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Asset Indivisibility, Security Design and Asset Quality

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May 9, 2006

Abstract

This paper models and provides empirical evidence for the quality of assets that informed intermediaries sell to bankruptcy remote special purpose vehicles (SPVs) issuing tranched securities to finance the purchase of the assets. The model predicts that indivisible assets sold to SPVs will be of lower quality ("lemons") compared to assets that are not sold to SPVs. We find strong support for the model's 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. Furthermore, valuation estimates based on a two-factor structural model indicate that participation certificates sold to SPVs are, on average, valued at least $0.39 lower per $100 of face value relative to PCs not sold to SPVs (about 3-5 basis points in terms of yield-to-maturity). Given the size of these markets, these differences are clearly economically significant.

Keywords: Security design, financial innovation, capital structure, asymmetric information, mortgage-backed securities
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1 Introduction

Agents known to possess private information regarding the true value of their assets may confront problems of market breakdown or undervaluation when they attempt to sell the assets as in the classic "market for lemons" first analyzed by Akerloff (1970). One solution to these problems proposed in the signalling literature is to design a security representing a fractional claim on the underlying asset where the informed agent's retention of a residual interest in the asset serves as a credible but costly signal of its true quality (see Leland and Pyle (1977); Nachman and Noe (1994); Myers and Majluf (1984); DeMarzo and Duffie (1999); and DeMarzo (2005)). In these models, buyers rationally anticipate that the sale of a larger share of the asset is a signal of lower quality and hence the market-clearing price of the asset is lower than when a relatively smaller share is sold.

For a seller to retain a share of an asset, the asset must be divisible. However, asset divisibility is at odds with legal restrictions on securitized assets requiring that asset sales to special purpose vehicles (SPVs) be "bankruptcy remote" from the asset sellers.[1] Bankruptcy remoteness is achieved by requiring asset sales to be "true sales" in the sense that a bankruptcy judge cannot re-consolidate the securitized assets with the other assets of a seller in bankruptcy (see Klee and Butler (2002), Gorton and Souleles (2003)).[2] Since bankruptcy remoteness prohibits all future claims back to the asset sellers, securitized asset sales must be indivisible. In the theoretical signalling literature, this restriction amounts to a focus on corner-solution equilibria where assets are either sold or held, rather than the more typical focus on equilibria involving interior solutions with fractional sales (see Allen and Gale (1988); Leland and Pyle (1977); Nachman and Noe (1994); Myers and Majluf (1984); DeMarzo and Duffie (1999); and DeMarzo (2005) among many others).

In this paper, we focus on the predictions of the signalling model of DeMarzo and Duffie (1999) and DeMarzo (2005) for the case of indivisible asset sales to special purpose vehicles

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[1] Special purpose vehicles are legal entities that exist for the sole purpose of purchasing a discrete set of assets and issuing securities backed by this asset pool. The entities that we consider in this paper hold "static" portfolios of assets in which an asset is only removed from the portfolio upon default. Some SPVs, mainly those that securitize short-term assets such as trade and term receivables, are constructed such that the asset seller retains a residual interest in the assets. Our framework does not necessarily apply to such SPVs.

[2] True sale status is also required for securitized assets to enjoy off-balance sheet accounting and tax status (see Humphreys and Kreistman (1995) and Kramer (2003)). The Financial Accounting Standard No. 140 (FAS 140) "Accounting for Transfers and Servicing of Financial Assets and Extinguishment of Liabilities," September 2000, stipulates that: 1) a special purpose vehicle be qualifying in the sense that the vehicle is: a) "demonstrably distinct" from the sponsor; b) significantly limited in its permitted activities; c) holds only "passive" receivables; d) has the right to sell or otherwise dispose of non-cash receivables only in "automatic response" to the occurrence of certain events; 2) the sponsor must completely surrender control of the receivables.

that subsequently issue tranched securities to finance the purchase of the assets. This simple extension, carried out in the context of the home mortgage securitization market, produces the prediction that the assets sold to special purpose vehicles are of lower quality ("lemons") relative to assets not sold to SPVs.

We test this prediction using a comprehensive data set of sales of mortgage-backed securities (Freddie Mac Gold Participation Certificates, or PCs) to SPVs over the period 1991 through 2002. We compare the performance of PCs sold to special purpose vehicles relative to the performance of PCs that are not so sold. Our main empirical result is that, after controlling for all publicly-available information about these pools, in rising (falling) interest-rate environments, PCs sold to SPVs return principal at a significantly slower (faster) rate, on average, than pools that are not sold to SPVs. Since the rate at which principal is expected to be returned is a key determinant of the value of a mortgage-backed security, these results indicate that PCs sold to SPVs ought to have lower market values than PCs held outside of SPVs. In other words, re-securitized PCs are lemons relative to PCs that are not re-securitized.

We test the pricing implications of this result using an extension of a structural two-factor valuation model developed by Downing, Stanton and Wallace (2005). In this model, we estimate the coefficients of the relative background hazard rates, the relative time dependent seasoning components of prepayment and default exercise, and the relative distributions of transactions costs for PCs that are held by SPVs and for those not so held. We again find strong support for the prediction that PCs sold to SPVs exhibit systematically different termination behavior than PCs not sold to SPVs. The parameter differentials found for the structural model translate into pricing differentials for PCs sold to SPVs that are, on average, at least \$0.39 lower per \$100 of face value than PCs not sold to SPVs, or about 3-5 basis points in terms of yield-to-maturity. Given the scale of these markets, these differences are clearly economically significant.[3]

To our knowledge, this is the first paper to document that at least one important class of securitized assets, PC collateral sold to Real Estate Mortgage Investment Conduits (REMICs), is of significantly lower quality than PCs that are not sold to these SPVs. By re-focusing the DeMarzo and Duffie (1999) and DeMarzo (2005) modelling framework to study sales of indivisible asset sales, we provide a clear theoretical explanation for why assets sold to SPVs should be lemons. Importantly, the institutional structure of the PC market precludes *ex ante* revelation of pool-specific information known to mortgage originators, since PCs largely trade through an anonymous forward contracting, or to-be-announced (TBA)

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[3] In 2004, originations of home mortgages in the United States totaled \$3.075 trillion, of which \$2.143 trillion, or 69.6%, were repackaged as MBS (*Inside MBS & ABS*, January 20, 2006).

market. Hence we interpret our finding of statistically and economically significant *ex post* performance differentials between PCs sold to SPVs and those not sold to SPVs as evidence that these financial entities exist as a market response to the problem of providing liquidity for assets of low quality.

This paper is organized as follows. In the next section, we extend the signalling model of DeMarzo and Duffie (1999) and DeMarzo (2005) to consider indivisible asset sales and consider an application of the model to the securitized residential mortgage backed security market. Section 3 lays out our strategy for identifying PCs that are lemons and presents our empirical results, and section 4 presents our pricing results. Section 5 concludes.

2 Asset Securitization with Asymmetric Information

Most theoretical considerations of the role of asset securitization are based on theories of security design under asymmetric information. Several recent papers have focused on firms that possess private information about the value of their assets and seek to raise external capital to finance an investment opportunity (see Riddiough (1997); DeMarzo (2005); and DeMarzo and Duffie (1999)). Building upon the findings of Myers and Majluf (1984), these papers find that the security design problem involves a tradeoff between the retention cost of holding cash flows not included in the security design and the liquidity cost of including the cash flows and making the security design more sensitive to the firm's private information.

