Funding Fragility in the Residential-Mortgage Market*

David Echeverry† Richard Stanton‡ Nancy Wallace§

December 31, 2016

Abstract

We develop a model of repo-funded mortgage origination under trade imbalances. We highlight important differences in the time required for a newly issued mortgages to be securitized across the Government Sponsored Enterprises (GSE) and private label (PL) securitization channels. We construct a measure of the probability of securitization within thirty days, the securitization hazard, that can be viewed as an empirical proxy for the market liquidity of newly originated mortgages. We find that the securitization hazards are priced using trading prices for the GSE To-Be-Announced (TBA) forward contracts and the private-label residential-mortgage-backed-security (RMBS) markets. Our model of the repo funding of mortgage origination is sufficiently flexible to accommodate both constant volatility and first-order autocorrelation in TBA and private label RMBS bond-price volatility. We test for these dynamics using traded bond price dynamics from the PL and GSE securitization channels. We find important differences in the degree of autocorrelation in bond price volatility across the channels and these differences give rise to important differences in the level and volatility of the implied repo haircuts. Overall our results indicate haircut percentages that are on average lower in private label markets. However, they are also much more volatile, suggesting that the PL securitization channels are more fragile, in the sense that they are more susceptible to liquidity spirals and market breakdown.

JEL classification: G21, G22.

*We are grateful for financial support from the Fisher Center for Real Estate and Urban Economics. We thank Sanket Korgaonkar, Nirupama Kulkarni, Christopher Lako and Haoyang Liu for their assistance with the source data.

†Haas School of Business. Email: david_echeverry@haas.berkeley.edu.

‡Haas School of Business. Email: stanton@haas.berkeley.edu.

§Haas School of Business. Email: wallace@haas.berkeley.edu.

1 Introduction

Considerable recent research has focused on the role of short-term debt financing markets in the lead-up to the financial crisis. Several studies have concluded that runs on the Asset-Backed Commercial Paper (ABCP) market were central to the crisis (see, for example, Acharya, Schnabl, and Suarez, 2013; Covitz, Liang, and Suarez, 2013), especially for ABCP programs with exposure to subprime-mortgage credit losses or with less-than-full liquidity support. Other studies have argued that the haircut-setting practices in the repo market for U.S. structured products significantly amplified pro-cyclicality and led to rapid contractions in short-term collateralized funding markets, similar to traditional banking panics (see, for example, Gorton and Metrick, 2010, 2012; Dang, Gorton, and Holmström, 2013).

In contrast, Comotto (2012) and Krishnamurthy, Nagel, and Orlov (2014) caution against drawing too many conclusions from observed runs on structured-product repo, because this market was dwarfed pre-crisis by repo collateralized by U.S. Treasury and Agency securities, and these much larger repo markets did not experience runs or price pressure in the lead-up to the crisis. Moreover, the contraction in ABCP was an order of magnitude larger than the private-market runs on repo.

This paper considers the pre- and post-crisis role of warehouse lending in the U.S. mortgage market. Mortgage warehouse lending is another huge repo market, which accounted for more than 60% of the funding for pre-crisis mortgage origination (currently about 40%), yet has so far received little attention in the academic literature.[1] The whole-mortgage repo market also experienced run-like episodes over the period 2006 through 2007, mainly associated with market liquidity and operational risks of counterparties. These risks continue today, with the sudden closure in March, 2016 of a large non-depository lender, W. J. Bradley Mortgage.[2] The precipitating event for Bradley was a "pipeline backup," reportedly due to new regulatory oversight of the underwriting quality of individual loans under the Consumer Finance Protection Bureau's new TRID requirements.[3] The TRID violations arising from "small" errors in the underwriting reports for each loan made it impossible for W. J. Bradley to sell the mortgages to a securitization vehicle within the contractual repo maturity of 30

[1] As will be explained in more detail below, mortgage warehouse lending is a form of collateralized lending used to fund the mortgage pipeline — the funding period between the dispersal of funds to borrowers and the securitization of the loan. The whole-loan repo market that funds the mortgage pipeline enjoys the same legal protections as other forms of repo lending, and the market operates with identical pricing conventions and institutional structures, including a customized form of ABCP.

[2] See Paul Muolo, "A Wakeup Call for the CFPB — Tombstone Blues?" *Inside Mortgage Finance* March 18, 2016.

