale status is required for securitized assets to enjoy off-balance sheet accounting and tax treatment (Humphreys and Kreistman 1995; Kramer 2003).

[10] Depository institutions also hold large quantities of MBSs owing to capital ratio arbitrage. Under the current Basel I capital requirements, the capital ratio for a GSE MBS is less than half that of a whole mortgage. Institutions thus compare the benefit of the lower capital requirement on an MBS instrument with the fee charged by the GSE for its guarantee. This arbitrage may be eliminated under the forthcoming Basel II capital ratios.

[11] Furthermore, if the originator should decide, after all, to hold the mortgages in his own portfolio, or to sell the MBS to the GSE, it can always carry out a closing sale transaction in the TBA market or roll the delivery commitment to a later TBA contract.

[12] The Bond Market Association creates the detailed rules covering MBS delivery. Among other factors, a delivery order can be satisfied with more than one MBS pool, although there are maximum restrictions on how many pools.

cheapest to deliver are those where the borrowers are expected to exercise their prepayment options efficiently. TBA investors anticipate that the MBS pools delivered in the TBA market will be the cheapest to deliver, so market prices in the TBA market are based on the expected delivery of low-quality MBS pools.

It is worth noting the existence of a parallel market to the TBA market, organized by the same dealer network, in which buyers and sellers can require specific pool attributes, even to the level of the pool CUSIP number. This market is known as the STIP market, an acronym for "stipulated" pool features. Like the TBA market, the STIP market operates on an over-the-counter basis. Data on prices and trade volumes in the STIP market are unavailable, although market participants indicate that STIP market trading volume is minor compared to the TBA market.

In Cell 5 of Figure 1, a share of the new GSE MBS is purchased by the GSE itself. Fannie Mae and Freddie Mac currently hold close to 16% of all U.S. residential MBS pass-throughs in their retained mortgage portfolios. The GSEs make their purchases through the TBA and STIP markets, and directly from the originators. These investments are highly profitable, since the GSEs' funding costs are well below the yields on the MBSs, perhaps owing to their special status as government-sponsored enterprises. The GSEs are informed participants, since they receive detailed information on each loan in the pools they securitize. While the originators may possess greater information on the loans than the GSEs, the GSEs have the advantage of loan information provided by many originators. In addition, the GSEs possess proprietary modeling technologies developed to aid in pricing and hedging their MBS holdings.

As shown in the bottom row of Figure 1, the second stage of the mortgage securitization process occurs when MBS pass-through pools are resecuritized as REMIC instruments. REMICs are created in a process organized by the GSEs, starting with a GSE announcing its intention to create a new REMIC. At this stage, Freddie Mac (Cell 7), TBA investors (Cell 8), and originators (Cell 9) decide which MBS pools they will contribute in exchange for a new REMIC instrument. The TBA investors in Cell 8 include the investment banks who are the dealers in the TBA market, and who use the REMIC market as an outlet for any undesired MBS inventory. Although the investment banks are not as well informed about individual pools as the originators or the GSEs, they also operate in the non-GSE MBS market, and thus obtain unique information regarding market-wide conditions. Like the GSEs, the investment banks have developed sophisticated proprietary modeling technologies, as discussed in Bernardo and Cornell (1997).

Market participants deliver MBS pools to the GSE in return for a *pro rata* share of each REMIC tranche. Because market participants exchange equivalent *principal* positions of MBS pools for *principal* positions in the REMIC bonds, REMICs embed a cheapest-to-deliver option. As in the TBA market, market participants maximize the value of the REMIC cheapest-to-deliver option by contributing low-value pools, and they expect all other market participants

to do the same.[13] Finally, it is important to note that, despite the lack of FASB prohibitions on the partial sales of pools into REMICs, the predominant market practice is to resecuritize pools in their entirety. Apparently, informed market participants leverage their sources of private information to identify the cheapest-to-deliver pool, and then deliver the entire pool either to the TBA market or directly to the REMIC. The sale of pools to REMICs supports an equilibrium in which multiclass REMICs are created from MBS pass-through pools that are lemons. MBS pools that are not resecuritized as REMICs ought to exhibit less efficient option exercise on the part of mortgage borrowers.

1.2 Theoretical framework

Theoretical models of asset-backed securitization must explain why simply repackaging a portfolio of individual loans creates value for investors. Early models relied on the transaction costs associated with asset sales,[14] whereas more recent treatments rely on incomplete markets and asymmetric information.[15] Adverse selection is inherent in the MBS market due to: (i) the strictures of "true sale" accounting standards; (ii) the lack of full information revelation in the anonymous TBA market; and (iii) the principal swapping mechanisms used to transfer mortgage pools into REMICs. The most complete information concerning individual pool prepayment efficiency is likely to be held by informed originators because only they know both the level of points paid by borrowers at origination and other difficult to quantify characteristics of credit worthiness. For these reasons, a theory of asymmetric information in which originators are the informed agents should provide a fruitful approach to an empirically tractable prediction concerning the quality of assets transferred into REMICs.

We consider asset transfers from informed originators into pools as a sequence of separate one-period decision problems. However, in contrast to the signaling literature, we require that originators cannot transfer fractions of mortgages into agency MBS pools.[16] Each one-period problem shares the basic assumption that the end of period payoff (market value plus accrued coupon) of the ith mortgage asset is given by $M_i = W_i + Z_i$, where W_i represents the originator's private information, and Z_i represents idiosyncratic risk such that

---

[13] In fact, market participants have indicated to us that the vast majority of PC pools ending up in REMICs first pass through the TBA market.

[14] See Diamond (1984).

[15] Oldfield (2000) develops a model of asset securitization when markets are incomplete. Other important recent models of securitization focus on theories of asymmetric information such as the "hidden knowledge" model of DeMarzo and Duffie (1999), where the issuer learns information after the contract is signed, and the adverse selection models of DeMarzo (2005) and Riddiough (1997), where informed issuers optimally sell multiclass securities. Plantin (2004) and Axelson (2007) consider optimal security designs in issuance games where investors have private information.

[16] The voluminous and important signaling literature includes Leland and Pyle (1977); Myers and Majluf (1984); Allen and Gale (1988); DeMarzo and Duffie (1995); and DeMarzo (2005), among many others. This literature does not address asset sales that follow the requirements of FASB 140 prohibiting partial sales. As explained in footnote 9, the FASB 140 requirements justify our restriction on partial sales in agency MBS pools.

$E[Z_i|W_i] = 0$. We assume that the asset i remains risky regardless of information released on assets other than i, and that the worst-case outcome on W_i is $w_{i0} > 0$.

Trade occurs because the informed risk-neutral originator values each retained dollar of assets at only $\delta_i < 1$, due to the availability of alternative investment opportunities or because regulatory capital ratios are affected by whole mortgage asset sales. The originator sells the asset if $p_i \geq \delta_i W_i$, where p_i is the market price of the asset. In equilibrium, the market price of the asset, p_i^*, will satisfy[17]

$$p_i^* = E[W_i|\delta_i W_i \leq p_i^*] = E[W_i|W_i \leq p_i^*/\delta_i]. \tag{1}$$

In other words, market participants recognize that the originator's high opportunity cost will cause it to accept a discount δ_i in order to sell a given mortgage. In the special case that $\delta_i = 1$, the originator will not accept any price discount, so only the worst assets will be sold at $p_i^* = w_{i0}$; the equilibrium market price is the price for lemons. In the less extreme cases where $\delta_i < 1$, if W_i has a continuous support, then $p_i^* > w_{i0}$ and assets within a broader range of quality will be traded, namely, all assets where[18]

$$W_i \in [w_{i0}, p_i^*/\delta_i]. \tag{2}$$

Overall, the assets that are sold into pools will be those that are either the worst-quality type or those that are drawn from the lower tail of the quality distribution.[19]

Thus, each informed originator provides a binary signal as it makes its hold or sell decision, with a sell action signaling either a lower quality mortgage (first stage) or a lower quality MBS pool (second stage). Returning to Figure 1, this means that the uninformed MBS buyers in the TBA market (Cell 6) anticipate receiving low-quality MBSs, since they know that the originating institution could have retained the MBS in its own portfolio (Cell 3) or sold it to the partially informed GSE (Cell 5).[20] Similarly, uninformed REMIC buyers will anticipate that the underlying MBSs are lemons, since they will recognize that all contributors of MBS to the REMIC (Cells 7, 8, and 9) could have retained the MBS in their own portfolio, but chose not to do so.[21] For these reasons, the

---

[17] In general, there can be multiple solutions p_i^* that satisfy Equation (1). In those cases, the natural equilibrium is the maximal p_i^* that satisfies Equation (1) following the usual refinements developed in Cho and Kreps (1987).

[18] We thank Peter DeMarzo for pointing out the equilibrium developed in this section.

[19] This sketch suggests that in the first stage of the mortgage securitization process, originators will hold whole loans on their balance sheets that are of higher quality than those that are transferred into GSE pools. However, the data required to directly test this proposition are unavailable.

[20] Glaeser and Kallal (1997) also conclude that the TBA forward market is likely to be a market for low-quality mortgages.

[21] As pointed out by the referee, this theory does not explain why the mortgages are pooled and then subsequently tranched. Presumably, the monitoring costs saved by pooling (see Diamond 1984) more than outweigh pooling's

MBS pool collateral of REMICs is expected to be consistently within a range of relatively low-quality types in terms of the relative efficiency of prepayment option exercise.

2. Are Multiclass MBSs Lemons?

In this section, we test the key prediction of the theory developed in the previous section: are REMICs backed by PC pools of lower quality than the PC pools that are not resecuritized? Specifically, we test whether an indicator of the REMIC status of a PC pool is a statistically significant predictor of the rate of mortgage termination in the pool. First we discuss our methodology and main results, followed by a battery of robustness checks.

It is important to emphasize that the unit of analysis for our empirical work is a Freddie Mac Gold PC pool, since Freddie Mac restrictions on mortgage-level data preclude a loan-level analysis. In our analysis, we treat the individual pools as if the mortgages are homogeneous, sharing a common structure defined by the weighted average coupon (WAC), weighted average maturity (WAM), and initial principal amount of the pool. Our analysis tracks the relative termination rates of the REMIC and non-REMIC pools; the pool-level termination rates reflect the aggregate terminations of individual mortgages in the pool.

2.1 Regression methodology

Our dependent variable is the cumulative termination rate of the mortgage pool, measured after a pool is designated as either REMIC or non-REMIC. We define the cumulative termination rate as the fraction of original pool principal that is returned on an unscheduled basis, that is, the fraction of pool principal over and above scheduled amortization that is returned over a given holding period.[22]

The *ex post* cumulative termination rate for a pool principally reflects the trajectory of interest rates over the life of the pool, though movements in house prices and other factors also play roles.[23] Pools that experience substantial decline in interest rates are expected to exhibit greater cumulative termination

---

information destruction effects. In addition, at the REMIC stage, consistent with DeMarzo (2005), as the size of the asset pool grows large, there is the potential for the risk diversification benefits of pooling to outweigh the information destruction effects. Alternatively, as suggested by Plantin (2004) and Axelson (2007), the structuring of lemon pools into tranched REMIC securities may reflect an optimal mechanism designed to address adverse selection problems between sophisticated buyers of the riskier junior bonds and uninformed senior tranche investors.

[22] The mortgages that appear in the Freddie Mac Gold PC pools are fully amortizing, which means that at the end of their scheduled thirty-year terms, the remaining balance on each mortgage is zero, assuming no prepayment, default, or early payments of principal (curtailments). Each month, the mortgage payment is constant, implying that the relative shares of interest and principal in the total payment are changing over time. Our measure is the share of principal returned over and above that implied by the coupon rate and amortization period. Specifically, the dependent variable is one less the survival factor for each pool at each time horizon. The survival factor is defined as the pool factor divided by the scheduled amortized balance (Bartlett 1989).