DeMarzo (2005) and Riddiough (1997) have considered the consequences of issuing securities backed by the pooled assets of an informed seller who seeks to raise external capital. The Demarzo model is derived from the signaling models of Demarzo and Duffie (1995) and Leland and Pyle (1977) in which informed sellers signal a high quality security by retaining a portion of the issue. In these models, rational inference on the part of investors leads to an equilibrium demand function that is strictly downward sloping. The Riddiough (1997) model focuses less on the signalling component of the equilibrium, although he does argue that his results provide support for the financing "pecking order" found in Myers and Majluf (1984), and more on the importance of interactions between security governance and security design.

The DeMarzo (2005) model represents a significant extension of the signalling literature for the study of asset backed securities because he considers the differential consequences of simply pooling versus the practice of pooling and then structuring derivative tranches from the pools. He shows that pooling assets prior to sale is not advantageous to an informed issuer because pooling destroys the option value of selling each asset individually and thus reduces the issuer's payoff. If assets are not too correlated, he finds there is a risk diversification benefit of pooling. The pooled assets can then be tranched to create a low-risk debt-security that is less sensitive to the issuer's private information and thus is more liquid. He also shows that as the size of the pool grows large, the risk diversification effect dominates the information destruction effect, so that pooling and tranching is optimal for an informed issuer.

Glaeser and Kallal (1997) implement an alternative modelling strategy and consider asset-backed security issuers' incentives to disclose information. They find that asset pooling has an ambiguous effect on an issuer's incentives to inform investors and thus on the liquidity of the pooled assets. Their modelling framework, however, does not preclude a view of the mortgage-pool forward contracting market as a market for the "worst" mortgages. Since forward contract markets allow agents who sell obligations to provide any bundle, the only bundles such agents are likely to deliver are the worst bundles. These forward contracts will be highly liquid, because there will only be one value reflecting the market valuation of the worst quality.

In a departure from the prior literature, Axelson (2005) assumes that investors have private information about the prospects of the issuer. He shows that as the number of assets grows large, auction revenues can be improved by pooling assets prior to sales due to the reduction in the adverse selection problem. Plantin (2004) extends the literature on the design of a single security under private information to consider a setting in which informed sellers and competition among heterogeneously informed buyers that differ in both their abilities to screen the collateral and to redistribute the securities will lead to tranching as the optimal security structure for multiple asset sales. Segmenting the securities by risk exposure is optimal because it reduces adverse selection on senior tranches and spurs information collection on junior tranches.

Since pooling and tranching is a major security design in the residential mortgage backed security market, the basic framework for our signalling model of asset sales to SPVs follows DeMarzo (2005). Mortgage securitization will be treated as a sequence of separate one-period decision problems. Each one-period problem shares the basic assumption that at the end of the period the payoff (market value plus accrued coupon) of the i^{th} mortgage asset, M_i^a, is given by $M_i^a = W_i + Z_i$ where W_i represents the private information of the mortgage originator, and Z_i represents idiosyncratic risk such that $E[Z_i|W_i] = 0$. Denote by W_{-i} the information on the set of mortgages other than mortgage i in the originator's portfolio. Following DeMarzo (2005), we assume that:

1. Given any W_{-i}, the conditional support of W_i is a closed interval;
2. Given any W_{-i}, the conditional support of W_i has greatest lower bound $w_{i0} > 0$.

The first assumption says that asset i remains risky regardless of information released on assets other than i; the second assumption sets w_{i0} as the worst-case outcome on W_i and allows this outcome to be independent of W_{-i}.

The signalling models of Leland and Pyle (1977), DeMarzo and Duffie (1999), and DeMarzo (2005) all assume that assets are perfectly divisible, so that owning a fraction $q \in [0,1]$ of a mortgage i entitles the owner to a final cash flow qM_i^a. DeMarzo and Duffie (1999) and DeMarzo (2005) motivate trade by assuming that the originator is risk neutral and faces a discount rate δ that exceeds the market rate, $1 > 1/(1+r) > \delta$, and hence prefers to liquidate mortgage assets for cash.[4] Following DeMarzo (2005), if the mortgage assets are perfectly divisible then the payoff to the informed originator is given by:

$$E\left[\delta(1-q)M_i^a + qp|W_i\right] = \delta W_i + q\left(p - \delta W_i\right), \tag{1}$$

where p is the market-clearing price for sold/securitized mortgages. The total payoff for any fraction q sold is the value of the unsold fraction $(1-q)$ of the mortgage and its associated coupon payment plus any cash raised by the sale. If the originator anticipates a demand schedule given by $P(q)$ and if $W_i = w$, then DeMarzo (2005) shows that the mortgage originator will choose a quantity to sell such that:[5]

$$\prod(w) = \max_{q \in [0,1]} q\left(P(q) - \delta w\right). \tag{2}$$

It can be shown that an originator's profit is decreasing and convex in w (DeMarzo (2005), Lemma 1, p. 8) and that a unique separating equilibrium exits where the equilibrium price is, $P^*(q) = w_{i0}q^{\delta-1}$, as long as the worst case outcome is positive, $w_{i0} > 0$ (DeMarzo (2005), Lemma 2, p. 8).[6] Since the worst case is not affected by W_{-i}, this equilibrium depends only on the worst-case outcome for each mortgage.

Now consider the situation where the initial decision to sell a mortgage must meet the

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[4] In contrast, Leland and Pyle (1977) assume risk sharing motivates trade. DeMarzo (2005) shows that the Leland and Pyle (1977) motivation leads to the same profit maximizing strategies on the part of informed sellers.

[5] $P(q)$ is downward sloping following DeMarzo and Duffie (1999) and Leland and Pyle (1977) because investors know whatever the expectations of the issuer regarding demand that the optimal liquidation decision by the issuer implies a higher quantity sold when the expected outcome on the asset is poor. Rational inference on the part of investors thus leads to an equilibrium demand function that is downward sloping.

[6] The DeMarzo and Duffie (1999) and DeMarzo (2005) models formally assume that the issuer is a monopolist, however, the facts of the mortgage backed security market indicate there are a substantial number of competitive issuers. Clearly, the market price would have to be determined differently in a competitive setting, but we are not using the pricing implications in our application of these models. We believe that the process in these models by which issuers determine the quality to be sold, which we do rely on, could be extended to a competitive setting. For example, if investors can still identify the quality decision made by each issuer, which seems institutionally reasonable, then the model would still hold.

institutional requirement that asset sales to SPVs must be indivisible. In this case, the decision to sell is over $q = 0$ or $q = 1$; that is, the mortgage must be sold as a whole loan or held. For $q = 1$, we see that $P^* = w_{i0}$; hence if $w_{i0} > 0$, originators will only sell mortgages of the lowest qualities and market prices will reflect the worst-case outcomes for mortgage cash flows. Put another way, asset indivisibility leaves only the 0-1 signal of quality and hence the market equilibrium returns to the Akerloff (1970) result that only the lowest-quality assets are traded to SPVs.