[3] These rules are part of the new Truth in Lending Act (TILA) — Real Estate Settlement Procedures Act (RESPA) Integrated Disclosure Rule, implemented by the CFPB in 2016 (see CFPB, 2016).

days. This covenant violation in its whole-loan repo contract then precipitated the sudden cancellation of all of its warehouse lines. This precipitous line cancellation on the part of the repo buyer for W. J. Bradley was remarkably similar to the cancellation of billions of dollars of lines to mortgage originators in the fourth quarter of 2006 and first quarter of 2007 due to slowdowns in the securitization of mortgages in both the Government Sponsored Enterprise (GSE) and private-label markets. In both cases, these cancellations led to the immediate demise of the mortgage originator (the repo seller).

As with all bilateral repo markets, the whole-loan repo market is difficult to monitor due to a lack of available trading data. We propose a novel method to monitor the performance of the market through an analysis of loans' securitization hazards (the probability that a not-yet-securitized mortgage is securitized within the next 30 days). We develop metrics for the securitization hazards for individual loans and a measure of dispersion in the timing of securitization for new mortgage originations that trade within the two securitization channels — private label and government-sponsored enterprise. We apply our metrics to calibrate an equilibrium model of trade frictions with haircut constraints for such a collateralized lending market. The mortgage repo buyers and sellers in our setting face a choice in transacting through either the private label or GSE channels, and they are uncertain with respect to the securitization hazards and the level of autocorrelation in mortgage bond price volatility within the channels.

We consider the role of the haircuts in inducing either stability or instability in the channels given empirical differences in the securitization hazards and autocorrelation in bond price volatility in these markets. Based upon the historical performance of these securitization channels, we then consider what our setting can tell us about the expected fragility of these channels. We define securitization channels to be fragile when mortgage repo haircuts are pro-cyclical and exacerbate existing market illiquidity. Fragile securitization channels could be subject to illiquidity spirals and market breakdowns in response to funding frictions. We find that the PL label is significantly more fragile, i.e., more prone to market crashes, than the GSE channel. This indicates a key and unpriced role for the GSEs as market-liquidity providers. This liquidity provision is different from, and potentially more important than, the credit and tail-risk insurance currently provided to the investors in GSE mortgage backed securities.

The paper is organized as follows. Section 2 describes the operation of the mortgage securitization pipeline, introduces the institutions involved in this lending market, and provides statistics on its overall size in both the pre- and post-crisis period. Section 3 presents the contractual structure of the whole-loan repo market and discusses important changes in U.S.

bankruptcy legislation that has imparted significant new rights to repo buyers in this market. Section 4 presents existing data on loan-level securitization hazards for approximately 60 million single-family residential mortgages securitized through either the GSE or private-label pipeline channels between 2000 and 2013 and establishes empirically that these hazards are priced in mortgage bond trading with each channel. Section 5 presents a model of trade frictions with haircut constraints that is calibrated to the observed securitization hazards and the autocorrelation in mortgage bond price volatility in the pre-crisis period (2004–2007) for the three competing mortgage securitization channels. Section 6 concludes.

2 The mortgage-securitization pipeline

The "pipeline" phase of mortgage securitization remains an important outstanding issue in our understanding of funding fragility in the pre- and post-crisis U.S. mortgage market. The pipeline is structured to last, on average, roughly 30–120 days, depending on whether the securitization channel is the Government Sponsored Enterprises (GSEs) or private-label special-purpose entities (SPEs). The key participants in the pipeline are the "warehouse lenders." Currently, these are the domestic and international commercial banks, finance companies and hedge funds. Pre-crisis warehouse lenders were the investment banks, REITs, commercial banks, insurance companies, savings and loan institutions, finance companies, and hedge funds. The warehouse lenders provide funding via lines of credit to mortgage originators, who lend the borrowed funds to individual borrowers in return for a mortgage (or deed of trust) on a house and a promissory note for the debt. The warehouse lenders secure the originators' draws on their credit lines through a repurchase agreement collateralized by a legally recorded ownership interest, called a perfected interest, in the newly originated mortgages. Once the mortgage originators successfully sell the newly originated mortgages to SPEs, the dollars received from the sales are used to "buy back" the mortgages on the repurchase agreements, thus releasing capacity on the outstanding lines of credit. Upon receipt of the proceeds from the sale, the warehouse lenders transfer the perfected interest in the mortgage and the promissory note to the SPEs.