[23] As noted earlier, because Freddie Mac insures Gold PCs against default, default events look like prepayments in terms of their effects on MBS cash flows.

Table 1
**Number of months from PC origination to REMIC sale**

Months from PC origination	Number of PC pools	Share of total
0	16,904	0.394
1–3	18,775	0.438
4–6	3,332	0.078
7–12	2,439	0.057
>12	1,402	0.033
Total	42,852	1.000

The number of months from the date a PC pool is formed to the date it is sold into a REMIC. For each interval of time, we show the number of pools and share of the sample that are sold to REMIC in the indicated interval.

rates than pools that experience no change or increases in interest rates, as declining interest rates produce an incentive for households to refinance their mortgages. Hence for REMIC pools to be identified as lower quality, the interaction of the cumulative interest rate movements and the REMIC status of pools should be found to have a statistically significant and negative coefficient in a regression on pool-level cumulative terminations. This would imply that REMIC PCs exhibit faster prepayment speeds in falling interest rate environments (and slower prepayment speeds in rising interest rate environments) than non-REMIC PCs.

The sale of a PC to a REMIC deal typically occurs one to three months after the PC is created. As shown in Table 1, of the PCs that are sold into REMIC deals, nearly half are sold immediately upon the creation of the PC; 87% are sold to REMICs within the first three months from the date the PCs are originated, and 93% of the PCs are sold within the first six months. The sizable fraction of PCs sold to REMICs a few months after the PC origination date raises a potential endogeneity issue: the sale of a PC to a REMIC likely depends, at least in part, on the cumulative terminations in the pool over these first few months. In order to eliminate this potential source of endogeneity, we construct our cumulative terminations variable starting from the end of the third month of each pool's history, as illustrated in Figure 2. In this way, we eliminate the potential for bias in our results owing to reverse causality between the sale of a PC to a REMIC deal and the cumulative termination experience in the PC pool. By the end of three months, the vast majority of pools have already been sold to a REMIC deal. We test the robustness of our results to the three-month cutoff at the end of this section.

Table 2 provides summary statistics for the Freddie Mac PC pools in our analysis. Between 1991 and 2002, Freddie Mac securitized 76,030 pools through their Gold PC Swap Program. We focus on unseasoned pools (those with a weighted-average remaining term of 356 or more months at the time of origination) in order to maintain an MBS data set that *ex ante* is as homogeneous as possible. In addition to deleting seasoned pools, we also delete pools for which key variables are missing, and a few pools with less than 90% of their pool
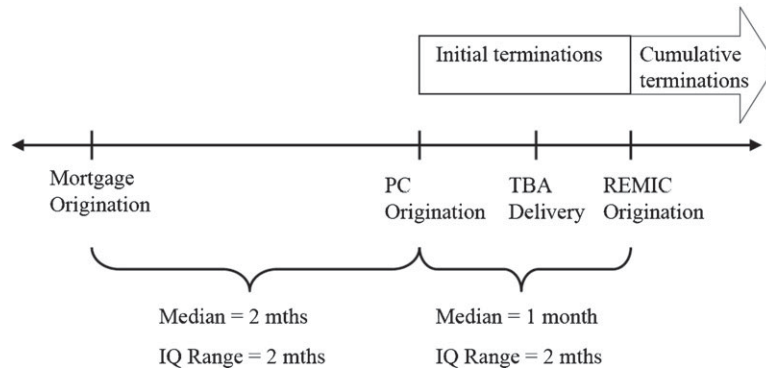
Figure 2
REMIC creation time line
Time line of the creation of a REMIC pool, from the time the mortgages are originated to the time they are sold into a REMIC deal. The arrow at the top of the figure shows how we decompose the performance of the mortgages over time. The history of each pool's terminations is broken into two pieces: (i) initial terminations are defined from the time a mortgage is included in a PC pool to the end of the third month from the origination date; and (ii) cumulative terminations are defined over the remainder of the pool life. The measure of initial terminations is an independent variable, and the measure of cumulative terminations over the remainder of the holding period forms our dependent variable.

principal either in a REMIC pool or outside a REMIC pool.[24] These three data screens together reduce the total number of pools in the sample from 76,030 to 67,804. As can be seen from Table 2, the weighted average coupon rates on the remaining pools vary by year, reflecting movements in the term structure of interest rates. In general, long-term interest rates are falling over our sample period, as reflected in the declining weighted-average coupon rates. The average balance in the pools ranges from about $2.6 million to $20.4 million, and the trend appears to be toward larger pool balances in the later years of the sample.

Table 3 provides summary statistics for the variables that we use in our regression analysis. As can be seen, the observed cumulative termination rate averages 13.1% over the first year for the pools in our sample. As expected, the average cumulative termination rate rises monotonically as the holding period lengthens, with the five-year average termination rate registering 59.5%. There is substantial variation in the termination rates across pools at each horizon, with the extrema indicating that some pools experience no unscheduled terminations while others almost completely exhaust their initial principal balance over longer horizons (the maximum termination rate is almost 1.0 for the 2–5-year horizons).

The variable *summed treasury deviations* captures the movements in long-term interest rates over the lifetime of a PC pool. It is constructed as the sum of the percentage point deviations between the ten-year Treasury rate at the end of

---

[24] The average percentage of pool principal sold to REMIC if any of the pool principal is in a REMIC is 99%.

Table 2
Summary statistics for the unseasoned Freddie Mac participation certificates

Year	Weighted-average coupon (%)	Weighted-average remaining term	Average balance ($)	Number of loans	Number of pools
1991	9.58	356.1	5,790,852	244,269	4,327
1992	8.76	356.9	2,640,649	207,336	8,073
1993	7.79	356.9	3,720,559	310,376	8,828
1994	7.97	357.9	5,898,187	463,036	7,795
1995	8.35	358.0	3,868,419	109,434	2,916
1996	8.12	358.0	5,390,400	427,812	5,066
1997	7.87	358.1	6,788,863	269,683	4,418
1998	7.19	357.5	9,420,774	988,666	9,476
1999	7.51	357.8	8,137,470	330,270	4,722
2000	7.76	358.5	9,990,811	95,786	1,386
2001	6.96	358.5	15,735,050	608,815	5,842
2002	6.43	358.0	20,481,022	624,088	4,955
Total				4,679,571	67,804

Summary statistics for the unseasoned Freddie Mac Participation Certificate pools that we use in our analysis. Unseasoned PCs are pools for which the weighted-average remaining maturity is 356 or more months in the second pool-month. Pools with missing data have also been deleted.

Table 3
Summary statistics for the regression variables

Variable	Mean	Std. dev.	Min.	Max.
One-year holding period or less (months 4–15)				
Cumulative termination rate	0.131	0.130	0	0.882
Summed treasury deviations	−0.960	7.371	−16.530	17.990
Summed house price deviations	48.483	54.681	−144.075	491.903
Two-year holding period or less (months 4–27)				
Cumulative termination rate	0.307	0.222	0	0.969
Summed treasury deviations	−3.075	17.806	−34.150	35.850
Summed house price deviations	179.804	195.200	−379.117	1413.335
Three-year holding period or less (months 4–39)				
Cumulative termination rate	0.407	0.233	0	0.978
Summed treasury deviations	−5.897	24.102	−58.780	48.290
Summed house price deviations	382.845	419.310	−607.378	2960.355
Four-year holding period or less (months 4–51)				
Cumulative termination rate	0.504	0.231	0	0.979
Summed treasury deviations	−10.638	31.036	−83.300	61.370
Summed house price deviations	669.762	713.648	−866.980	5193.848
Five-year holding period or less (months 4–63)				
Cumulative termination rate	0.595	0.225	0	0.985
Summed treasury deviations	−18.253	36.997	−112.810	62.790
Summed house price deviations	987.243	976.822	−1111.925	6831.794

Summary statistics for the regression variables that change with the length of the holding period. The line labeled *cumulative termination rate* shows the cumulative amount of unscheduled return of principal as a share of total principal at origination of the PC pool, starting three months after the origination date. Note that the holding periods are defined as one year *or less*, and so on, so that pools that completely pay down over the horizon do not exit the sample. The line labeled *summed treasury deviations* displays the cumulative deviations in the ten-year Treasury rate from the rate prevailing in the third month after the PC pool is formed. The line labeled *summed house price deviations* shows the cumulative deviations in the pool-specific house price index from the index level prevailing in the third month after the PC pool is formed. The sample period is 1991 through 2002. The total number of observations is 67,804 pools at each horizon.

each month and the rate that prevailed three months after the pool origination date,

$$\text{Summed treasury deviations}_T = \sum_{t=4}^{12\,T} (r_t - r_3),\tag{3}$$

where r_t is the ten-year Treasury rate at the end of month t and T is the number of years in the holding period. We start from the end of the third month because, as discussed above, we begin measuring cumulative terminations from the end of the third month in order to eliminate endogeneity. One potential drawback to this measure is that it takes on a value of zero both when interest rates are unchanged and when rising and falling rates cancel out. At the end of this section, we show that our results are robust to alternative measures that are not subject to these shortcomings. We focus on this measure because it produces a parsimonious specification that is easy to interpret.

As shown in Table 3, the mean of the *summed treasury deviations* variable becomes more negative as the holding period lengthens, reflecting the fact that, as noted above, long-term Treasury rates exhibit a secular decline over the period. Like the cumulative termination rate variable, the standard deviations of the *summed treasury deviations* are quite large, reflecting wide variation in the interest-rate experiences across the different pool vintages.

In order to test our null hypothesis of equal asset quality across REMIC and non-REMIC pools, we interact this measure with an indicator variable, REMIC, that takes the value 1 when a pool is resecuritized in a REMIC structure, and 0 otherwise. As noted earlier, for the vast majority of the pools in our sample, if a pool is assigned to a REMIC structure, this designation occurs within three months from the origination of the PC pool. Moreover, if any portion of a PC is sold to REMIC, the entire PC tends to be sold to REMIC.

For each pool, we compute a weighted index of house prices using publicly available information on the geographic composition of a pool (the shares of total pool principal accounted by mortgages originated in each state) and Freddie Mac repeat sales house price indices.[25] We rescale the weighted house price index for each pool, so that the index value is 100.0 on the date a pool is constructed, and then accumulate the deviations in the index for each pool from its value at the end of the third month.[26] The variable *summed house price deviations* accumulates the deviations in the relevant house price index from the end of the third month to the end of the indicated holding period,

$$\text{Summed house price deviations}_T = \sum_{t=4}^{12\,T} (H_t - H_3),\tag{4}$$

---

[25] We employ the Freddie Mac CMHPI, available online at http://www.freddiemac.com/finance/cmhpi/.

[26] Since the weighted-average LTV of each pool is roughly 80%, it is the changes in house prices from origination that matter for terminations and not the level of house prices.