2.1 Residential Mortgage Securitization

As one of the largest bond markets in the U.S., the mortgage-backed security market is interesting in its own right. As shown in Figure 1, as of the third quarter of 2005, MBS accounted of 12.3% of the total holdings of U.S. capital assets and other types of asset backed securities (ABS) accounted for 9.3% of the total. Over the last ten years, the annual growth rate for the aggregate securitized asset market share has been 3.5%. For some asset types, such as residential single family mortgages, the securitized asset sector is now a primary funding source.[7]

From the broader perspective of security design theory, the MBS market is of interest because it exhibits significant *ex ante* information asymmetries among its participants concerning the likely payment behavior of the mortgages in different MBS pools. Mortgage originators have detailed information on mortgage borrowers which they use to select which mortgages to securitize and which to hold as whole loans in their portfolios. Moreover, the MBS market is dominated by two government sponsored enterprises (GSEs), Fannie Mae and Freddie Mac. These GSEs have chosen not to release all of the information available to them regarding the mortgages backing MBS.[8]

In addition, the payment behavior of each MBS pool is revealed *ex post* in terms of its rate of total terminations (sum of prepayments and defaults). The availability of these data is critical to our subsequent empirical tests. Expected termination rates are a key determinant of *ex ante* MBS prices because the expected termination patterns drive the expected cash flows to MBS holders. Finally, the MBS market is of interest in that a substantial share of MBS are re-packaged into multi-class securities, providing a unique opportunity to compare

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[7] By the last quarter of 2005, approximately 67.2% of all new residential mortgages were securitized *See Inside MBS & ABS, November 25, 2005.*

[8] The issue of asymmetric information in the MBS market is studied in United States Department of the Treasury (2003), a staff report of the Task Force on Mortgage-Backed Securities Disclosure. Following the release of this report, both GSEs “voluntarily” expanded the range of information they release on newly issued MBS, although potentially important information is still not released. In a November, 2005, press release Freddie Mac indicated that they intend to release significant loan level data in the future.

the performance of MBS residing in re-packaged pools and those that are not re-packaged.

The transformation of residential mortgages into single-class mortgage backed securities and subsequently into multi-class tranched securities occurs in four stages. Once the mortgages are originated, the process of securitization requires, on average, about three months to complete. For the most part it is the mortgage originators who act first. The four stages of possible actions are:

1. *Mortgage origination.* Mortgage originators devise a mortgage menu and screen for the credit worthiness and prepayment efficiency of borrowers.

2. *Credit risk securitization.* Current regulatory capital requirements provide incentives for the mortgage originators to prefer mortgage backed securities with GSE default risk guarantees to whole mortgages, because they have lower risk based capital weights. Most commonly, mortgage originators securitize selected mortgages through the GSEs. The securitization of their own selected mortgages provides the originators with an equivalent face amount of mortgage backed securities representing an undivided interest in the mortgage pool. These mortgage backed securities are fully insured against credit risk by the GSEs.

   As noted above, the originator's unconstrained incentives would be to securitize only the lowest-quality mortgages through the GSEs programs.[9] The GSEs mitigate this asymmetric information problem by screening the individual mortgages using their proprietary automated screening models and by *ex post* monitoring of the default experience of each originator.[10] Diamond (1984) shows that monitoring costs can be minimized by bundling, or pooling assets. Because large numbers of originators securitize their residential mortgages, the GSEs reduce duplicative effort by undertaking monitoring of originator-specific pools and by taking advantage of scale economies through volume exchanges with originators.

3. *Pool Sales by Originators.* The mortgage originators sell off selected pools of mortgage backed securities. The highest trading volumes are in the to-be-announced (TBA) market, where pools are traded for forward delivery on a specified settlement day. Prices quoted in the TBA market are for contracts that specify only the type of MBS (*e.g.*, 30-year fixed rate Freddie Mac Gold PC), the weighted average coupon, and the

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[9] The benefit of securitization to the originator is the reduction in the risk-based capital weights for holding the same face amount of mortgage assets as mortgage backed securities. The cost is the premium for the guarantee that is deducted from the interest payments generated by the underlying mortgages that fund the mortgage backed securities.

[10] A more detailed discussion of how the GSEs use both automated origination software and reputation controls to deal with the originating banks is described by VanOrder (2000).

date of delivery. Pools to be assembled for future delivery do not have determinate pool-specific characteristics at the time of forward contracting, so it is not feasible to embed pool-specific characteristics into the prices of the forward contracts. Mortgage originators can also sell on the relatively thin pool-specific market—the stipulations (STIPs) market. In this market, pool specific information is available on the identity of the mortgage originator, and, more recently, borrower credit scores, the geographic composition of the pool, loan-to-value ratios, and pool termination histories.[11]

4. *Re-securitizing and tranching.* Traded pools of mortgage backed securities, either from TBA or less commonly STIPS, are re-securitized through Real Estate Mortgage Investment Conduits (REMICs). REMIC collateral is comprised of pools of pools and REMICs issue multi-class, tranched, securities in a senior subordinated structure.

The predominant collateral underlying Freddie Mac PCs over our analysis period are callable and defaultable fixed-rate home mortgages.[12] We denote by $B_i(t)$ the "underlying bond", that is, the market value of the remaining scheduled payments of the i^{th} mortgage at time t in the absence of any options. At any time after taking out the mortgage, the borrower may choose to stop making the remaining scheduled payments and, instead, pay off the remaining principal amount, $F_i(t)$, or default and payoff some fraction of the remaining principal. Thus, the value of the i^{th} mortgage liability at time t, $M_i^l(t)$, is the value of the underlying bond less the value of this embedded option:

$$M_i^l(t) = B_i(t) - J_i^l(t), \tag{3}$$

where $J_i^l(t)$ is the value of the joint termination option to the mortgage borrower.[13] The borrower's optimal exercise strategy is to maximize the value of his/her joint option position. Prepayment is optimal for the borrower if:

$$M_i^l(t) \geq F_i(t)(1 + X_{ip}), \tag{4}$$

where X_{ip} represents possible prepayment transactions costs that the borrower may face. For ease of exposition, we assume that these costs are proportional to the outstanding balance on the bond, $F_i(t)$.

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[11] Pool-specific information on credit scores and the loan-to-value distributions for the pools were not made available before June 2003

[12] Although many mortgage types are securitized, our focus is 30-year, fixed-rate mortgages—the loans backing more than 90% of Freddie Mac's Swap program guarantees.

[13] We have suppressed the arguments to these functions for simplicity

In the absence of transaction costs, the borrower will optimally default if the value of the mortgage is greater than or equal to the value of the house. However, like prepayment, default may incur significant direct and indirect costs. These costs represent another proportional transaction cost, X_{id}, payable by the borrower at the time of default. Default is optimal for the borrower if:

$$M_i^l(t) \geq H_i(t)(1 + X_{id}), \tag{5}$$

where $H_i(t)$ is the value of the house that is the collateral on the i^{th} mortgage at time t.

To the extent that borrowers maximize their joint option position, the value of their mortgage liability, $M_i^l(t)$, is minimized. The value of the mortgage asset, $M_i^a(t)$, is a function of $M_i^l(t)$ and depends on the mortgage holder's ability to capture the transactions costs, X_{ip} and X_{id}, paid by the borrower at exercise. In addition, higher borrower transactions costs always constrain the optimal option exercise policies of borrowers, whether or not the holder captures the transactions costs. These constraints increase the value of the mortgage holder's asset, $M_i^a(t)$, to a maximal possible value equal to the value of the underlying bond, $B_i(t)$. If the borrowers transactions costs are zero, borrowers will exercise their joint options efficiently with respect to market interest rates and house prices. In this case, the holder's mortgage asset values, $M_i^a(t)$, will be minimized.