By far the largest class of pre-crisis warehouse lenders were commercial banks, savings and loan institutions, insurance companies, finance companies, and investment banks, all with highly variable regulatory-capital requirements and considerable discretion in the GAAP and regulatory accounting treatments of their positions. Pre-crisis, off-balance sheet entities called Structured Investment Vehicles were another important class of warehouse lender. These entities were bankruptcy-remote from the mortgage originator and were funded by commercial paper (called Extendable Asset Backed Commercial Paper, ABCP) issued by the holding company of the mortgage originator. The assets of the SIVs were the committed warehouse lines and the perfected mortgage interests on those lines.

As an indication of the size of the warehouse lending market and its funding structures, in 2006 total mortgage origination in the U.S. was \$2.98 trillion, of which \$1.86 trillion was originated through wholesale, or third-party, origination channels.[4] Countrywide was the largest residential mortgage lender in 2006 with \$462.5 billion in origination, New Century was the twelfth largest with origination of \$59.8 billion, and American Home Mortgage was the thirteenth largest with origination of \$58.9 billion.[5] The Home Mortgage Disclosure Act (HMDA) data for U.S. mortgage origination provide a breakdown of the origination channels by lender. The 2006 HMDA data indicate that Countrywide's mortgage production was \$297.58 billion through purchase and \$297.27 billion through retail. HMDA reports New Century to have originated \$54.83 through purchase and \$8.49 through retail and American Home Mortgage to have originated \$54.83 through purchase and \$2.96 through retail.

As of fourth quarter of 2006, the funding for Countrywide's origination activity included two SIVs, Park Granada, LLC, and Park Sierra, LLC, with total repurchase agreement balances of \$18.3 billion[6] and with another \$42.1 billion in outstanding balances in repurchase agreements with counterparties.[7] New Century had balances of \$7.4 billion in outstanding repurchase agreements (\$14.35 billion total credit lines)[8] and \$2 billion drawn on its \$2 billion credit line with its SIV, Van Karman Funding Trust.[9] American Home Mortgage had \$2.49 billion drawn from its SIV, Broadhollow Funding, LLC.[10] and \$8.57 drawn on its lines of credit with counterparties.[11] The securitization channel for Countrywide's origination activity was through both the GSEs and through private-label conduits, whereas the securitization

[4]See Inside Mortgage Finance (2015).

[5]See *Inside Mortgage Finance*, February 2, 2007, p. 5. *Inside Mortgage Finance* accounts for origination as an aggregate of retail, wholesale purchases, and correspondent lending

[6]The balance on Park Granada was \$12.4 billion on a \$21 billion credit line and the balance for Park Sierra was \$5.8 billion on a \$10.15 billion credit line. See Moody Investor Services for quarterly reports on Park Sierra and Park Granada.

[7]See Countrywide, Form 10-Q, For the quarterly period ended September 30, 2007.

[8]The repurchase agreement counterparties for its credit lines were Bank of America, N.A. Bear Stearns Mortgage Capital, Citigroup Global Markets Realty Corp, Credit Suisse First Boston Capital, LLC, Deutsche Bank, IXIX Real Estate Capital, Inc, Morgan Stanley Bank, Morgan Stanley Mortgage Capital, Inc., and UBS Real Estate Securities, Inc. See `http://www.sec.gov/Archives/edgar/data/1287286/000089256906000258/0000892569-06-000258-index.htm`

[9]See Moody Investor Services for quarterly reports on Van Karman.

[10]The total credit available from Broadhollow Funding, LLC was \$3.25 billion as reported in quarterly reports on Broadhollow Funding LLC from Moody's Investor Services.

[11]`http://www.sec.gov/Archives/edgar/data/1256536/000119312507044477/0001193125-07-044477-index.htm`

channels for New Century and American Home Mortgage were primarily through private-label conduits. All three of these institutions had foundered or failed by the end of 2007.[12]

Warehouse lending to non-bank originators and to smaller originators remains an important component of current mortgage origination activity. In 2014, total originations were $1.16 trillion, of which 41.8% was through non-retail channels. However, even the retail channels for some non-bank lenders are largely funded through credit lines and repurchase agreements. In December 2014, PHH Mortgage was the fifth largest lender in the U.S. and 92% of its origination was retail originated[13] and this retail origination was funded by $1.95 billion of committed lines on repurchase agreements.[14] with another uncommitted facility of $2.5 billion from Fannie Mae. All of this origination was securitized through the GSEs.