Table 4
Summary statistics, contd

Variable	Mean	Std. dev.	Min.	Max.
Initial terminations	0.015	0.037	0.000	0.890
WAC	7.819	0.858	5.750	9.875
REMIC	0.632	0.482	0.000	1.000
Originator dummy variables				
ABN AMRO	0.049	0.216	0.000	1.000
Countrywide	0.056	0.230	0.000	1.000
Washington Mutual	0.036	0.187	0.000	1.000
Chase	0.057	0.231	0.000	1.000
Flagstar	0.023	0.150	0.000	1.000
Bank of America	0.020	0.139	0.000	1.000
Suntrust	0.017	0.131	0.000	1.000
USBank	0.014	0.119	0.000	1.000
Accubanc	0.017	0.128	0.000	1.000
Resource Mort. Grp.	0.013	0.111	0.000	1.000
Crossland	0.013	0.113	0.000	1.000
Wachovia	0.010	0.100	0.000	1.000
Bishops	0.009	0.094	0.000	1.000

Summary statistics for the regression variables that do not change with the length of the holding period. The line labeled initial terminations shows the cumulative amount of unscheduled return of principal over months 1–3 from the PC origination date as a share of total principal at the time the PC pool is formed. The line labeled *WAC* shows the weighted-average coupon of the mortgages in the pool. The line labeled *REMIC* displays summary statistics for the *REMIC* indicator variable. The summary statistics for the share of the largest originating institutions are reported as indicator variables by the name of the institution. All other originators are grouped into an omitted "Other" category. The sample period is 1991 through 2002. The total number of observations is 67,804 pools.

where H_t is the house price index value at the end of month t and T is the number of years in the holding period.

As can be seen from Table 3, in general house prices are rising over the period. The dispersion in the house price variable is high and the extrema indicate that some pools experienced significant decline in house prices. Most of the pools that experienced decline in house prices contain mortgages originated in California in the early 1990s.

Table 4 displays summary statistics for controls that do not vary with the length of the holding period. The variable initial terminations measures the cumulative unscheduled mortgage terminations over the first three months of a pool, as shown in Figure 2. This measure is interacted with the REMIC status of the pool to test for different prepayment patterns over the initial few months of a pool's history when the decision about whether to resecuritize the pool is presumably made. The average three-month cumulative termination rate is 1.5% of the original pool balance, with a range from 0% to 89%, and the standard deviation is quite large, indicating that a few pools terminate rapidly while others experience few termination events over the first three months.

The lower portion of the table displays summary statistics for the originator dummy variables that we use in our robustness checks, with the omitted category capturing the shares of smaller originators. As can be seen, Countrywide and Chase account for the largest shares of the mortgages appearing in the

Table 5
The relative performance of pass-through and resecuritized MBS

	Horizon (Years)				
	1	2	3	4	5
Summed treasury deviations	−0.0037*	−0.0039*	−0.0021*	−0.0009*	−0.0002*
	(0.0001)	(0.00006)	(0.00005)	(0.00004)	(0.00003)
Summed treasury deviations × REMIC	−0.0018*	−0.0018*	−0.0018*	−0.0014*	−0.001*
	(0.0001)	(0.00007)	(0.00006)	(0.00004)	(0.00003)
Summed house price deviations	0.0004*	0.0003*	0.0001*	0.0001*	0.0001*
	(0.00002)	(7.00e-06)	(3.00e-06)	(2.00e-06)	(1.00e-06)
Summed house price deviations × REMIC	−0.00009*	−0.00009*	0.0001*	0.00002*	0.00002*
	(0.00002)	(8.00e-06)	(4.00e-06)	(2.00e-06)	(1.00e-06)
Initial terminations	0.3887*	0.2129*	0.0140	−0.2717*	−0.5429*
	(0.0232)	(0.0263)	(0.0264)	(0.024)	(0.0214)
Initial terminations × REMIC	0.2053*	0.1322*	0.2025*	0.3076*	0.3126*
	(0.0341)	(0.0367)	(0.0374)	(0.035)	(0.0307)
REMIC	0.0303*	0.0693*	0.0076*	−0.0395*	−0.0522*
	(0.0014)	(0.0022)	(0.0023)	(0.0024)	(0.0025)
WAC	0.0179*	0.0731*	0.1041*	0.1184*	0.1173*
	(0.0007)	(0.0009)	(0.0009)	(0.0008)	(0.0008)
Constant	−0.0551*	−0.3743*	−0.4829*	−0.4911*	−0.4057*
	(0.0055)	(0.0074)	(0.0073)	(0.0068)	(0.0067)
Adj. R^2	0.16	0.40	0.43	0.46	0.49
F test	1,863	7,338	8,673	9,752	8,530

The table displays linear regression results where the dependent variable is the ratio of cumulative unscheduled return of principal (return of principal net of scheduled amortization) to total pool principal at origination of the PC pool, starting three months after the origination date. The independent variable *summed treasury deviations* is measured as the summed monthly deviations in the ten-year Treasury rate from the rate prevailing at the end of the third month; the variable *summed house price deviations* is measured as the summed monthly deviations in the pool-specific house price index from the index level prevailing at the end of the third month; the variable *initial terminations* is measured as the cumulative unscheduled return of principal over months 1–3 following pool formation divided by total pool principal; and *WAC* is the weighted-average coupon. Each term except WAC is interacted with the indicator variable REMIC that is 1 when the pool is assigned to a REMIC structure, and 0 otherwise. The sample period is 1991–2002. The number of pools in each regression is 67,804. Robust standard errors (Huber 1967; White 1980) are displayed in parentheses below each estimated coefficient; an asterisk next to a coefficient estimate indicates statistical significance to at least 95% level.

pools. In general, however, the individual shares are low, reflecting the highly competitive nature of the mortgage origination business.

2.2 Regression results

We report the main regression results in Table 5. As expected, increases in interest rates damp terminations at all horizons, as shown by the negative and statistically significant coefficients on the *summed treasury deviations* variables. More importantly, the results indicate that REMIC pools exhibit relatively lower cumulative terminations when Treasury rates are rising, and higher terminations when Treasury rates are falling: the coefficient on the interaction term summed treasury deviations × REMIC is statistically significant and negative at all horizons. Hence, we confirm the key prediction of the theory developed in the previous section: REMIC pools are lemons that return principal relatively slowly in rising rate environments and relatively rapidly in falling rate environments. As noted earlier, these results imply that the mortgage borrowers in REMIC pools tend, on average, to exercise their prepayment options more

efficiently than the mortgage borrowers in non-REMIC pools. That is, REMIC pool behavior is closer to the predictions of a rational expectations model of mortgage prepayment in which a mortgage borrower finds it optimal to prepay as soon as the market interest rate falls below the coupon on his or her existing mortgage. As expected, given that both types of the mortgage pools eventually pay back all of the borrowed principal, the differences between REMIC and non-REMIC pools decline over time.[27]

Examining the house price variable, we find that, in general, increases in house prices tend to accelerate terminations. This result reflects the net effect of the two different influences that house price movements exert on mortgage terminations. On the one hand, increases in house prices depress defaults (and vice versa). On the other hand, increases in house prices generate home equity that homeowners can tap by refinancing to a higher loan-to-value ratio, or that can help to offset the costs of moving and serve as a down payment on a larger home. The results here indicate that the latter mobility-related effects are likely to be dominant. Notably, the positive boost to terminations provided by increases in house prices is weaker for REMIC pools over one- and two-year horizons. Over four- and five-year horizons, the housing mobility effects are somewhat stronger in REMIC pools, as evidenced by the positive coefficients on the *house price deviations* × *REMIC* interaction terms.

We find a positive and statistically significant effect of *initial terminations* on cumulative terminations over the one- and two-year investment horizons. Over the longer horizons, positive initial terminations are associated with lower cumulative terminations. These results support the conventional wisdom on mortgage pool "burnout."[28] High initial terminations reflect termination activity by the households that most assiduously exercise their termination options, leaving a less responsive pool in their wake.

At all horizons, the interaction of the initial termination history with the REMIC indicator is positive and statistically significant. These results indicate that the behavior of REMIC and non-REMIC pools is very different: positive initial terminations predict higher cumulative terminations for REMIC pools at all horizons. Finally, all else equal, higher weighted-average coupon pools exhibit higher cumulative terminations over each horizon, as evidenced by the positive and significant coefficients on the WAC variable.

The REMIC covariate measures differences in the average termination rates between non-REMIC and REMIC PCs that are unrelated to interest rate or house price movements. As shown, in the first three holding periods, the REMIC termination rates are higher, on average, than non-REMIC termination rates. Since

---

[27] An alternative approach is based on cumulative terminations over discrete intervals. We experiment with this approach at the annual frequency and find results consistent with what we report here: REMIC pools terminate much more efficiently early on and converge to non-REMIC pools over time. Given the path dependency in pool behavior, the regression approach based on complete pool histories is arguably easier to interpret.

[28] Burnout refers to the conventional wisdom that a given decline in interest rates elicits less and less prepayment response from a pool as it ages (see Richard and Roll 1989).

rates are generally falling over our analysis period, rapid terminations unrelated to interest rate or house price movements would have a negative impact on investors' returns. Over the longer holding periods, REMIC terminations become statistically significant and negative due to the relatively high rates of terminations early on.

2.3 Robustness

The basic results just discussed establish that REMIC pools exhibit more efficient terminations relative to non-REMIC pools. We turn now to examine the robustness of these results along three important dimensions. First, we interact the *summed treasury deviations* variable with a full set of issuer and vintage dummy variables to check if our results are robust across issuers and time periods. Second, we examine alternative specifications of the summed Treasury and house price deviations variables. Finally, we explore whether our results are sensitive to the three-month cutoff we used to eliminate endogeneity bias. We find that our results are robust in all of these dimensions.

2.3.1 Issuer and vintage interactions.   We first construct a set of dummy variables for each issuer shown in Table 4, with all of the remaining issuers in the omitted category, a total of fourteen issuer dummies. We also construct a set of dummy variables for each of the twelve years in our sample; we refer to these as our vintage dummies. We interact all of these dummy variables, producing a set of 122 interaction terms.[29] Next, we multiply these interaction terms by the *summed treasury deviations* variable to produce a variable that measures our main effects interactions. Finally, we create a second variable by multiplying the *summed treasury deviations* main effects interactions with issuer and vintage by the REMIC indicator. We then regress the *cumulative terminations* on the WAC of the pool, its REMIC status, the two sets of the new *summed treasury deviations* interaction terms, and, as before, the *summed house price deviations* and the *initial terminations* main effects and their interactions with REMIC. Our goal is to determine whether the relative termination efficiency of REMIC pools is evident for all issuers and vintages. For this regression, we cluster the robust standard errors at the issuer–vintage level.

   Table 6 displays a summary for the coefficient estimates on the interactions of *issuer*, *vintage*, and *summed treasury deviations* and for the coefficient estimates on the interactions of *issuer*, *vintage*, REMIC status, and *summed treasury deviations* for each horizon. We focus only on these two sets of coefficient estimates for brevity and because they represent our main result. Panel A reports the average of the set of estimated coefficients on the *issuer* $\times$ *vintage* $\times$ *summed treasury deviations* interactions, the share of the estimates that are negative, and the shares of these coefficient estimates that are negative and

---

[29] Because not all issuers originated in every year, our full set of interactions is less than 168.