The transactions cost, X_{ip} and X_{id}, are the private information of the mortgage borrowers. Mortgage originators rely on a variety of screening mechanisms to induce borrowers to willingly reveal their type. A key mechanism that is widely used by originators is points, or interest paid up front. Points reveal valuable information concerning the borrower's expected investment horizon and credit worthiness (see Chari and Jagannathan (1989); LeRoy (1996); Brueckner (1994); and Stanton and Wallace (1996)). However, points are never revealed when mortgages are either sold or securitized. Mortgage originators may also have extensive information concerning local real estate and labor markets that may make them uniquely able to evaluate the true levels of these transaction costs and thus uniquely able to accurately evaluate the value of their mortgage assets. For these reasons, much of the private information concerning X_{ip} and X_{id} is actually known to the mortgage originators prior to their decisions about which mortgages to sell.

In the context of the model, the GSE guarantee improves the worst case outcome for a securitized mortgage from w_{i0} to $\tilde{w}_{i0}$, where $\tilde{w}_{i0} > w_{i0}$. Since the GSE guarantee program leaves the mortgage originator with mortgage backed securities that are collateralized by its own mortgages, these pools will have default characteristics that are at, or possibly somewhat above, the GSE limits.

The mortgage originator's private information concerning prepayment and default, W_i, is retained for the MBS since the mortgage collateral is known. Armed with this information, the mortgage originator then selects which pools to deliver into the forward contract, or to-be-announced (TBA), market.[14] The TBA market is anonymous, there is extensive heterogeneity in the total termination quality of MBS pools, and the pools possess GSE guarantees against default risk. However, the mortgage originators still possess unique private information not held by the forward contract purchasers concerning termination speeds (early unscheduled return of mortgage principal) due to prepayment or default. Again, by Equation (2), TBA market prices are given by $P^*_{TBA}(q) = \sum_{i=1}^{n} \tilde{w}_{i0} q^{\delta-1}$, where n is the number of mortgages in the pool, and lemons, or "cheapest-to-deliver", pools are traded. Here a lemon pool is one characterized by efficient option exercise on the part of borrowers. Pools retained by the originators are relatively high-quality, meaning they have total transactions costs associated with default and prepayment of sufficient magnitude that borrowers would be unlikely to efficiently exercise their embedded prepayment and default options. Of course, the valuation of such pools would be closer to the underlying bond value, than that for TBA-delivered pools.

The final stage of residential mortgage securitization involves a re-securitization of certain mortgage backed security pools through a REMIC structure. Investment banks and other investors take delivery of PC pools through the TBA market and then select pools to sell into REMICs. Based on our theoretical analysis, we conjecture that these pools will exhibit termination patterns that render the pools lemons. In other words, the mortgage borrowers will behave closer to the rational model and terminate their mortgages relatively efficiently. We further expect that the relatively greater termination efficiency of the mortgages in these pools would be anticipated and hence priced by the market. Therefore the market prices of pools of mortgage backed securities that become REMIC collateral should be lower *ceteris paribus* than pools that are not sold into REMIC.

If markets are incomplete, repackaging assets into a sequence of prioritized bonds, such as a multi-tranche senior-subordinated structure, can maximize issuer returns by expanding the investor base into distinctive clienteles. Hence the fair market value of the tranched bonds can exceed the fair market value of the pooled assets (see Allen and Gale (1988); Oldfield (2000); Axelson (2005); and DeMarzo (2005)). As shown by Plantin (2004), if institutions that invest in tranched securities differ in their ability to screen the collateral and to redistribute the securities, relatively sophisticated institutions with high distribution costs will focus on the subordinated, or "junior", tranches and the "senior" tranches will be purchased by relatively less sophisticated institutions. DeMarzo (2005) establishes that if the

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[14] As previously discussed, an alternative market for trading MBS pools that is available to mortgage originator is the STIPS market. Trading volume in this market is a fraction of the TBA market as would be expected when privately informed originators try to sell cherries.

residual risk in the assets is sufficiently heterogeneous, then tranching increases the payouts of a security structure relative to selling the assets for a single pooled price. The magnitude of the relative benefit of pooling and tranching is, however, sensitive to the number of common factors in the residual risk of the assets.

In summary, residential mortgage securitization under the GSE guarantee programs is quite unique in that there are two stages of asset sales rather than the single stage that is employed in the rest of the asset-backed securities markets. At each stage, issuers select the specific securitized assets, such that, on average, securitized mortgage instruments are expected to contain poorer quality mortgages, that is mortgages on which the prepayment options will be more efficiently exercised. Unfortunately, it is difficult to test theories of markets for lemons because the causative factor—asymmetric information—necessarily makes it difficult to observe the key quality variables that determine asset prices. A particular advantage of the securitized residential mortgage market is that although the *ex ante* private information held by the mortgage originator is unobservable, the relative efficiency of option exercise behavior on the part of the mortgage borrowers is revealed *ex post*. In addition, GSE monitoring generates both detailed performance data as well as a means to track whether or not a given pool has been re-securitized in a REMIC structure. Thus it is possible to test two key theoretical implications of our modified version of the signalling model of DeMarzo (2005). First, we can test whether the option exercise behavior of REMIC pools is more efficient than for pools that are not re-securitized. That is, are REMIC pools lemons? Second, we can test whether the fair market value of REMIC pools would reflect these relative efficiencies: if REMICs are expected to be lemons, then they should trade for lower prices. In the next two sections of the paper, we empirically test these two hypotheses.

3 Are Multi-Class MBS Lemons?

In this section, we test whether REMICs are backed by PC pools that are of lower quality than the PC pools that are not re-securitized. Specifically, we test whether an indicator of the REMIC status of PC pools is a statistically significant predictor of the rate of mortgage terminations in the pools. It is important to emphasize that the unit of analysis for our empirical work is a Freddie Mac Gold PC pool comprised of between 20 and about 150 individual loans. Since we do not observe the individual mortgage-level performance data discussed in the previous section, in the reduced form analysis we treat the individual pools as if the mortgage borrowers are homogeneous sharing a common mortgage amortization structure defined by the Weighted Average Coupon (WAC), the Weighted Average Maturity (WAM), and initial principal amount on the pool. We also assume that mortgage borrowers respond to a common house price index constructed as the initial pool balance weighted average of the pool's composite exposure to housing markets that are identified for each pool at the state-level. Our reduced form analysis thus tracks the relative termination performance of pools and reflects a weighted average of the performance of the individual mortgages in the pool. Freddie Mac restrictions on pool-level data limits us to mortgage-level principal weights that are defined only at the pool origination date.

3.1 Regression Methodology

We define the cumulative termination rate of a mortgage pool 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.[15]

The expected cumulative termination rate for a pool is principally a function of how interest rates evolve over the life of a pool, though movements in house prices and other factors will also play roles.[16] All pools that experience substantial declines in interest rates are naturally expected to exhibit greater cumulative termination 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 pool's expected cumulative terminations due to interest rate movements and its REMIC status should have a statistically significant and negative effect on predicted 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. We also include a number of controls for other publicly available information, such as movements in house prices, the pool's weighted average origination coupon, and the financial institution that originated the mortgages.

Table 1 provides summary statistics for the Freddie Mac PC pools in our analysis. Between 1991 and 2002, Freddie Mac securitized 76,030 pools though 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 a MBS dataset that *ex*

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[15] The mortgages that appear in the Freddie Mac Gold PC pools are fully amortizing, which means that at the end of their scheduled 30-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 (See Bartlett (1989)).