3 Master Repurchase Agreements

Since the passage of the Bankruptcy Abuse Prevention and Consumer Protection Act (BAPCPA) in 2005, the credit lines used for mortgage warehouse lending have been structured as Master Repurchase Agreements (MRAs). As shown in Table 1, MRAs have a number of customized features that are potentially highly advantageous to the warehouse lender (which we shall refer to as the repo buyer), and thus potentially reduce the cost of capital to the mortgage originator (which we shall also refer to as the repo seller).[15] Table 1 presents the repo buyer's and seller's ownership positions in the MRAs both in the pre-crisis period and currently. Pre-crisis, MRAs were widely used to fund the mortgage originations of the so-called private-label securitized bond markets, although as previously discussed Countrywide was a significant user of MRAs and they securitized heavily in the GSE markets. Currently the MRA funding structure is widely used, especially for non-depository and small depository lenders, for conventional conforming mortgage origination intended for GSE and Government National Mortgage Association (GNMA) securitization.[16]

[12]Countrywide was sold under duress to Bank of America in early 2008, New Century declared Chapter 11 bankruptcy in the second quarter of 2007 and Ameriquest entered Chapter 11 bankruptcy at the end of 2007.

[13]See Inside Mortgage Finance (2015, p. 49).

[14]The repo counterparties were Credit Suisse First Boston Mortgage Capital, LLC, $575 M, Fannie Mae, $500M, Bank of America, N.A., $400M, Wells Fargo Bank, N.A. $350M, Royal Bank of Scotland, $150M.

[15]Other funding structures include traditional lines of credit (LOC), true sale agreements, and structured investment vehicles (SIVs) funded by asset backed commercial paper (ABCP).

[16]See Warehouse Lending from A to Z, Part One and Two, Mortgage Banking Association Webinars by Sophie B. Schubert, Joe Lathrop, Tom Kelly, Esquire, September 17, 2013 and September 24, 2013.

Table 1 summarizes the key characteristics of MRAs for repo buyers and sellers. As shown in the upper segment of Table 1, the collateral transfers to the warehouse lender (repo buyer) provide the repo buyer with a strong ownership position in the mortgage and the promissory note under the provisions of the U.S. Universal Commercial Code, UCC Article 9.[17] The accounting treatment recognizes the perfected collateral as a loan to a commercial borrower that is held on the hold for investment balance sheet of the repo buyer and requires a 100% risk weight. Under DFAST, the stress tests for these positions focus on the performance of the Allowances for Loan and Lease Losses (ALLLs) for defined shocks to market fundamentals and the pre-crisis performance monitoring for these positions was also on the ALLLs. Upon the bankruptcy of the repo seller the perfected mortgage collateral is exempt from automatic stay and can be immediately liquidated by the repo buyer without consolidation into the bankruptcy estate of the repo seller. Finally, the MRAs typically allow for rehypothecation of the mortgage collateral either for Federal Home Loan Bank Advances or as other bilateral repurchase agreements.

Warehouse Lender: Repo Buyer		
	Economic Ownership	UCC Article 9 transfer — full note ownership
	Accounting Treatment	Hold for Investment: Mortgage Loans
	Stress Tests	Allowances for Loan and Lease Losses
	Bankruptcy of Counterparty	Exempt from Automatic Stay
	Collateral Rehypothecation	Yes
Mortgage Originator: Repo Seller		
	Economic Ownership	Do not hold mortgage note.
	Accounting Treatment	Hold for Sale: Mortgage Loans
	Secondary Market Recourse	Putback Options
	Time to Sale Requirements	Defined in MRA
	Covenant Triggers	Margin calls, Net Worth Requirements, Financial Ratio Requirements

Table 1: Repo Buyer and Seller Positions under Mortgage Warehouse Master Repurchase Agreements

The repo seller does not hold the mortgage promissory note because the perfected interest in the mortgage is the collateral for the repurchase agreement. Instead as shown in Table 1, the accounting treatment for the balance sheet of the repo seller recognizes the collateral on the repo position as hold-for-sale mortgage loans. Typically, the repo seller is required to guarantee the performance of the loan against origination defects over the life of the loan.[18] As previously discussed, to avoid additional interest charges or loss of their lines, the repo

[17] See Schroeder (1996), and for the code, `https://www.law.cornell.edu/ucc/9`.