Table 6
Issuer and vintage dummy interactions

Panel A: Summary of the δ_{jk} coefficient estimates for issuer–vintage interactions with the variable summed treasury deviations

	Horizon (Years)				
	1	2	3	4	5
Average of the δ_{jk} coefficient estimates	−0.0045	−0.0068	−0.0043	−0.0021	−0.0004
Share negative	0.87	0.90	0.84	0.62	0.50
Share negative and significant at 10% level	0.78	0.85	0.71	0.51	0.43
Share negative and significant at 5% level	0.75	0.80	0.68	0.47	0.41
F test ($\bigvee \delta_{jk} = 0$)	22*	159*	156*	89*	46*

Panel B: Summary of the γ_{jk} coefficient estimates for issuer–vintage–REMIC interactions with the variable summed treasury deviations

	1	2	3	4	5
Average of the γ_{jk} coefficient estimates	−0.00007	−0.0005	−0.0014	−0.0015	−0.0015
Share negative	0.51	0.61	0.70	0.74	0.78
Share negative and significant at 10% level	0.45	0.43	0.56	0.63	0.60
Share negative and significant at 5% level	0.42	0.38	0.52	0.60	0.56
F test ($\bigvee \gamma_{jk} = 0$)	8*	8*	9*	7*	7*

The table displays summaries of the key coefficient estimates from regressions of cumulative termination rates on a fully interacted set of 14 issuer and 12 vintage (annual) dummy variables with the *summed treasury deviations* variable (Panel A), and with the *REMIC* dummy variable (Panel B). For each T period horizon, we estimate

$$\sum_{t=4}^{12T} (\% \text{ Terminations}_t)_i = \beta_0 + \beta_1 WAC_i + \beta_2 REMIC_i$$

$$+ \beta_3 \sum_{t=1}^{3} (\% \text{ Terminations}_t)_i + \beta_4 \sum_{t=1}^{3} (\% \text{ Terminations}_t)_i \times REMIC_i$$

$$+ \beta_5 \sum_{t=4}^{12T} (H_t - H_3)_i + \beta_6 \sum_{t=4}^{12T} (H_t - H_3)_i \times REMIC_i$$

$$+ \sum_{j=1}^{14} \sum_{k=1}^{12} \delta_{jk} \left(\text{Issuer}_j \times \text{Vintage}_k \times \sum_{t=4}^{12T} (r_t - r_3)_i \right)$$

$$+ \sum_{j=1}^{14} \sum_{k=1}^{12} \gamma_{jk} \left(\text{Issuer}_j \times \text{Vintage}_k \times \sum_{t=4}^{12T} (r_t - r_3)_i \times REMIC_i \right).$$

For each horizon, the table shows the average of the δ_{ij} and the γ_{ij} coefficient estimates across the set of 122 interaction terms that are estimable in the sample due to missing years for some issuers. We report the percentages of the δ_{ij} and the γ_{ij} coefficient estimates that are negative, and the percentages that are significant at the 10% and 5% levels, respectively. As shown above, each T horizon regression also includes WAC, and REMIC indicator variables (not interacted with the issuer–vintage dummies), the *initial terminations*, the *initial terminations* × *REMIC*, the *summed house price deviations*, and the *summed house price deviations* × *REMIC*. We omit these coefficient estimates for brevity. The robust standard errors (Huber 1967; White 1980) are clustered at the issuer and vintage levels. The sample period is 1991–2002. The number of observations is 67,804.

significant (under a one-tailed test) at the 5% and 10% levels, respectively. As expected from the previous results, the average coefficient estimate is negative at all horizons. Over the one- to three-year horizons, almost 90% of the point estimates are negative, with the vast majority being negative and significant at the 10% level. Over the four- and five-year horizons, the share of negative point estimates falls to about one half, with somewhat under half of the coefficient

estimates being statistically significant at the 10% level at the five-year horizon. The *F* test that the coefficients are jointly zero is rejected at the 0.001% level at all horizons.

Panel B of Table 6 reports the results for the coefficient estimates on the *issuer × vintage × summed treasury deviations × REMIC* interactions. Here again, consistent with prior results, our main result that REMIC pools are more efficient is robust, though the large number of issuer–vintage combinations produces an erosion in statistical precision. Most importantly, the average coefficient value is negative at all horizons. At the one-year horizon, 51% of the point estimates are negative, with 45% statistically significant at the 10% level. The share of negative coefficients rises to over 70% at the four- and five-year horizons, with the bulk being statistically significant. Again, the *F* test that these coefficients are jointly zero is rejected at the 0.001% level at all horizons. Combining these results suggests that the prior finding of the relative termination efficiency of REMIC pools is stable both over time in different interest rate environments and across issuers.

2.3.2 Alternative measures of interest rate movements. In this section, we examine the robustness of our results in two ways. First, we examine relative performance looking across pools, comparing pools where the *summed treasury deviations* variable is positive to those where it is negative. Second, we examine the response of a given pool to positive and negative interest rate deviations by breaking up the *summed treasury deviations* variable into its positive and negative components.

As noted earlier, the *summed treasury deviations* variable is defined over both rising and falling interest rate environments. Here we consider rising and falling environments separately to see if the differences across REMIC and non-REMIC pools exist in both environments. We first interact the *summed treasury deviations* variable with a dummy variable that is 1 when *summed treasury deviations* is non-negative, and 0 otherwise. This has the effect of grouping vintages of pools that experience rising interest rates over the indicated horizon, since all of the pools in a given vintage have the same interest rate experience. We label the resulting variable *summed treasury deviations* ≥ 0. Similarly, we construct the variable *summed treasury deviations* < 0 by interacting the *summed treasury deviations* variable with a dummy that is 1 when *summed treasury deviations* is negative, and 0 otherwise. As before, both of these variables are then interacted with the REMIC dummy variable. We employ a similar strategy with the *summed house price deviations* variable.

Table 7 shows that, while the differences between REMIC and non-REMIC pools are robust under this alternative specification, there are important asymmetries in these differences across the two interest rate environments. As shown by the pattern of coefficient estimates on *summed treasury deviations* ≥ 0 $\times$ *REMIC*, when interest rates rise REMIC pools initially tend to exhibit a sharper slowdown in terminations followed by termination rates that are somewhat

Table 7
Asymmetries in interest rate responses across vintages

	Horizon (Years)				
	1	2	3	4	5
Summed treasury deviations ≥ 0	−0.0044*	−0.0053*	−0.0045*	−0.003*	−0.0022*
	(0.0001)	(0.0001)	(0.00008)	(0.00008)	(0.00008)
Summed treasury deviations ≥ 0 $\times$ REMIC	−0.0024*	−0.001*	−0.0003*	−0.0008*	−0.0011*
	(0.0002)	(0.0001)	(0.0001)	(0.00009)	(0.0001)
Summed treasury deviations < 0	−0.0032*	−0.0027*	−0.0002*	0.0003*	0.0005*
	(0.0002)	(0.0002)	(0.00009)	(0.00006)	(0.00004)
Summed treasury deviations < 0 $\times$ REMIC	−0.0009*	−0.0023*	−0.0028*	−0.0013*	−0.0005*
	(0.0003)	(0.0002)	(0.0001)	(0.00007)	(0.00005)
Summed house price deviations ≥ 0	0.0005*	0.0004*	0.0002*	0.0001*	0.0001*
	(0.00002)	(8.00e-06)	(4.00e-06)	(2.00e-06)	(1.00e-06)
Summed house price deviations ≥ 0 $\times$ REMIC	0.0001*	−0.00009*	8.53e-07	0.00003*	0.00003*
	(0.00002)	(1.00e-05)	(4.00e-06)	(2.00e-06)	(2.00e-06)
Summed house price deviations < 0	−0.0005*	−0.0004*	0.00003	0.0001*	0.00009*
	(0.00007)	(0.00003)	(0.00002)	(1.00e-05)	(1.00e-05)
Summed house price deviations < 0 $\times$ REMIC	−0.00004	0.0003*	−0.00005*	0.0001*	−0.00008*
	(0.00008)	(0.00004)	(0.00002)	(1.00e-05)	(1.00e-05)
Initial terminations	0.364*	0.1481*	0.0001	−0.2779*	−0.5434*
	(0.0234)	(0.0262)	(0.0265)	(0.0239)	(0.0219)
Initial terminations $\times$ REMIC	0.2114*	0.1558*	0.1707*	0.2364*	0.2244*
	(0.0342)	(0.0366)	(0.0373)	(0.0343)	(0.0308)
REMIC	0.0314*	0.0626*	−0.0218*	−0.0578*	−0.0581*
	(0.002)	(0.0032)	(0.0031)	(0.0031)	(0.0031)
WAC	0.0206*	0.0754*	0.1088*	0.129*	0.1268*
	(0.0007)	(0.001)	(0.0009)	(0.0009)	(0.0008)
Constant	−0.0839*	−0.3972*	−0.4878*	−0.5321*	−0.4468*
	(0.0058)	(0.0082)	(0.0076)	(0.0071)	(0.0068)
Adj. R^2	0.17	0.41	0.44	0.48	0.51
F test	1,619	5,802	7,043	7,441	6,228

Linear regression results where the dependent variable is the ratio of cumulative unscheduled return of principal (return of principal net of scheduled amortization) to total pool principal at origination of the PC pool, starting three months after the origination date. The independent variable, summed treasury deviations, is defined as before, but here it is interacted with a dummy that is 1 if the *summed treasury deviations* are positive and 0 otherwise, producing the variable *summed treasury deviations* ≥ 0, and is similarly interacted with a dummy variable that is 1 when the summed deviations are negative and 0 otherwise, producing summed treasury deviations < 0. We follow a similar strategy for the *summed house price deviations* variable. As before, the variable, *initial terminations*, is measured as the cumulative unscheduled return of principal over months 1–3 following pool formation divided by total pool principal; and *WAC* is the weighted-average coupon. Each term except WAC is interacted with the indicator variable *REMIC,* which is 1 when the pool is assigned to a REMIC structure, and 0 otherwise. The sample period is 1991–2002. The number of pools in each regression is 67,804. Robust standard errors (Huber 1967; White 1980) are displayed in parentheses below each estimated coefficient; an asterisk next to a coefficient estimate indicates statistical significance to at least 95% level.

slower than non-REMIC pools. In contrast, as can be seen from the pattern of coefficient estimates on *summed treasury deviations* $< 0 \times$ *REMIC*, when interest rates fall REMIC pools exhibit a somewhat more sustained acceleration in terminations relative to non-REMIC pools.

These results isolate the prepayment behavior of mortgage borrowers in two very different situations: (i) exercising the prepayment option when it is in the money (interest rates having fallen); and (ii) *not* exercising it when it is out of the money (following an increase in interest rates). As expected, we find a greater difference between efficient and inefficient exercise when the options are in the money following a decline in rates, since refinancing is a

decision fully within the control of the borrower. Again, as expected, we find a lesser difference when the options are out of the money, since extraneous factors requiring home sales, which inefficiently extinguish the option, affect all borrowers.

Turning to the house price variables, we see that when house prices increase, both non-REMIC and REMIC pools experience an acceleration in terminations, though the differences between the two classes of pools are muted. As shown by the *summed house price deviations* $< 0 \times REMIC$ variable, when house prices fall both REMIC and non-REMIC pools also experience an acceleration in terminations over the one-year horizon. The differences between REMIC and non-REMIC pools are less pronounced over longer horizons.

Table 8 presents results for a decomposition of the *summed treasury deviations* variable into its positive and negative components. For each pool, we construct a variable that is the sum of positive deviations in Treasury rates from the month-3 benchmark, labeled *summed positive treasury deviations*, and an analogous measure that captures negative movements, labeled *summed negative treasury deviations*. Our original *summed treasury deviations* variable is the sum of the positive and negative pieces; by decomposing the variable in this way, we eliminate the potential for positive and negative movements in interest rates to cancel out. We construct similar measures for house price movements, and all of the variables are interacted with the REMIC dummy.

Focusing first on positive interest rate deviations—the first two lines of Table 8—we see that, in general, rising rates produce a significant slowdown in a pool's termination rate, as expected. More importantly, as before we find that the termination rate of a REMIC pool slows more quickly when rates rise, as evidenced by the preponderance of negative and significant coefficient estimates on the *summed positive treasury deviations* $\times$ *REMIC* variable. Turning to negative interest rate movements, over a one-year horizon, falling rates accelerate terminations. At the two-year horizon and beyond, falling rates have little effect or even a negative effect on terminations for non-REMIC pools (what we might refer to as a "super cherry" effect). In contrast, for REMIC pools, falling rates accelerate terminations relative to non-REMIC pools at all horizons, and the overall marginal effect (the sum of the main effect and REMIC interaction coefficients) of falling rates on REMIC terminations is negative at the one- and three-year horizons and about zero at the four- and five-year horizons.