[16] Because Freddie Mac guarantees the Gold PCs against default, default events look like prepayments in terms of their effects on MBS cash flows.

ante is as homogenous as possible.[17] In addition to deleting seasoned pools, we also delete pools for which key variables are missing, such as geographic location information, and pools with less that 90% of their pool principal either in a REMIC pool or outside a REMIC pool.[18] These three data screens together reduce the total number of pools in the sample from 76,030 to 69,769. As can be seen from Table 1, the weighted average coupon rates on the remaining pools vary by year reflecting the term structure of interest rates at the time of origination. In general, long-term interest rates are falling over our sample period, as reflected in the declining weighted-average coupon rates over the period. The average balance in these 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 2 provides summary statistics for the variables that we use in our regression analysis. As can be seen, the observed cumulative termination rate, "Termination rate", averages 13.1% over the first year for the pools in our sample. As expected, the average 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 rate variable across the 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 the 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 10-year Treasury rate at the end of each month and the rate that prevailed three months after the pool. It is measured over an investment holding period as:

$$\text{Summed Treasury deviations}_T = \sum_{t=4}^{12T}(r_t - r_3), \tag{6}$$

where r_t is the 10-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 below, we will directly condition on the termination rates observed from the time a mortgage is originated through the first three months that the mortgage appears in a PC pool.

As shown in Table 2, the mean of the Summed Treasury deviations variable becomes

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[17] Seasoning refers to the conventional wisdom that, for a given interest-rate decline, mortgage pools closer to their origination dates tend to exhibit slower prepayments (see Richard and Roll (1989)). In contrast, "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.

[18] The average percentage of pool principal assigned to REMIC collateral if any of the pool principal went into REMIC was 99%.

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 of study. 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 vintages of the pools. 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 re-securitized in a REMIC structure, and 0 otherwise.

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 for by mortgages originated in each state) and Freddie Mac repeat sales house price indices.[19] We re-scale 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.[20] The variable "Summed house price deviations" variable sums the deviations in the relevant house price index from the end of the third month to the end of the indicated holding period:

$$\text{Summed house price deviations}_T = \sum_{t=4}^{12T} (H_t - H_3), \tag{7}$$

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 2, 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 declines in house prices. Most of the pools that experienced declines in house prices contain mortgages originated in California in the early 1990s.

Table 3 displays summary statistics for controls that do not vary with the length of the holding period. The variable "Origination SMM" proxies for the cumulative single-month mortality rates for each pool from the time the mortgages in the pool are originated to the time that the pool is constructed. We construct this proxy by multiplying the weighted average loan age by the first month SMM of a pool. As can be seen, there is on average little evidence of termination activity over this initial period.

The variable "Initial terminations" measures the cumulative unscheduled mortgage terminations over the first three months of a pool. This measure is interacted with the REMIC status of the pool to test for different prepayment patterns over the initial few months of a

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[19] We employ the Freddie Mac CMHPI, available on-line at http://www.freddiemac.com/finance/cmhpi/.

[20] 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.

pool's history when the decision about whether to re-securitize 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 very rapidly while others experience very few termination events over the first three months.

The lower portion of the table displays summary statistics for the originator dummy variables that we include in each regression, with the omitted "Other" category capturing the shares of smaller originators. As can be seen, Countrywide and Chase account for the largest shares of the mortgages appearing the pools. In general, however, the individual shares are low, reflecting the highly competitive nature of the mortgage origination business.

3.2 Regression Results

We report the regression results in Table 4. 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 variable at all horizons. 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 our theoretical analysis of asset indivisibility and quality: the 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, the 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.[21]

Examining the house prices variable, we find that, in general, increases in house prices tend to accelerate terminations. This result reflects the net effect of the different influences that house price movements exert on mortgage terminations. On the one hand, increases in

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[21] An alternative estimation approach could be based on cumulative terminations over discrete intervals. We have experimented with this approach at the annual frequency and found 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 somewhat easier to interpret.

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 downpayment 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 stronger for REMIC pools over 1- and 2-year horizons, but the effect fades as the horizon lengthens. Over 4- and 5-year horizons, the housing effect is weaker for REMIC pools, as evidenced by the negative coefficient on the "House prices × REMIC" interaction terms.

None of the coefficients on the Origination SMM variable or its interaction terms are statistically significant, likely a result of the fact that termination activity is muted over the first few months following mortgage origination. In contrast, we find a positive and statistically significant effect of the cumulative initial termination rates on the subsequent cumulative termination experience for the 1-year investment horizon. At longer horizons, positive initial terminations are associated with lower cumulative terminations, which is consistent with the notion that high initial terminations reflect termination activity by the households that most assiduously exercise their termination options, leaving a less responsive pool in their wake. These results are consistent with the conventional wisdom on mortgage pool "burnout" discussed earlier.

At all horizons, the interaction of the initial termination history with the REMIC indicator is positive and statistically significant, though the coefficient estimate declines monotonically as the holding period lengthens. 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. 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 the background termination differences between Non-REMIC and REMIC PCs. As shown, in the first three holding periods, the REMIC background termination rates are faster than Non-REMIC pools. Since rates are generally falling over our analysis period, very rapid terminations unrelated to interest rates or house price movements would have a negative impact on investors returns. In the longer holding periods, the burnout effect dominates and the REMIC background terminations become statistically significant and negative as the pools burnout due to high levels of prior cumulative terminations.

As shown in Table 5, there appears to be significant heterogeneity across mortgage originators. For example, ABN AMRO, Bank of America, USBank, and Bishops pools have statistically significantly higher cumulative termination rates over most horizons. In contrast, the pools formed from mortgages originated by Countrywide, Washington Mutual, and Chase, exhibit lower terminations early on, but higher terminations over longer horizons. These results might indicate the presence of originator-specific factors that affect the seasoning patterns of the mortgages. For example, some firms might originate a higher share of mortgages with points or they might focus on originating mortgages in particular geographic regions.

3.3 Robustness

Table 6 presents sub-period regression results designed to test how robust our results are over time. Panel A displays regression results where we have estimated the regressions on data for pools formed from 1991 through 1995. Panel B displays results for pools formed from 1996 through 2002. For brevity, we have suppressed the coefficient estimates on the originator dummy variables.[22]

As can be seen by comparing the sub-period and full-period estimates, our key conclusion—that REMIC pools prepay more efficiently—is robust over time. In both Panels A and B, the coefficients on the "Summed Treasury deviations × REMIC" interaction terms are negative and statistically significant, as in the full sample. In these smaller samples the coefficient estimate on the Summed Treasury deviations variable is positive and statistically significant at the 2- and 3-year horizons. Similarly, in Panel B we see these coefficients are again positive at the 4- and 5-year horizons, though in all other cases the coefficients are negative and significant, as expected. In most other respects the results are very similar to those for the full sample.[23]

4 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

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[22] The coefficient estimates on the originator dummies are available from the authors upon request. The patterns of the coefficient estimates are much the same as for the full sample.

[23] One exception is the anomalous results on the 10-yr Treasury rate for the two and three year horizons for the 1991-1995 pools and for the four and five year horizons for the 1996-2002 pools. We attribute these results to data truncation issues at differing horizons. The full sample regressions, reported in Table 4, are less susceptible to truncation given the sheer size of the sample and we do not find sign changes for 10-yr Treasury at various horizons.

and interest reflect the exercise of prepayment or default options by mortgage borrowers; the model is a modification of that in Downing et al. (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 these two classes of pools. Moreover, the estimation results for the structural model provide an important additional robustness check on the results we presented in the previous section.