[18] These putback options have led to billions of dollars of clawbacks on the part of the GSEs to the mortgage originator and on the part of the SPEs to the mortgage originators.

seller must arrange for the sale of the loans to the securitization entities within a period of time that is defined in the MRA. The MRA also typically contains covenants that define accounting statement and performance triggers that would allow the repo buyer to cancel the lines of credit. Common covenants include cancellation rights if any of the other MRA counterparties to the repo seller have exercised their rights to require additional margin due to tardy loan sales. Net worth requirements for the repo seller are another common covenant. Lastly, MRA covenants usually do not define specific underwriting requirements for the mortgage loans.

An important reason for the prevalence of MRAs in structuring mortgage warehouse facilities involves the treatment of these facilities under BAPCPA.[19] Again, as shown in Table 1, under BAPCPA, MRAs qualify as "repurchase agreements," so the mortgage collateral can be safe harbored upon the bankruptcy of the counterparty, the repo seller. Since the repo buyer has a perfected interest in the unsold mortgage collateral within the facility, the exemption from automatic stay enables them to take over the collateral upon the default of the mortgage originator, the repo seller. The warehouse lender can then immediately sell its interests in the mortgage loans to repay the related advances, repurchases, and other obligations of the mortgage originator.[20]

The treatment of whole loan mortgage repurchase agreements under BAPCPA and their eligibility for exemption from automatic stay guarantees that the mortgage repo buyer has significant discretion within the dictates of the MRA covenants to liquidate the mortgage collateral and close down the repo facilities. As Table 1 notes, the MRA covenants also allow the repo buyer the right to close down the repo facility and take over the collateral due to triggers tied to the economic performance of the originator or due to the inability of the originator to make the additional interest charges associated with holding loans seasoned by more than the number of days stipulated in the MRA. Given the contractual features of the MRAs, the warehouse lender typically has an incentive to focus on the counterparty risk and the liquidity of the mortgage collateral, rather than on the underwriting quality of any given loan.[21] As a result, these facilities are vulnerable to systemic slowdowns in the liquidity of whole loan sales into the secondary mortgage market. Without reliable short-term demand

[19]See Bankruptcy Abuse Prevention and Consumer Protection Act of 2005, Pub. L. No. 109-8, §907, 119 Stat. 23, 171–172 (codified as amended at 11 U.S.C. §101(47) (2012)).

[20]See Schweitzer, Grosshandler, and Gao (2008).

[21]A further reason for this focus is that the put-back options for all loans that are sold out of the facility remain with the repo seller, the originator, since the originator underwrote and funded the loan in its own name. Interestingly, the new TRID requirements now require loan monitoring and this change in repo pipeline risk management, as previously discussed, is leading to severe dislocations or backups in the mortgage pipelines.

for whole loans in the secondary mortgage market, whether from the GSEs or pre-crisis from private-label securitization, the MRA funding structure for mortgage origination is quite vulnerable to runs.

4 Securitization timing

Given the prior discussion, an important risk of the pipeline phase of mortgage securitization is the level and the predictability of the rate at which repo sellers can consummate the SPE sales of their outstanding repo funded mortgages. These securitization hazards are, of course, priced ex ante by the repo buyers using contractual haircuts and interest charges that are defined in the MRAs. Between 2000 and 2002, there was effectively only one SPE investor channel, the GSEs. Between 2002 and 2007, there were two important SPE investor channels that competed with each other, the GSEs and the private label securitizers managed by the investment banks, commercial banks, and finance companies. After the first quarter of 2008, the private label SPE investors had exited the market, so the primary SPE investor channel became again the GSEs. While the collapse in private label markets and relative stability of GSE markets has been well documented in terms of volumes (Vickery and Wright, 2013), the pipeline measures we propose here are novel.

Measuring these pipeline channels requires loan-level information on the origination date of the loans matched to information on the close date for the SPE that securitized the loan. Our data sources for tracking the loans through these channels are Moody's Lewtan/ABSNet Data for residential single family loans that are securitized in non-GSE SPEs (privately label securitization) and the McDash Analytics, LLC data for GSE securitized loans. We focus only on first lien fixed rate mortgages collateralized by single family residential homes.