The coefficients on the summed house price deviation variables indicate that our previous results on the relation between house price movements and terminations are also robust. While positive and negative house price movements both lead to an acceleration in terminations, the marginal effect of a positive move in house prices is larger than an equal-sized move in the downward direction. As before, the differences between REMIC and non-REMIC pools are modest in the house price dimension. The other coefficient estimates are not substantially different from those in the baseline regression.

Table 8
Asymmetries in interest rate responses within vintages

	Horizon (Years)				
	1	2	3	4	5
Summed positive treasury deviations	−0.0054*	−0.0079*	−0.0073*	−0.0043*	−0.0023*
	(0.0002)	(0.0001)	(0.0001)	(0.00009)	(0.00009)
Summed positive treasury deviations × REMIC	−0.0021*	−0.0005*	0.0008*	−0.0009*	−0.0016*
	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Summed negative treasury deviations	−0.0019*	0.0003	0.0027*	0.0017*	0.001*
	(0.0003)	(0.0002)	(0.0001)	(0.00007)	(0.00005)
Summed negative treasury deviations × REMIC	−0.001*	−0.0027*	−0.0036*	−0.001*	−0.0002*
	(0.0004)	(0.0002)	(0.0001)	(0.00009)	(0.00006)
Summed positive house price deviations	0.0005*	0.0004*	0.0002*	0.0001*	0.0001*
	(0.00002)	(9.00e-06)	(4.00e-06)	(2.00e-06)	(1.00e-06)
Summed positive house price deviations × REMIC	0.0001*	−0.00009*	−3.00e-06	0.00003*	0.00004*
	(0.00002)	(1.00e-05)	(4.00e-06)	(2.00e-06)	(2.00e-06)
Summed negative house price deviations	−0.0004*	−0.0004*	3.00e-06	0.0001*	0.0001*
	(0.00007)	(0.00003)	(0.00002)	(1.00e-05)	(1.00e-05)
Summed negative house price deviations × REMIC	0.0001	0.0003*	−9.00e-06	0.0001*	0.0001*
	(0.00008)	(0.00004)	(0.00002)	(1.00e-05)	(1.00e-05)
Initial terminations	0.3672*	0.1072*	−0.0517	−0.3224*	−0.5734*
	(0.0234)	(0.0262)	(0.0267)	(0.024)	(0.0221)
Initial terminations × REMIC	0.2019*	0.1344*	0.1492*	0.2131*	0.2056*
	(0.0341)	(0.0361)	(0.0368)	(0.0339)	(0.0307)
REMIC	0.0311*	0.0609*	−0.0478*	−0.0547*	−0.0463*
	(0.0025)	(0.0039)	(0.004)	(0.0037)	(0.0036)
WAC	0.0211*	0.0873*	0.1296*	0.148*	0.1374*
	(0.0007)	(0.0011)	(0.0011)	(0.001)	(0.0009)
Constant	−0.0795*	−0.4416*	−0.5731*	−0.6301*	−0.5064*
	(0.0059)	(0.0087)	(0.0082)	(0.0074)	(0.007)
Adj. R^2	0.17	0.41	0.45	0.49	0.51
F test	1,619	5,838	7,266	7,545	6,103

Linear regression results where the dependent variable is the ratio of cumulative unscheduled return of principal (return of principal net of scheduled amortization) to total pool principal at origination of the PC pool, starting three months after the origination date. The independent variables are: the summed positive monthly deviations in the ten-year Treasury rate from the rate prevailing at the end of the third month, *summed positive treasury deviations*, and its negative counterpart, *summed negative treasury deviations*. Similar variables are defined for deviations in house prices. The cumulative unscheduled return of principal over months 1–3 following pool formation divided by total pool principal is the variable *initial terminations*; the weighted-average coupon is *WAC*. Each term except WAC is interacted with the indicator variable *REMIC* that is 1 when the pool is assigned to a REMIC structure, and 0 otherwise. The sample period is 1991–2002. The number of pools in each regression is 67,804. Robust standard errors (Huber 1967; White 1980) are displayed in parentheses below each estimated coefficient; an asterisk next to a coefficient estimate indicates statistical significance to at least 95% level.

2.3.3 Endogeneity. Finally, we consider the sensitivity of our results to the three-month cutoff that we imposed in order to eliminate endogeneity between cumulative terminations and the REMIC indicator. For these regressions, we compute *cumulative terminations*, *summed treasury deviations*, and *summed house price deviations* starting from the end of the sixth month of each pool's history. We redefine *initial terminations* to capture terminations from the time a PC pool is formed to the end of the sixth month of its history; our other control variables are not affected by the cutoff. If, despite our careful decomposition of cumulative termination rates, there remains a channel for cumulative terminations to affect the REMIC indicator, then we should see the coefficient on the

Table 9
Relative performance starting six months from pool origination

	Horizon (Years)				
	1	2	3	4	5
Summed treasury deviations	−0.0031*	−0.0027*	−0.0011*	−0.0003*	0.0003*
	(0.0001)	(0.00006)	(0.00005)	(0.00004)	(0.00003)
Summed treasury deviations × REMIC	−0.0035*	−0.002*	−0.0018*	−0.0013*	−0.0008*
	(0.0001)	(0.00007)	(0.00006)	(0.00004)	(0.00003)
Summed house price deviations	0.0006*	0.0003*	0.0001*	0.0001*	0.0001*
	(0.00002)	(7.00e-06)	(3.00e-06)	(2.00e-06)	(1.00e-06)
Summed house price deviations × REMIC	−0.0003*	0.0001*	8.00e-06*	0.00002*	0.00002*
	(0.00002)	(8.00e-06)	(3.00e-06)	(2.00e-06)	(1.00e-06)
Initial terminations	0.2243*	0.0338*	−0.1696*	−0.4523*	−0.664*
	(0.0139)	(0.0165)	(0.0166)	(0.0155)	(0.0141)
Initial terminations × REMIC	0.0354*	0.0238	0.0993*	0.191*	0.1901*
	(0.0177)	(0.0204)	(0.0206)	(0.0195)	(0.0179)
REMIC	0.0527*	0.0582*	−0.0118*	−0.0512*	−0.0584*
	(0.0017)	(0.0023)	(0.0024)	(0.0026)	(0.0026)
WAC	0.039*	0.1006*	0.1282*	0.1324*	0.1341*
	(0.0007)	(0.0009)	(0.0008)	(0.0008)	(0.0008)
Constant	−0.209*	−0.5589*	−0.6385*	−0.5742*	−0.5083*
	(0.0058)	(0.0073)	(0.0068)	(0.0064)	(0.0061)
Adj. R^2	0.23	0.37	0.41	0.45	0.48
F test	2,967	6,743	7,822	8,904	8,341

The table displays linear regression results where the dependent variable is the ratio of cumulative unscheduled return of principal (return of principal net of scheduled amortization) to total pool principal at origination of the PC pool, starting three months after the origination date. The independent variables are: the summed monthly deviations in the ten-year Treasury rate from the rate prevailing at the end of the sixth month, *summed treasury deviations*; summed monthly deviations in the pool-specific house price index from the index level prevailing at the end of the sixth month, *summed house price deviations*; the cumulative unscheduled return of principal over months 1–6 following pool formation divided by total pool principal, *initial terminations*; and the weighted-average coupon, *WAC*. Each term except WAC is interacted with the indicator variable *REMIC* that is 1 when the pool is assigned to a REMIC structure, and 0 otherwise. The sample period is 1991–2002. The number of pools in each regression is 67,804. Robust standard errors (Huber 1967; White 1980) are displayed in parentheses below each estimated coefficient; an asterisk next to a coefficient estimate indicates statistical significance to at least 95% level.

REMIC indicator change as we lengthen the period over which these feedbacks can operate on the REMIC indicator.

As can be seen in Table 9, our qualitative, and in fact most of our quantitative, conclusions are unchanged when we employ the longer six-month cutoff. The *summed treasury deviations* variables carry coefficient estimates that are close in magnitude to the estimates under the three-month cutoff. Similarly, the *summed house price deviations* variable exhibits a pattern very similar both qualitatively and quantitatively to our original set of results. We conclude that our strategy of measuring cumulative terminations after the three-month point effectively eliminates any potential for endogeneity bias to affect our results.

We next consider a two-stage estimation strategy that provides an alternative test of the importance of private information as a key determinant of the REMIC status of MBS pools.[30] As previously discussed, most pools are sold to REMICs within three months of their origination date or not at all. At the

---

[30] We thank an anonymous referee for suggesting this strategy.

Table 10
Two-stage estimation of the probability that a pool is sold into REMIC and the conditional termination behavior of unanticipated REMIC status by investment horizon

First-stage probit	
Intercept	−0.817*
	(0.019)
Initial terminations	−1.319*
	(0.059)
WAC	0.151*
	(0.002)
Wald χ^2	4346.13*

	Horizon (Years)				
	1	2	3	4	5
Summed treasury deviations	−0.0048*	−0.0051*	−0.0033*	−0.0019*	−0.0009*
	(0.00007)	(0.00004)	(0.00003)	(0.00002)	(0.00002)
Summed treasury deviations × unanticipated REMIC	−0.0027*	−0.0019*	−0.0019*	−0.0014*	−0.001*
	(0.0002)	(0.00007)	(0.00006)	(0.00004)	(0.00003)
Summed house price deviations	0.0003*	0.0002*	0.0001*	0.0001*	0.0001*
	(1.00e-05)	(4.00e-06)	(2.00e-06)	(9.83e-07)	(6.94e-07)
Summed house price deviations × unanticipated REMIC	−0.0005*	0*	0*	0.00002*	0.00002*
	(0.00004)	(8.00e-06)	(4.00e-06)	(2.00e-06)	(1.00e-06)
Initial terminations	0.4964*	0.2607*	0.1216*	−0.0918*	−0.3583*
	(0.0125)	(0.0184)	(0.0191)	(0.0181)	(0.0158)
Initial terminations × unanticipated REMIC	0.0358	0.0546	0.1166*	0.2291*	0.2593*
	(0.0326)	(0.0388)	(0.0406)	(0.039)	(0.0334)
Unanticipated REMIC	0.063*	0.0683*	0.0092*	−0.0397*	−0.0572*
	(0.0032)	(0.0022)	(0.0023)	(0.0024)	(0.0025)
WAC	0.0198*	0.077*	0.1059*	0.1182*	0.1167*
	(0.0006)	(0.0009)	(0.0009)	(0.0008)	(0.0008)
Constant	−0.0533*	−0.3586*	−0.4907*	−0.5136*	−0.4328*
	(0.0052)	(0.0073)	(0.0072)	(0.0068)	(0.0066)
R^2	0.1617	0.3952	0.4268	0.4605	0.486
F test	1,622*	7,393*	8,783*	9,793*	8,571*

The first stage is a probit regression of REMIC status on the observed first three months of the pool's termination performance and the weighted-average coupon of the pool at origination. From the first-stage predicted values, we compute the probability of *unanticipated REMIC status* as the difference between the actual REMIC status and the predicted REMIC status. For the second-stage regression, we interact the *unanticipated REMIC probability* with *summed treasury deviations*, *summed house price deviations*, and *initial terminations*. The sample period is 1991–2002. The number of pools in each regression is 67,804. We apply an error-in-variables correction to obtain the standard errors displayed in the parentheses below each estimated coefficient; an asterisk next to a coefficient estimate indicates statistical significance to at least 95% level. The second-stage dependent variable is the ratio of cumulative unscheduled return of principal (return of principal net of scheduled amortization) to total pool principal at origination of the PC pool, starting three months after the pool's origination date.

end of the third month, the cumulative percentage of outstanding pool principal and the weighted-average coupon of the pool would be publicly available. We estimate a probit regression of REMIC status on this information, and then include the "unanticipated" portion of REMIC status in our previous regression specifications.