4.1 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 mortgage-backed security was issued, or the unpaid balance remaining in the underlying mortgage pool. Appendix A contains details on how we parameterize the underlying interest rate and house prices processes.

4.1.1 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 are 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 following Equation (4).

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 $\beta.$ are coefficients to be estimated. The beta distribution is chosen because it can take many possible shapes, and is bounded by zero and one. Its mean and variance are:

$$\mu = \frac{\phi_1}{\phi_1 + \phi_2} \tag{8}$$

$$\sigma^2 = \frac{\phi_1 \phi_2}{(\phi_1 + \phi_2)^2(\phi_1 + \phi_2 + 1)} \tag{9}$$

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, defaulting 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 following Equation (5). We assume that default costs, X_{id}, for all borrowers are constant at $X_d = 0.05$ (five percent 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.

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 sub-pools differentiated by their transaction cost levels, $X_{j,p}$, for $j = 1, 2, \ldots, J$. All else equal, sub-pools with higher transaction costs will exhibit less efficient prepayment option exercise than sub-pools with lower transaction costs.

4.1.2 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:

$$\begin{aligned} \lambda_j(t) &= \beta_1 + (\beta_2 + \beta_3 R)\,\mathrm{atan}\left(\frac{t}{(\beta_4 + \beta_5 R)}\right) P_{jt} + \beta_6 D_{jt} && (10) \\ &= \lambda_{jc} + \lambda_{jp} + \lambda_{jd}, && (11) \end{aligned}$$

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

The atan function captures the idea of seasoning discussed in the previous section. 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 (11) to refer to the hazard rates that apply in the various regions of the state space, where $\lambda_{jc} \equiv \beta_1$, $\lambda_{jp} \equiv (\beta_2 + \beta_3 R) \operatorname{atan}\left(\frac{t}{(\beta_4+\beta_5 R)}\right) P_{jt}$, 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.

Noting that the values of the mortgages in sub-pool j are identical under our model, for purposes of valuation we can simply think of the sub-pool as a single mortgage, where the face value of this mortgage is equal to the sum of the face values of the individual mortgages in the sub-pool. The value of the sub-pool 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 sub-pool. These points in mind, standard arguments show that in the absence of arbitrage, the value of the sub-pool, $M_j^l(H_t, r_t, t)$, paying coupon c must satisfy the partial differential equation:

$$\begin{aligned}&\tfrac{1}{2}\phi_r^2 r M_{rr}^l + \tfrac{1}{2}\phi_H^2 H^2 M_{HH}^l + (\kappa(\theta_r - r) - \eta r) M_r^l + ((r - q_H)H) M_H^l + M_t^l - rM^l + \\ &\quad (\lambda_c + \lambda_p)\left(F(1+X_p) - M^l\right) + \lambda_d\left(H(1+X_d) - M^l\right) + c = 0,\end{aligned} \tag{12}$$

where λ_c, λ_p, and λ_d are the state- and time-dependent hazards for seasoning, prepayment and default.[24]

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

$$M^l(H, r, T) = 0, \tag{13}$$

$$\lim_{r\to\infty} M^l(H, r, t) = 0, \tag{14}$$

$$\lim_{H\to\infty} M^l(H, r, t) = C(r, t), \tag{15}$$

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 sub-pool, but with no house price dependence.[25] Equation (13) is the terminal condition, reflecting the amortization of the mortgage. Equation (14) arises because all future payments are worthless when interest rates approach

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[24] Note that in equation (12) 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

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

infinity, and equation (15) 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

$$\begin{aligned} M^l(H, r^*(H,t), t) &= F(t)(1+X_p), & (16)\\ M^l(H^*(r,t), r, t) &= H^*(r,t)(1+X_d). & (17) \end{aligned}$$

Equation (16) states that, on the optimal prepayment boundary, the mortgage value is just equal to the remaining balance multiplied by one plus the appropriate transaction cost. Equation (17) states that, on the default boundary, the mortgage is just equal to the value of the house multiplied by one plus the default transaction cost.[26]

Solving equation (12) subject to these boundary conditions gives us the value of the sub-pool 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 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.

4.1.3 Structural Model Coefficient Estimates

We estimate the hazard parameters and the parameters of the transaction cost distribution following the methodology of Downing et al. (2005). Our objective here is to 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 7, 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 69,769 pools of the previous section.

Since the sample size is very large, it is not surprising that all of the coefficient estimates

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[26] 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 et al. (2005).

are highly statistically significant and any restriction on the model is rejected, so our primary interest is in understanding 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 1 year and 6.8% per month after 5 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 higher—after 10 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 prepay 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 7 indicate that the average transaction cost for non-REMIC pools is 16.39% of 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%.

4.2 Pricing Results

Finally, it remains to estimate the economic implications of the differences in termination behavior that we have identified. Unfortunately, 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 way of estimating the magnitude of the lemons discount.[27]

Under our model, for both non-REMIC and REMIC pools we hold the term of the underlying mortgages fixed at 30 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 7. The only remaining variables that are inputs to the model are the coupon rate and 10-year Treasury rate. Hence we next match REMIC and non-REMIC pools issued with the same coupon rate and under the identical prevailing 10-year Treasury rate.[28] There are 1,209 such unique combinations of coupon and Treasury rate levels observed over our period of study.[29] 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. 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 10-year Treasury rate settings.

In terms of yield-to-maturity, these results indicate differences of roughly 3-5 basis points between the pools. Given the scale of the REMIC market, these differences are clearly economically meaningful. Moreover, we view these estimates as lower bounds because our model can only capture long-term average speed differences between the pools—it is an equilibrium model. In summary, this confirms a main hypothesis of this paper, namely 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.

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[27] As discussed in Downing et al. (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 be cancel to the extent that the models exhibit similar pricing errors for REMIC and non-REMIC pools.

[28] Alternatively, one could hold the prices of the two securities at par and estimate the par-coupon rates at a fixed 10-year Treasury rate. The two approaches are equivalent.

[29] 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.

5 Conclusions

In this paper, we extended a signalling model of security design to consider the sale of indivisible assets by an informed intermediary to a financial entity that subsequently issues fractional claims on the assets in order to signal their quality. The extended model produces the testable implication that the assets backing asset-backed securities are of lower quality than assets that are not securitized. We tested this implication on a comprehensive dataset of all single-class mortgage-backed securities (Freddie Mac Participation Certificates, or PCs) issued over the period 1991 through 2002. We found that, indeed, re-securitized PCs are lemons relative to PCs that are not re-securitized for issuance as multi-class securities.

We implemented a structural valuation model and found that 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 are again confirmatory of our theoretical model that informed originators will trade lemons in the mortgage market. The structural model also allows us to test whether the relative efficiencies of the option exercise characteristics of REMIC and non-REMIC pools lead to important pricing differentials. The results of our pricing exercise suggest that the prices of re-securitized PCs are on average \$0.39 lower per \$100 of face value than PCs not destined for re-securitization (about 3-5 basis points in terms of yield-to-maturity). Given the size of these 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 (compared to direct asset sales), market incompleteness (motivating multi-tranche ABS), and asymmetric information (which can motivate both ABS pooling and tranching). Our results provide strong empirical confirmation that among these factors, asymmetric information relating to individual transaction costs and the efficiency of termination option exercise has a predictable and economically important impact on the operation of the market for mortgage-backed securities. We thus conjecture that comparable research into other ABS securitization line would likely be fruitful.