4.1 The securitization hazard

Figure 1 presents the pipeline period for about 13 million residential mortgages that were securitized through private label channels. As shown, the average time required to securitize a newly originated mortgage was about one year in 2000, and then gradually fell to a low of about sixty days by 2007. By the third quarter of 2008, the time required to securitize through the private label securitization channels rose dramatically, to 500–600 days, after a complete hiatus in securitization between July 2007 and July 2008.

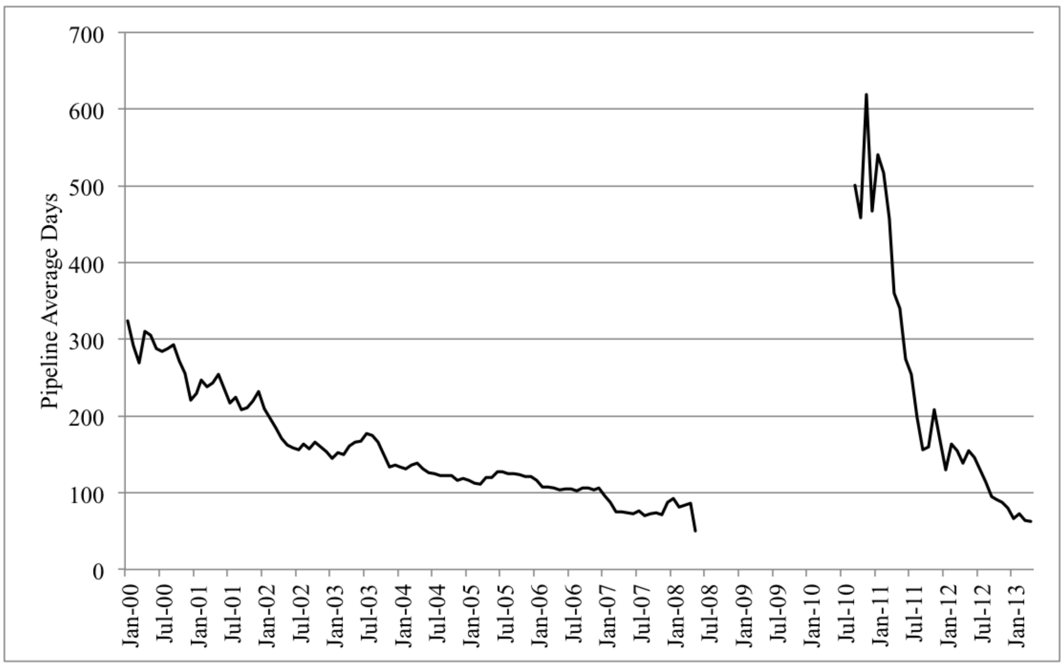


Figure 1: Pipeline period for private label mortgage backed securities. The pipeline period is measured as the average number of days between the loan origination date and the origination date of the SPE in which the loan was securitized. Sample is 12.997 million single family residential fixed-rate mortgages securitized through private label channels, as reported in Moody's Lewtan/ABSNet Data.

Figure 2 presents the same pipeline timing information for GSE securitized loans. As shown, the average number of days between the loan origination date and the origination date of the grantor trust pass through security that is guaranteed by either Freddie Mac or Fannie Mae using data for about 45 million GSE insured loans as reported in McDash Analytics, LLC data. As shown in Figure 2, the securitization timing for private label securitized mortgage origination started out at sixty days from 1998 up until 2004 when the accounting scandals at the GSEs significantly increased the pipeline timing up to about 100 days. As is clear in Figure 2, the accounting scandals starting in June of 2003 had very significant effects on the securitization hazard of the GSE channel. On June 9, 2003, Freddie Mac was forced by its regulator, the Office of Federal Housing Enterprise Oversight (OFHEO), to fire its CEO and several senior executives. Then on June 11, 2003, Freddie Mac became the subject of a criminal investigation.