The results from our first-stage probit estimation are reported in the upper portion of Table 10. All of the coefficients are statistically significant and we find that higher initial termination speeds are negatively associated with a pool's

sale to a REMIC at the end of the third month. This result suggests that very high termination speeds within the first three months of a pool's life appear to burn the pool out, so that the remaining pool is primarily composed of borrowers who do not prepay despite decreases in interest rates. Such pools would be less efficient going forward, and thus less likely to end up in REMICs.

In the second stage, we compute the probability of "unanticipated" REMIC status as the difference between the actual REMIC status of the pool and the predicted REMIC status from our first-stage probit estimates. We then interact *unanticipated REMIC status* with *summed treasury deviations*, *summed house price deviations*, and *initial terminations,* and run our previous regressions as a means to test whether unanticipated selling into REMIC affects unanticipated termination behavior of the pool. Our second-stage results are reported in the lower section of Table 10. Controlling for sales of pools into REMICs that are not based on public information, we again find that REMIC pools prepay more efficiently. These results suggest that there is, indeed, an important private information channel that is exploited to sort MBS pools into REMIC and non-REMIC status. This valuable private information channel allows agents that are transferring pools into REMIC to primarily transfer those pools containing borrowers that efficiently exercise their termination options.

3. Implications for MBS Prices

In this section, we provide estimates of the pricing implications of the termination speed differences between REMIC and non-REMIC pools that we identified in the previous section. Since the MBS market is a brokered market, market prices for REMIC and non-REMIC pools are not available. Hence we employ a structural model to estimate the prices of the REMIC and non-REMIC pools. Under this model, the cash flows in excess of scheduled principal and interest reflect the exercise of prepayment or default options by mortgage borrowers; the model is a modification of that in Downing, Stanton, and Wallace (2005). The structural approach has the advantage that the lines of causality between the state variables and investor behavior are clear. Since the parameters of the model are obtained within an optimizing framework that controls for key exogenous information, such as the term structure of interest rates and house prices for specific pools, the results provide a clearer view of the potentially different roles of transactions costs and exogenous background terminations across the two pool classes. Moreover, the estimation results for the structural model provide an important additional robustness check on the results we presented in the previous section.[31]

---

[31] House price and interest rate dynamics are the key exogenous factors of the structural model as they are in the reduced form models that are presented in the prior section. The key difference between the two classes of models is the explicit solution for the optimal exercise timing of the embedded options in the structural model estimation framework. In the structural framework, we solve for optimal option exercise, and then conditional on optimal termination behavior, we can identify and estimate parameters for the differing transaction cost

3.1 Valuation framework

We consider two primary sources of risk: interest rates and house prices. These variables enter our valuation equation as risk factors, and as arguments to other explanatory variables that are essentially transformations of interest rates, house prices, and time, such as the time elapsed since the MBS was issued, or the unpaid balance remaining in the underlying mortgage pool. The appendix contains details on how we parameterize the underlying interest rate and house prices processes and solve the pricing model.

3.1.1 Transaction costs and borrower heterogeneity.

Under the structural modeling approach, mortgage terminations arise from the exercise of options by mortgage borrowers. However, as previously discussed, option exercise usually involves both direct monetary costs, such as origination fees and mortgage closing costs, as well as implicit costs, such as the time required to complete the process, and these constitute the private information of the borrower. Mortgage originators obtain at least some portion of this information from borrowers through screening at origination. We model all of these via a proportional transaction cost, $X_{ip} \geq 0$, payable by the borrower at the time of prepayment.

Different borrowers might face different transaction costs, and we also allow for the possibility that the distribution of transaction costs varies across REMIC and non-REMIC pools. We assume that the costs X_{ip} are distributed according to a beta distribution with parameters $\phi_1 = \beta_7 + \beta_8 R$ and $\phi_2 = \beta_9 + \beta_{10} R$, where R is the REMIC-pool indicator defined earlier and the β are coefficients to be estimated. The beta distribution is chosen because it can take many possible shapes, and is bounded by 0 and 1. Its mean and variance are

$$c\mu = \frac{\phi_1}{\phi_1 + \phi_2}, \tag{5}$$

$$\sigma^2 = \frac{\phi_1 \phi_2}{(\phi_1 + \phi_2)^2 (\phi_1 + \phi_2 + 1)}. \tag{6}$$

Hence we can test the hypothesis that the distributions of X_{ip} for REMIC and non-REMIC pools are the same by testing $H_o : \beta_8 = \beta_{10} = 0$.

Like prepayment, default incurs significant direct and indirect costs, such as the value of the lost credit rating. We model these costs via another proportional transaction cost, X_d, payable by the borrower at the time of default. We assume that default costs, X_{id}, for all borrowers are constant at $X_d = 0.05$ (5% of house value) for both REMIC and non-REMIC pools; since all Freddie Mac PCs have the same guarantee against default, security issuers would have no reason to select based on default costs.

---

characteristics of borrowers in REMIC and non-REMIC pools. In contrast, the differing effects of optimal exercise and frictions arising from transaction costs are *not* separately identifiable determinants of mortgage termination in the reduced-form framework. The "optimal" termination behavior of a pool can only be inferred from a structural model.

When implementing our algorithm to solve for the prices of REMIC and non-REMIC pools, we discretize the distribution of prepayment transaction costs. Each pool is broken into J subpools differentiated by their transaction cost levels, $X_{j,p}$, for $j = 1, 2, \ldots, J$. All else equal, subpools with higher transaction costs will exhibit less efficient prepayment option exercises than subpools with lower transaction costs.

3.1.2 Option exercise. The probability that borrowers exercise their prepayment and default options is described by a hazard function (Kalbfleisch and Prentice 1980; Cox and Oakes 1984). Informally, if the hazard function governing some event is λ, then the probability that the event occurs in a time interval of length ζt, conditional on not having occurred prior to t, is approximately $\lambda \zeta t$. As noted earlier, borrowers might also be forced to prepay or default for nonfinancial reasons (such as divorce, job relocation, or sale of the house), which we assume is also governed by a hazard rate, which we refer to as the "background" hazard rate.

We assume that the probability of prepayment or default in any time interval is governed by the state- and time-dependent hazard function, λ_j. The value of λ_j depends on whether it is currently optimal for borrowers with transaction costs X_d and X_{jp} to default or prepay, which in turn is determined as part of the valuation of the mortgage. We model the overall hazard rate governing mortgage termination as

$$\lambda_j(t) = \beta_1 + (\beta_2 + \beta_3 R) \text{ atan } \left(\frac{t}{(\beta_4 + \beta_5 R)} \right) P_{jt} + \beta_6 D_{jt} \qquad (7)$$

$$= \lambda_{jc} + \lambda_{jp} + \lambda_{jd}, \qquad (8)$$

where β_1 denotes the background hazard; the indicator variable R is 1 when a pool is incorporated into a REMIC structure, and 0 otherwise. The indicator variable P_{jt} is 1 when prepayment is optimal at time t, and 0 otherwise, and the indicator D_{jt} is 1 when default is optimal, and 0 otherwise.

The atan function captures the idea of seasoning, discussed earlier. In the prepayment region, the termination rate rises over time at a rate governed by β_2 and β_3 to a maximum rate dictated by the value of β_4 and β_5. In the default region, termination rates rise to a rate governed by β_6. For simplicity in what follows, we will use the notation given in Equation (8) to refer to the hazard rates that apply in the various regions of the state space, where $\lambda_{jc} \equiv \beta_1$, $\lambda_{jp} \equiv (\beta_2 + \beta_3 R) \text{ atan } (\frac{t}{(\beta_4 + \beta_5 R)}) P_{jt}$, and $\lambda_{jd} \equiv \beta_6 D_{jt}$. A test of the null hypothesis $H_o : \beta_3 = \beta_5 = 0$ is a test that REMIC and non-REMIC pools have the same seasoning patterns.

3.1.3 Structural model coefficient estimates. We estimate the hazard parameters and the parameters of the transaction cost distribution following the methodology of Downing, Stanton, and Wallace (2005). Our objective here is to

Table 11
Structural model estimation results

Coefficient	Estimate	Standard error
β_1	−4.277473	0.000000716
β_2	−0.610199	0.000149415
β_3	0.038703	0.000163560
β_4	−0.619280	0.000584316
β_5	0.450234	0.000455823
β_6	0.256143	0.001650568
β_7	0.428570	0.000240915
β_8	−0.059467	0.000208988
β_9	2.057829	0.000180318
β_{10}	0.116915	0.000173656
χ^2	123.8	
N	5,300,935	

The table displays the nonlinear least-squares estimates of the coefficients of the pricing model. The coefficient β_1 summarizes termination speeds when continuation of the mortgage is optimal. When a mortgage is in the region of the state-space where prepayment is optimal, the relevant hazard rate is given by $\lambda_p = (\beta_2 + \beta_3 R)\text{atan}(t/(\beta_4 + \beta_5 R))$, where t is the number of months since the mortgage was originated. When default is optimal, the hazard rate is determined by $\lambda_d = \beta_6$. The coefficients $\phi_1 = \beta_7 + \beta_8 R$ and $\phi_2 = \beta_9 + \beta_{10} R$ define the transaction cost distribution; the mean transaction cost is given by $\phi_1/(\phi_1 + \phi_2)$. The time period is 1991–2002. The pools are clustered into 34 coupon groups distributed over a grid from a minimum coupon of 5.75% up to 9.875%, where the increment between each coupon group on the grid is 12.5 basis points. There are 67,804 pass-through pools in the sample.

determine whether the structural model reveals statistically significant *ex post* differences in the efficiency of REMIC versus non-REMIC pools. In columns 2–3 of Table 11, we report the estimation results for the sample of all Freddie Mac PCs issued over the period. The sample consists of 5,300,935 pool-month observations on the 67,804 pools of the previous section.

Since the sample size is very large, it is not surprising that all of the coefficient estimates are highly statistically significant, and any restriction on the model is rejected. In particular, it is clear that the transaction cost distributions are different in the two samples, providing support for the notion that private information on transaction costs is an important source of asymmetric information in this market. Turning to the economic implications of the estimates, recall that for non-REMIC pools the overall hazard rate for terminations is given by the function

$$\lambda(t) = \beta_1 + \beta_2 \text{ atan}\left(\frac{t}{\beta_4}\right) P_t + \beta_6 D_t.$$

The estimates of β_1, β_2, β_4, and β_6 indicate that, when $P_t = D_t = 0$, the "background hazard" rate, given by β_1, produces terminations equal to about 0.1% of pool balance per month regardless of the age of the pool. When prepayment is optimal ($P_t = 1$), the rate of terminations is 6.3% per month after one year

and 6.8% per month after five years. When default is optimal ($D_t = 1$), the rate of terminations rises to 10.2% of pool balance per month.

When a pool is part of a REMIC structure, then the relevant overall hazard rate is

$$\lambda(t) = \beta_1 + (\beta_2 + \beta_3) \, \text{atan} \left(\frac{t}{(\beta_4 + \beta_5)} \right) P_t + \beta_6 D_t.$$

The estimates of β_3 and β_5 indicate that for REMIC pools, the rate of terminations in the prepayment region is 6.2% per month after one year and 6.9% per month after five years—somewhat higher than for non-REMIC pools. Over longer horizons, the differences between REMIC and non-REMIC prepayment rates are greater—after ten years the model predicts a non-REMIC monthly rate of 6.8% and a REMIC monthly rate of 7.0%. We conclude from these results that, on average over our sample, REMIC pools terminate somewhat faster than non-REMIC pools, consistent with the characterization of REMIC pools as lemons in an economic environment marked by a secular decline in long-term interest rates.