A Structural Model Details

Interest Rates Following Downing et al. (2005), we assume interest rates are governed by the Cox, Ingersoll and Ross (1985) model:

$$dr_t = (\kappa(\theta_r - r_t) - \eta r_t)dt + \phi_r \sqrt{r_t} dW_{r,t}, \tag{18}$$

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 et al. (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:

$$dH_t = \theta_H H_t dt + \phi_H H_t dW_{H,t}, \tag{19}$$

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:

$$dH_t = (r_t - q_H)H_t dt + \phi_H H_t dW_{H,t}. \tag{20}$$

We calibrate equation (20) 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.

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Figure 1: The ABS and MBS Share of Total Credit Market Assets in the United States

The figure plots the share of all U.S. capital market assets represented by mortgage backed securities (light gray) and all other classes of asset backed security (darker gray). The values were calculated from the Federal Reserve Board, Flow of Funds Accounts of the United States, Table L.1, Credit Market Debt Outstanding, Lines 35, 54, 55. Tables Z.1 release (Flow of Funds). The total in the denominator is the holdings in the financial sector of credit market assets. The MBS share is thus the total holdings of mortgages in MBS pools as a share of total financial sector credit market assets. The ABS share is the total holdings of different types of asset backed loans divided by the same scaling factor.

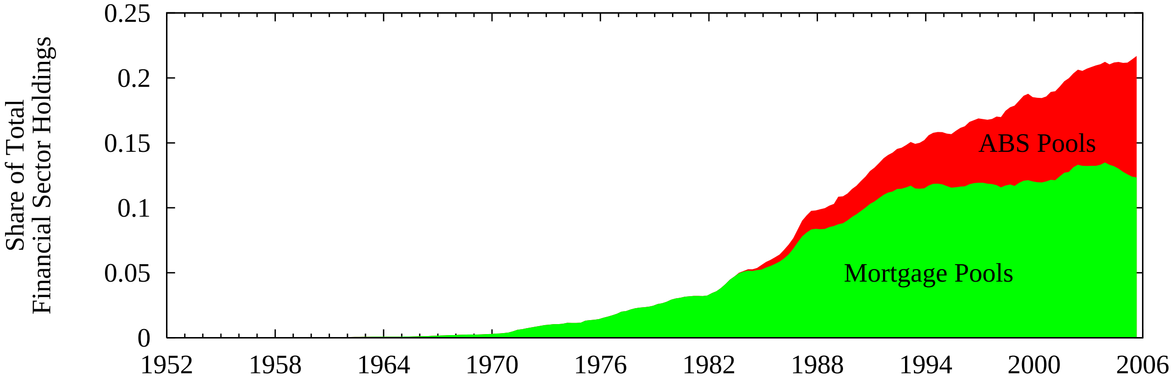

Table 1: Summary Statistics for the Unseasoned Freddie Mac Participation Certificates

This table provides 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.

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	8.75	354.9	2,611,826	226,762	8,927
1993	7.77	357.0	3,869,981	363,211	9,937
1994	7.97	357.9	5,897,570	463,047	7,796
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	20,477,130	624,093	4,956
Total				4,751,848	69,769

Table 2: Summary Statistics for the Regression Variables

The table displays 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. 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 10-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 69,769 pools at each horizon.

Variable	Mean	Std. Dev.	Min.	Max.
One year holding period or less (Months 4-16)				
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 4-28)				
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 4-40)				
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 4-52)				
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 4-64)				
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

Table 3: Summary Statistics, Cont.

The table displays summary statistics for the regression variables that do not change with the length of the holding period. The line labeled "Origination SMM" shows the cumulative single-month mortality (SMM) rates for the MBS mortgage pools from the time the mortgages are originated to the time the MBS is originated. The line labeled "Initial terminations" shows the cumulative amount of unscheduled return of principal over months 1-3 from the MBS 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 "REMIC" displays summary statistics for the REMIC indicator variable, and the other variables show statistics for indicator variables for each major originator; all other originators are grouped into the omitted "Other" category. The sample period is 1991 through 2002. The total number of observations is 69,769 pools.

Variable	Mean	Std. Dev.	Min.	Max.
Origination SMM	0.004	0.032	0.000	1.759
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

Table 4: The Relative Performance of Pass-Through and Re-Securitized MBS

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 pool formation. The indepdendent variables are: the summed monthly deviations in the 10-year Treasury rate from the rate prevailing at the end of month 3, "Summed Treasury Deviations"; summed monthly deviations in the pool-specific house price index from the index level prevailing at the end of month 3, "Summed House Price Deviations"; the weighted average loan age times the single-month mortality rate over the first month following the formation of the PC pool, "Origination SMM"; the cumulative unscheduled return of principal over months 1-3 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 "REMIC" that is one when the pool is assigned to a REMIC structure, and zero otherwise. The regressions also include controls for mortgage originators; these estimated coefficients are displayed in Table 5 below. The sample period is 1991-2002. The number of pools in each regression is 69,769. Robust standard errors are displayed in parentheses below each estimated coefficient; an asterisk next to a coefficient estimate indicates statistical significance to at least the 95% level.

	Horizon (Years)				
	1	2	3	4	5
Summed Treasury deviations	-0.0035*	-0.0035*	-0.0018*	-0.0008*	-0.0002*
	(0.0001)	(0.00006)	(0.00005)	(0.00004)	(0.00003)
Summed Treasury deviations × REMIC	-0.0017*	-0.0017*	-0.0017*	-0.0013*	-0.001*
	(0.0001)	(0.00007)	(0.00005)	(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*	1.00e-05*	1.00e-05*
	(0.00002)	(8.00e-06)	(3.00e-06)	(2.00e-06)	(1.00e-06)
Origination terminations	-0.0143	-0.0359	0.0146	0.0065	-0.0086
	(0.0384)	(0.035)	(0.0352)	(0.0288)	(0.0252)
Origination terminations × REMIC	-0.0176	-0.0163	-0.034	-0.0189	-0.0114
	(0.0487)	(0.0454)	(0.0459)	(0.0415)	(0.037)
Initial terminations	0.3865*	0.1965*	-0.0331	-0.3177*	-0.579*
	(0.0251)	(0.0278)	(0.0275)	(0.0251)	(0.0229)
Initial terminations × REMIC	0.2059*	0.1238*	0.1963*	0.3002*	0.3042*
	(0.0364)	(0.0388)	(0.0387)	(0.0362)	(0.0325)
REMIC	0.0291*	0.0689*	0.0119*	-0.0343*	-0.0478*
	(0.0014)	(0.0022)	(0.0022)	(0.0024)	(0.0025)
WAC	0.022*	0.086*	0.119*	0.1307*	0.1256*
	(0.0007)	(0.001)	(0.001)	(0.0009)	(0.0009)
Constant	-0.0873*	-0.4804*	-0.6138*	-0.6022*	-0.4816*
	(0.0057)	(0.0081)	(0.0081)	(0.0076)	(0.0072)
Adj.-R^2	0.1665	0.4107	0.4429	0.4761	0.4994
F	689.8666	2686.8	3265.983	3617.687	3236.935

Table 5: Originator Dummy Coefficient Estimates

The table displays estimates of the coefficients on the originator dummies included in the regressions reported in the previous table.