The differences in the estimated transaction cost distributions for non-REMIC and REMIC pools reinforce the conclusion that, on average, REMIC pools terminate faster. For non-REMIC pools, the average transaction cost is given by $\frac{\beta_7}{\beta_7 + \beta_9}$. The estimates displayed in Table 11 indicate that the average transaction cost for non-REMIC pools is 16.39% of the remaining principal. For REMIC pools, the mean transaction cost is given by $\frac{\beta_7 + \beta_8}{\beta_7 + \beta_8 + \beta_9 + \beta_{10}}$, or 14.12% at the estimated coefficient values. Hence the REMIC pools exhibit lower average prepayment transaction costs, which means that a given decline in interest rates will generate more terminations in a REMIC pool than a non-REMIC pool. We also note that the variance of the transaction cost distribution is slightly lower for REMIC pools than non-REMIC pools. The variance of the REMIC distribution is estimated to be 1.1%, while the variance of the non-REMIC distribution is estimated to be 1.3%.

4. Pricing Results and Economic Importance

Finally, it remains to estimate the economic implications of the differences in termination behavior that we have identified. As noted earlier, PCs trade in broker markets, so pool-specific market prices are not available. For this reason, we cannot simply examine the relative prices of REMIC and non-REMIC pools to assess the lemons discount that the market applies to premium REMIC pools. However, we can use our structural model to compare the estimated prices of otherwise identical pools as a rough way of detecting a lemons discount.[32]

---

[32] As discussed in Downing, Stanton, and Wallace (2005), the structural model exhibits pricing errors on the order of a few percentage points when used to predict TBA prices. Because we are differencing prices across the REMIC and non-REMIC pools, we can expect these pricing errors to cancel out, at least to the extent that the models exhibit similar pricing errors for REMIC and non-REMIC pools.

Under our model, for both non-REMIC and REMIC pools we hold the term of the underlying mortgages fixed at thirty years, the initial average loan-to-value ratio at 80%, and the coefficients of the hazard function and transaction cost distribution at their values given in Table 11. The only remaining variables that are inputs to the model are the coupon rate and the ten-year Treasury rate. Hence, we next match REMIC and non-REMIC pools issued with the same coupon rate and under the identical prevailing ten-year Treasury rate.[33] There are 1209 such unique combinations of coupon and Treasury rate levels observed over our period of study.[34] At each of these points, we subtracted the fitted REMIC new-issue price from the fitted non-REMIC new-issue price: we call this difference the lemons discount applied to the REMIC MBS. In the matched sample, the average lemons discount is $0.39 per $100 of principal, and ranges from $0.27 to $0.55, depending on the coupon level and ten-year Treasury rate settings.

To further evaluate the relative economic importance of these results, we use our structural model and the largest coupon groups in the full sample of Freddie Mac PCs to determine the relative importance of the REMIC status on the overall prepayment risk of the pools. We first apply our structural model to value hypothetical PCs for four coupon groups that have no embedded termination options by construction. As shown in Table 12, in our yield curve environment the value of these hypothetical PCs per $100 of face value is between $114.68 for 9.5% coupon PCs and $109.09 for 6.5% PCs. We then apply our structural model to value all the observed REMIC and non-REMIC PCs in the sample that have these coupons. In the second and third columns of the upper panel of Table 12, we report average model-based estimated pool values for each of the four coupon groups. As shown, the REMIC PCs have consistently lower values, although for the 6.5% and 7.5% coupon groups the value differentials are relatively small. To obtain an estimate of the payout life of the pools, we compute the average observed time in months when at least 97.5% of the total initial principal is paid off. These average lives are reported in parentheses for each coupon group. We find that in our sample period, where interest rates were primarily falling, the REMIC pools consistently paid off their principal more rapidly than the non-REMIC pools.

We compute yields for the hypothetical PC pools without embedded options, given our model-based valuations and assuming that such pools have a life of 360 months. We similarly compute the yields for the REMIC and non-REMIC pools using the model-based valuations and the observed lives of these pools. For each coupon group, we compute a measure of the total termination spread

---

[33] Alternatively, one could hold the prices of the two securities at par and estimate the par-coupon rates at a fixed ten-year Treasury rate. The two approaches are equivalent.

[34] Note that under this approach the non-REMIC and REMIC pools could be from different vintages. However, from the perspective of our model, this is irrelevant. All that matters for purposes of computing fitted prices are the coupon rate and initial risk-free rate, both of which we are holding fixed, along with all of the other inputs to the model.

Table 12
Lemon's component of the prepayment spread found in Freddie Mac REMIC pools

Coupon groups	Estimated value PCs with no. embedded options ($/100)	Estimated value REMIC PCs with options ($/100) (Aver. life months)	Estimated value non-REMIC PCs with options ($/100) (Aver. life months)	
6.5%	109.09	106.10	106.34	
		(56)	(63)	
7.5%	111.60	107.27	107.60	
		(67)	(73)	
8.5%	113.67	108.07	107.69	
		(71)	(87)	
9.5%	114.68	108.12	109.42	
		(65)	(89)	
	Estimated total termination spread (Basis points)	Estimated lemon spread (Basis points)	Estimated credit spread (Basis points)	Lemon share of prepayment spread (%)
6.5%	56.92	6.30	11.0	13.72
7.5%	40.98	4.32	11.0	14.41
8.5%	24.21	5.93	11.0	44.86
9.5%	24.09	5.11	11.0	39.02
Average	36.55	5.41		28.01

The table presents an evaluation of the relative importance of the lemon's component of the prepayment spread found in Freddie Mac pools. To estimate this yield, we first estimate the value of hypothetical Freddie Mac pools, for each coupon group, without any embedded options using our structural model (reported in column 1 of the upper panel). In columns 2 and 3 of the upper panel, we report our structural model valuations for the REMIC and non-REMIC pools in our sample for the four coupon groups. These estimates are all reported in dollars per $100 of face value. In the parentheses in the upper panel of the table, we report the average observed number of months until the pools have paid off 97.5% of their initial principal. The bottom panel of the table computes yield spreads based on the model-based valuations and the observed average lives of the pools. In column 1 of the lower panel, we report the average yield differential between the hypothetical Freddie Mac pool without embedded options and the average yield for the sample Freddie Mac pools within each coupon group. In column 2 of the lower panel, we report the estimated lemon's spread as the difference between the sample of REMIC and non-REMIC estimated yields. In column 3 of the lower panel, we provide estimates of the embedded credit spreads in Freddie Mac pools using calculations explained in footnote 36. In column 4 of the lower panel, we report the lemon spread as a percentage of the total termination spread (prepayment, credit, and background terminations) minus the estimated credit spread. This percentage represents an estimate of the lemon's component of the prepayment spread found in Freddie Mac pools.

as the difference between the yield on a hypothetical PC without exposure to the embedded prepayment, background, and default options and the estimated yields of the observed sample PCs that include the embedded options. As shown in the first column in the bottom panel of Table 12, these spreads range between 57 basis points for the 6.5% coupon group and 24 basis points for the 9.5% coupon group. In the second column of the bottom panel of Table 12, we report the difference between the average yields of the REMIC and non-REMIC pools within each coupon group and we call this difference the "Lemon Spread." The lemon spreads for the 8.5% and 9.5% coupon groups are 5.9 and 5.1 basis points, respectively, while the spreads for the 6.5% and 7.5% are 6.3 and 4.3 basis points, respectively. We consider the 5.9 and 5.1 basis point estimates of the two higher coupon groups to be more reliable.[35]

---

[35] The computed average lives for 6.5% and 7.5% coupon groups likely exhibit truncation bias. Since these pools were more likely to be originated closer to the end of our sample period, we are unable to fully track them over

For the default option, an estimate of 11 basis points is very conservative.[36] We subtract the 11 basis point credit spread from the total termination spread and consider the remainder as the net prepayment risk. The ratio of the lemon spread to the net prepayment risk is reported in the last column of the bottom panel of Table 12. As shown, the cherry–lemon differential represents on average about 28% of the total value of the prepayment option, and as much as about 45% of this value for the 8.5% coupon group. Obviously, this is an economically significant difference for traders.

In terms of yield-to-maturity, these results indicate differences of roughly 4–6 basis points between the REMIC and non-REMIC pools. We view these estimates as lower bounds because our model can only capture long-term average differences in termination rates between the pools—it is an equilibrium model. Moreover, the data that we have available to distinguish the two types of MBS are limited relative to those available to many market participants. Market participants have access to detailed information on each MBS pool, including recent prepayment behavior, likely allowing them to identify greater differences in value between the two types of MBS. The 4–6 basis point differences, furthermore, appear significant relative to the yield adjustments associated with other MBS risks as illustrated in Table 12.

In addition to our quantitative results, two further factors underscore the economic importance of the differences between REMIC and non-REMIC pools. The first factor is the enormous size of the MBS markets. At year-end 2006, the total volume of all outstanding MBSs is estimated to be $5.7 trillion. Assuming for simplicity that half are lemons and half are cherries, the pricing differential of $0.39 per $100 par value creates an aggregate dollar difference of $11.1 billion. This equals about 40% of the recent annual budgets for the U.S. Department of Housing and Urban Development. It is also worth noting that these calculations are for the existing stock of mortgages, and do not take into account the present value of the differences in the value of REMIC and non-REMIC pools yet to be issued.[37]

---

comparable time intervals. The 8.5% and 9.5% coupon groups do not exhibit this bias and we view them as generating more reliable estimates of the relative differentials between the REMIC and non-REMIC pools.

[36] Over the period of our sample, Freddie Mac's credit losses as a percentage of its portfolio averaged 6 basis points, but overall this was a benign period for mortgage defaults, so it is likely that the expected default rate for the period exceeded the observed 6 point average. In fact, over the same period, Freddie Mac charged an annual fee of 23 basis points for guaranteeing the mortgages underlying its PCs against default. While 6 basis points would seem a low estimate of the expected default rate, 23 basis points is too high, because it embeds the duopoly power that Freddie Mac and Fannie Mae maintain in insuring mortgages (see Hermalin and Jaffee 1994). In particular, the Basel I bank capital requirements impose a 50% risk weighting on whole mortgages, but only a 20% risk weighting on Agency MBS. We estimate that a bank will save approximately 12 basis points in its annual cost of capital simply by converting a pool of mortgages into an Agency MBS. If we make the conservative assumption that Freddie Mac and Fannie Mae extract this full 12 basis points as profits, this leaves 11 basis points of the total guarantee fee of 23 basis points that can be attributed to expected default.

[37] Further analysis is required to link the 4–6 basis point higher yield required on lemon MBS (that is, those where the prepayment option is expected to be exercised efficiently) with the real welfare gain achieved by resolving the asymmetric information problem. Since we assume competitive lenders, we would expect the lenders to pass on the higher prepayment costs created by efficient mortgage borrowers by charging these borrowers higher

In summary, these pricing and yield results appear to confirm the efficiency of the U.S. mortgage markets with respect to prepayment risk by showing that discount pricing is applied to those MBS pools where the borrowers can be expected to be effective in exercising their prepayment options. Hence, they confirm the main hypothesis of this paper, that if REMIC pool terminations are carried out more efficiently, then the termination option is more valuable, and investors will set lower prices for REMIC securities.

5. Conclusions

In this paper, we characterized the current structure of the securitized market for residential MBSs using a model of asymmetric information between originators and investors, and generated the empirical prediction that securitized mortgage assets ought to be of lower quality than assets that are not securitized. We tested this prediction on a comprehensive data set of MBSs (Freddie Mac PCs) issued over the period 1991 through 2002. We found that securitized PCs are lemons relative to PCs that are not securitized for issuance as multiclass securities. In the context of the theory, the REMIC structure serves as a signal facilitating a market equilibrium with separate prices for PCs resecuritized into REMICs and those not resecuritized.

We also implemented a structural valuation model to quantify the pricing implications of our findings, since market prices on MBSs are not available. Under the model, REMIC and non-REMIC PCs have statistically significant differences in the underlying transactions costs faced by borrowers. Since transactions costs are an important potential source of private information held by mortgage originators, these results offered further support for the theoretical prediction that informed originators will trade lemons in the mortgage market. The structural model also allowed us to test whether the relative efficiencies of the option exercise characteristics of REMIC and non-REMIC pools led to important pricing differentials. The results of our pricing exercise suggested that the prices of resecuritized PCs are on average \$0.39 lower per \$100 of face value than PCs not destined for resecuritization. Using the full sample of Freddie Mac PCs, we found a lemon spread of about 4–6 basis points in terms of yield-to-maturity and this spread accounted for about 13–45% of the overall prepayment risk of these securities. Given the size and importance of PC and REMIC markets, these differences are clearly economically significant.

The security design literature contains a variety of theoretical motivations for asset-backed securitization, including transaction cost savings relative to direct asset sales, market incompleteness, and asymmetric information. Our results provide empirical support for the notion that, among these explanations,

---

coupons. The size of the welfare effect then depends on the elasticity of mortgage demand by these borrowers, an analysis which is beyond the scope of this paper.

asymmetric information has a predictable and economically important impact on the operation of the market for MBSs.

Appendix: Structural Model Details

Interest rates

Following Downing, Stanton, and Wallace (2005), we assume interest rates, r_t, are governed by the Cox, Ingersoll, and Ross (1985) model,

$$dr_t = (\kappa(\theta_r - r_t) - \eta r_t)dt + \phi_r \sqrt{r_t} dW_{r,t}, \tag{A1}$$

where κ is the rate of reversion to the long-term mean of θ_r, η is the price of interest rate risk, and ϕ_r is the proportional volatility in interest rates. The process $W_{r,t}$ is a standard Wiener process.

The following parameters for the model are estimated in Downing, Stanton, and Wallace (2005):

$$\begin{aligned} \kappa &= 0.13131, \\ \theta_r &= 0.05740, \\ \phi_r &= 0.06035, \\ \eta &= -0.07577. \end{aligned}$$

House prices

The house price, H_t, is assumed to evolve according to a geometric Brownian motion,

$$dH_t = \theta_H H_t dt + \phi_H H_t dW_{H,t}, \tag{A2}$$

where θ_H is the expected appreciation in house prices, and ϕ_H is the volatility of house prices. Denoting the flow of rents accruing to the homeowner by q_H, after risk adjustment house prices evolve according to

$$dH_t = (r_t - q_H)H_t dt + \phi_H H_t dW_{H,t}. \tag{A3}$$

We calibrate Equation A3 as follows:

$$\begin{aligned} q_H &= 0.025, \\ \phi_H &= 0.085. \end{aligned}$$

The value of q_H is roughly consistent with estimates of owner-equivalent rents from the BEA, and we estimate the annualized volatility of housing returns from our data on house prices, discussed below. For simplicity, we assume that house prices and interest rates are uncorrelated.

Noting that the values of the mortgages in subpool j are identical under our model, for purposes of valuation we can simply think of the subpool as a single mortgage, where the face value, $F(t)$, of this mortgage is equal to the sum of the face values of the individual mortgages in the subpool. The value of the subpool will be homogeneous in the face value. In other words, we can solve for the price of the pool assuming that it has \$1 of face value, and then multiply this price by the actual face value at origination to find the value of the subpool. Keeping these points in mind, standard arguments show that, in the absence of arbitrage, the value of the subpool $M_j^l(H_t, r_t, t)$ with coupon payments c must satisfy the partial differential equation

$$\frac{1}{2}\phi_r^2 r M_{rr}^l + \frac{1}{2}\phi_H^2 H^2 M_{HH}^l + (\kappa(\theta_r - r) - \eta r) M_r^l + ((r - q_H)H) M_H^l + M_t^l - r M^l$$
$$+ (\lambda_c + \lambda_p)(F(1 + X_p) - M^l) + \lambda_d(H(1 + X_d) - M^l) + c = 0, \tag{A4}$$

where λ_c, λ_p, and λ_d are the state- and time-dependent hazards for seasoning, prepayment, and default.[38]

We also need to impose boundary conditions. The first three of these are

$$M^l(H, r, T) = 0, \tag{A5}$$

$$\lim_{r \to \infty} M^l(H, r, t) = 0, \tag{A6}$$

$$\lim_{H \to \infty} M^l(H, r, t) = C(r, t), \tag{A7}$$

where $C(r, t)$ is the value of a callable bond with the same promised cash flows and same prepayment costs as the mortgages in the subpool, but with no house price dependence.[39] Equation A5 is the terminal condition, reflecting the amortization of the mortgage. Equation A6 arises because all future payments are worthless when interest rates approach infinity, and Equation A7 says that when the house prices rise to very high levels, default no longer occurs, so we only have to consider prepayment.

We need additional boundary conditions specifying the free boundary governing optimal default and prepayment. Prepayment is optimal when interest rates go below some (house-price-dependent) critical level, $r^*(H, t)$, and default is optimal when the house price drops below some (interest-rate-dependent) critical level, $H^*(r, t)$. At these boundaries, the mortgage values satisfy the conditions

$$M^l(H, r^*(H, t), t) = F(t)(1 + X_p), \tag{A8}$$

$$M^l(H^*(r, t), r, t) = H^*(r, t)(1 + X_d). \tag{A9}$$

Equation A8 states that, on the optimal prepayment boundary, the mortgage value is just equal to the remaining balance multiplied by 1 plus the appropriate transaction cost. Equation A9 states that, on the default boundary, the mortgage is just equal to the value of the house multiplied by 1 plus the default transaction cost.[40]

Solving Equation A4 subject to these boundary conditions gives us the value of the subpool j borrowers' liabilities, as well as the locations of the optimal default and prepayment boundaries, which in turn determine the values of the prepayment and default hazard rates, λ_p and λ_d. As noted earlier, we solve this problem for each transaction cost level j. The value of the overall mortgage pool is found by adding together the values at each j. Finally, we solve for the value of the lender's asset, M^a, simultaneously under the assumption that $X_d = X_p = 0$, that is, we assume that the investor captures none of the transaction costs—the costs are deadweight losses to both the borrower and the lender. However, it is important to point out that the borrower and lender problems are linked in that the cash flows to the lender depend upon the option exercise decisions of the borrower.

References

Allen, F., and D. Gale. 1988. Optimal Security Design. *The Review of Financial Studies* 1:229–63.

Axelson, U. 2007. Security Design with Investor Private Information. *Journal of Finance* 61:2587–632.

---

[38] Note that in Equation A4 we have dropped the subscripts j for notational clarity; in what follows, we will continue to omit the subscripts j. We have also dropped the arguments to the state variables in an effort to lessen the notational burden.

[39] This value is calculated following the process described in Stanton (1995).

[40] There are two additional "smooth-pasting" boundary conditions (see Merton 1973) that ensure the optimality of the boundaries $r^*(H)$ and $H^*(r)$. Our solution algorithm follows Downing, Stanton, and Wallace (2005).

Bartlett, W. 1989. *Mortgage-Backed Securities: Products, Analysis, Trading.* Englewood Cliffs, NJ: Prentice Hall.

Bernardo, A. E., and B. Cornell. 1997. The Valuation of Complex Derivatives by Major Investment Firms: Empirical Evidence. *The Journal of Finance* 52:785–98.

Cho, I. K., and D. Kreps. 1987. Signalling Games and Stable Equilibria. *The Quarterly Journal of Economics* 102:179–222.

Cox, J. C., J. E. Ingersoll, and S. A. Ross. 1985. A Theory of the Term Structure of Interest Rates. *Econometrica* 53:386–407.

Cox, D. R., and D. Oakes. 1984. *Analysis of Survival Data.* New York: Chapman and Hall.

DeMarzo, P. 2005. The Pooling and Tranching of Securities. *Review of Financial Studies* 18:1–35.

DeMarzo, P., and D. Duffie. 1995. Corporate Incentives for Hedging and Hedge Accounting. *Review of Financial Studies* 8:743–71.

DeMarzo, P., and D. Duffie. 1999. A Liquidity Based Model of Security Design. *Econometrica* 67:65–99.

Diamond, D. W. 1984. Financial Intermediation and Delegated Monitoring. *Review of Economic Studies* 51:393–414.

Downing, C., R. Stanton, and N. Wallace. 2005. An Empirical Test of a Two-Factor Mortgage Valuation Model: How Much Do House Prices Matter? *Real Estate Economics* 33:48–60.

Glaeser, E., and H. Kallal. 1997. Thin Markets, Asymmetric Information and Mortgage Backed Securities. *Journal of Financial Intermediation* 6:64–86.

Hermalin, B., and D. Jaffee. 1994. The Privatization of Fannie Mae and Freddie Mac: Implications for Mortgage Industry Structure. Working Paper, Fisher Center for Real Estate and Urban Economics, the University of California, Berkeley.

Huber, P. J. 1967. The Behavior of Maximum Likelihood Estimates under Nonstandard Conditions. *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability* 1:221–23. Berkeley, CA: University of California Press.

Humphreys, T., and R. M. Kreistman. 1995. *Mortgage-Backed Securities Including REMICS and Other Investment Vehicles.* New York: Little, Brown.

Kalbfleisch, J. D., and R. L. Prentice. 1980. *The Statistical Analysis of Failure Time Data.* New York: John Wiley.

Kau, J. B., D. C. Keenan, W. J. Muller, III, and J. F. Epperson. 1995. The Valuation at Origination of Fixed Rate Mortgages with Default and Prepayment. *Journal of Real Estate Finance and Economics.* 11:5–39.

Kramer, A. 2003. *Financial Products: Taxation, Regulation and Design.* New York: Aspen Publishers.

Leland, H. E., and D. H. Pyle. 1977. Informational Asymmetries, Financial Structure, and Financial Intermediation. *Journal of Finance* 32:371–87.

Merton, R. C. 1973. Theory of Rational Option Pricing. *Bell Journal of Economics and Management Science* 4:141–83.

Myers, S., and N. Majluf. 1984. Corporate Financing and Investment When Firms Have Information Shareholders Do Not Have. *Journal of Financial Economics* 13:187–221.

Oldfield, G. 2000. Making Markets for Structured Mortgage Derivatives *Journal of Financial Economics* 57:445–71.

Plantin, G. 2004. Tranching. Working Paper, Carnegie Mellon University.

Richard, S. F., and R. Roll. 1989. Prepayments on Fixed Rate Mortgage-Backed Securities. *Journal of Portfolio Management* 15:73–82.

Riddiough, T. 1997. Optimal Design and Governance of Asset-Backed Securities. *Journal of Financial Intermediation* 6:121–52.

Schwartz, E. S., and W. N. Torous. 1989. Prepayment and the Valuation of Mortgage-Backed Securities. *Journal of Finance* 44:375–92.

Stanton, R. 1995. Rational Prepayment and the Value of Mortgage-Backed Securities. *The Review of Financial Studies* 8:677–708.

Stanton, R., and N. Wallace. 1998. Mortgage Choice: What's the point? *Real Estate Economics* 26:173–205.

White, H. 1980. A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. *Econometrica* 48:817–30.