	Horizon (Years)				
	1	2	3	4	5
ABN AMRO	0.0371*	0.0852*	0.1047*	0.0875*	0.0536*
	(0.0024)	(0.0034)	(0.0034)	(0.0033)	(0.0033)
Countrywide	-0.0098*	-0.0057*	0.0253*	0.0587*	0.0781*
	(0.0017)	(0.0027)	(0.0029)	(0.0027)	(0.0023)
Washington Mutual	-0.0151*	-0.0259*	0.0123*	0.0214*	0.0304*
	(0.002)	(0.0029)	(0.003)	(0.003)	(0.0029)
Chase	-0.0104*	-0.0173*	-0.0027	0.0043	0.008*
	(0.0017)	(0.0027)	(0.0027)	(0.0026)	(0.0025)
Flagstar	0.001	0.0037	0.0432*	0.048*	0.0451*
	(0.0023)	(0.0034)	(0.0035)	(0.0034)	(0.0034)
Bank of America	0.0055	0.0368*	0.0501*	0.0332*	0.0038
	(0.0032)	(0.0054)	(0.0056)	(0.0052)	(0.0049)
Suntrust	0.0012	0.0698*	0.066*	0.0389*	0.0162*
	(0.0029)	(0.0055)	(0.0054)	(0.005)	(0.0048)
USBank	0.0754*	0.1298*	0.14*	0.137*	0.1196*
	(0.0044)	(0.0059)	(0.0057)	(0.0055)	(0.0056)
Accubanc	-0.0069*	-0.025*	0.0185*	0.0431*	0.0592*
	(0.0033)	(0.0042)	(0.0046)	(0.0046)	(0.0039)
Resource Morg. Grp.	-0.0044	-0.0223*	0.03*	0.0334*	0.0277*
	(0.003)	(0.0039)	(0.0042)	(0.0044)	(0.004)
Crossland	-0.0231*	-0.0433*	-0.0043	0.031*	0.0467*
	(0.0027)	(0.004)	(0.0045)	(0.0048)	(0.0045)
Wachovia	-0.0141*	-0.0433*	-0.0208*	0.0303*	0.0767*
	(0.0037)	(0.0048)	(0.0054)	(0.0061)	(0.0052)
Bishops	0.0249*	0.1003*	0.158*	0.1454*	0.1005*
	(0.0056)	(0.0082)	(0.0074)	(0.0067)	(0.0067)

Table 6: Sub-Period Regression Results

The table displays regression results where we have split the sample by the year when a PC pool is formed. Panel A displays the results for pools formed from 1991-1995; Panel B displays the results for pools formed from 1996-2002. The estimates of the coefficients on the originator dummies have been suppressed for brevity. The other details on the displayed results are as in Table 4 above.

Panel A: Pools Formed 1991-1995

	Horizon (Years)				
	1	2	3	4	5
Summed Treasury deviations	-0.0021*	0.0003*	0.0013*	-0.0004*	-0.0004*
	(0.0002)	(0.00009)	(0.00007)	(0.00004)	(0.00003)
Summed Treasury deviations × REMIC	-0.0011*	-0.0014*	-0.0012*	-0.00009*	0*
	(0.0002)	(0.0001)	(0.00007)	(0.00005)	(0.00004)
Summed house price deviations	-0.00002	-0.00008*	0.0001*	0.0001*	0.0001*
	(0.00004)	(0.00002)	(8.00e-06)	(5.00e-06)	(3.00e-06)
Summed house price deviations × REMIC	7.00e-06	0.0001*	-0.00006*	-0.00006*	-0.00002*
	(0.00005)	(0.00002)	(9.00e-06)	(5.00e-06)	(3.00e-06)
Origination terminations	0.0884	0.0591	0.0003	-0.0674	-0.0637
	(0.0729)	(0.0523)	(0.0498)	(0.0385)	(0.0364)
Origination terminations × REMIC	0.0266	-0.0326	0.0121	0.0254	-0.0049
	(0.0867)	(0.0645)	(0.0591)	(0.0492)	(0.0477)
Initial terminations	0.2656*	-0.0943*	-0.2823*	-0.2969*	-0.3779*
	(0.0333)	(0.0309)	(0.0332)	(0.0328)	(0.0329)
Initial terminations × REMIC	0.2297*	0.1632*	0.078	0.061	0.0952*
	(0.0474)	(0.0438)	(0.0448)	(0.0442)	(0.0446)
REMIC	0.0247*	0.0625*	0.0361*	0.0067*	-0.0097*
	(0.0018)	(0.0025)	(0.0028)	(0.003)	(0.0032)
WAC	0.0507*	0.2199*	0.2765*	0.2439*	0.2049*
	(0.0013)	(0.0017)	(0.0015)	(0.0014)	(0.0012)
Constant	-0.3209*	-1.5888*	-1.9607*	-1.6036*	-1.1928*
	(0.0109)	(0.0139)	(0.0124)	(0.0114)	(0.0107)
Adj.-R^2	0.2005	0.6027	0.6601	0.6791	0.6188
N=33,902					

Panel B: Pools Formed 1996-2002

Summed Treasury deviations	-0.0047*	-0.006*	-0.0025*	0.0008*	0.0014*
	(0.0001)	(0.00008)	(0.00006)	(0.00006)	(0.00005)
Summed Treasury deviations × REMIC	-0.0014*	-0.0009*	-0.0012*	-0.0009*	-0.0004*
	(0.0002)	(0.0001)	(0.00008)	(0.00007)	(0.00006)
Summed house price deviations	0.0004*	0.0003*	0.00003*	0.00003*	0.00006*
	(0.00002)	(1.00e-05)	(4.00e-06)	(2.00e-06)	(1.00e-06)
Summed house price deviations × REMIC	-0.00006*	-0.00002*	0.00003*	0.00003*	0.00002*
	(0.00003)	(1.00e-05)	(5.00e-06)	(3.00e-06)	(2.00e-06)
Origination terminations	-0.1156*	-0.0703	-0.0378	-0.0666	-0.11*
	(0.0406)	(0.0489)	(0.0433)	(0.0443)	(0.0465)
Origination terminations × REMIC	-0.0078	-0.0147	0.0034	0.0756	0.0987
	(0.0567)	(0.0627)	(0.0565)	(0.0544)	(0.0557)
Initial terminations	0.4599*	0.1547*	-0.1614*	-0.5057*	-0.8927*
	(0.0377)	(0.0405)	(0.039)	(0.0355)	(0.0328)
Initial terminations × REMIC	0.2061*	0.149*	0.1517*	0.1381*	0.07
	(0.0554)	(0.0569)	(0.0546)	(0.048)	(0.0417)
REMIC	0.0168*	0.0203*	-0.0116*	-0.0165*	-0.0146*
	(0.0027)	(0.0039)	(0.0037)	(0.0037)	(0.0036)
WAC	0.0136*	0.0673*	0.1504*	0.2015*	0.2085*
	(0.001)	(0.0015)	(0.0016)	(0.0018)	(0.0019)
Constant	-0.0231*	-0.2864*	-0.7157*	-0.9709*	-0.9597*
	(0.0079)	(0.0114)	(0.0119)	(0.0129)	(0.0134)
Adj.-R^2	0.1595	0.3784	0.4309	0.4371	0.5524

Table 7: Structural Model Estimation Results

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: $\lambda_p = (\beta_2 + \beta_3 R)\,\mathrm{atan}\,(t/\,(\beta_4 + \beta_5 R))$, 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 69,769 individual pass-through pools in the sample.

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	