On December 18, 2003, OFHEO released a report on Freddie Mac that resulted in a $125 million penalty and an extensive list of mandatory corrective actions. OFHEO then required Fannie Mae to revise by over $1 billion of its balance sheet data from its October 2003 earnings release. OFHEO released its special examination report of Fannie Mae on September 17, 2004 and on December 6, 2006 Fannie Mae announced that it would reduce its earnings for 2002, 2003, and the first half of 2004 by more than $6 billion[22] Each of the 2003 through 2004 scandal related announcement dates appear to have significantly disrupted GSE securitization rates although the December 2006 report appears to have been anticipated. The GSE pipeline securitization hazards again significantly increased in the early crisis period starting in February, 2007 and did not fall again until July, 2008 when they stabilized after the announcement of the GSE conservatorship in September 6, 2008. The post-crisis period under the conservatorship appears to represent a significant regime shift toward relatively stable pipeline securitization hazards of about forty days with a slight increase in 2014.

Of course, the frequency distributions of pipeline timing is also a concern to market participants and it is crucial for the ex ante pricing of the repo positions. For this reason we present the distributions for the volume of loan origination by time bins, measured in days, for loans securitized through the private-label and GSE channels. Figure 3 presents the pipeline volume by time bins for loans securitized through private label channels. The data are presented in eleven pipeline time bins starting at an up to a 30 day pipeline bin, a more than 30 up to a 60 day bin, and so on up to a more than 300 day bin. As is clear from Figure 3 about one half of the lower end of the private label frequency distribution lies in

[22]See Felton (2008); OFHEO (2003, 2004).

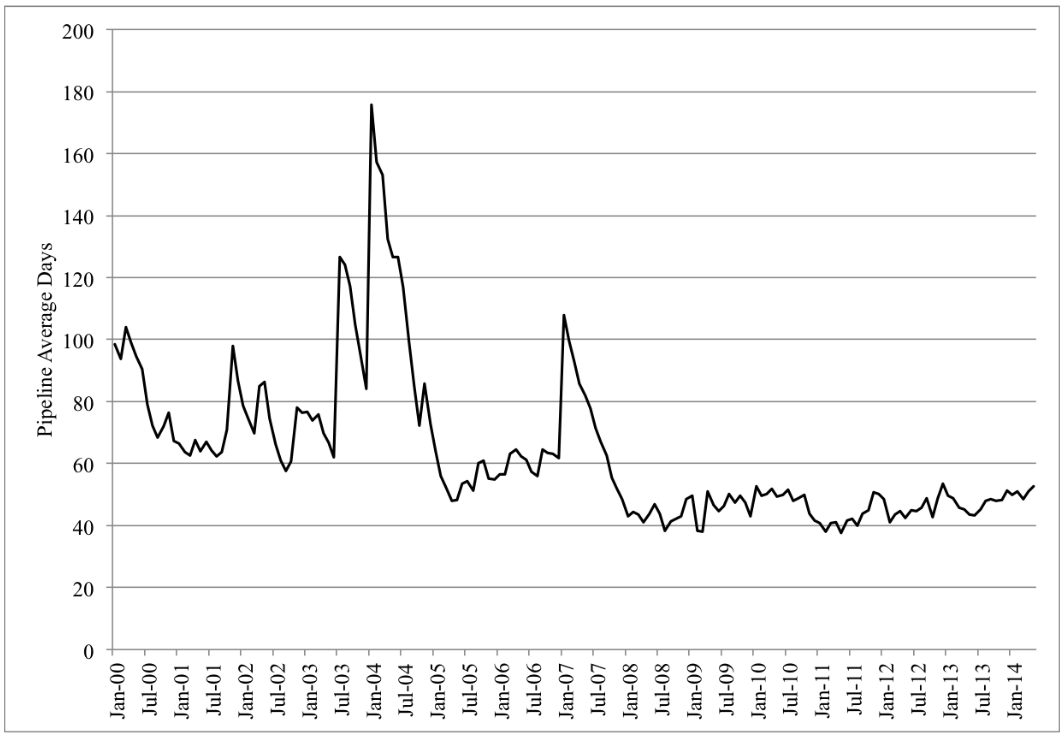


Figure 2: Pipeline period for GSE guaranteed mortgage backed securities. The pipeline period is measured as the average number of days from the loan origination date to the date the loan is recorded as part of a grantor trust pass through security that is guaranteed by either Freddie Mac or Fannie Mae. Sample is 45.7 million GSE insured residential single family fixed rate 8loans as reported in McDash Analytics, LLC Data.

the greater than 61–90 day and 91–120 day bins. The 121+ day and 151+ day bins also account for a sizable share of the origination volume.

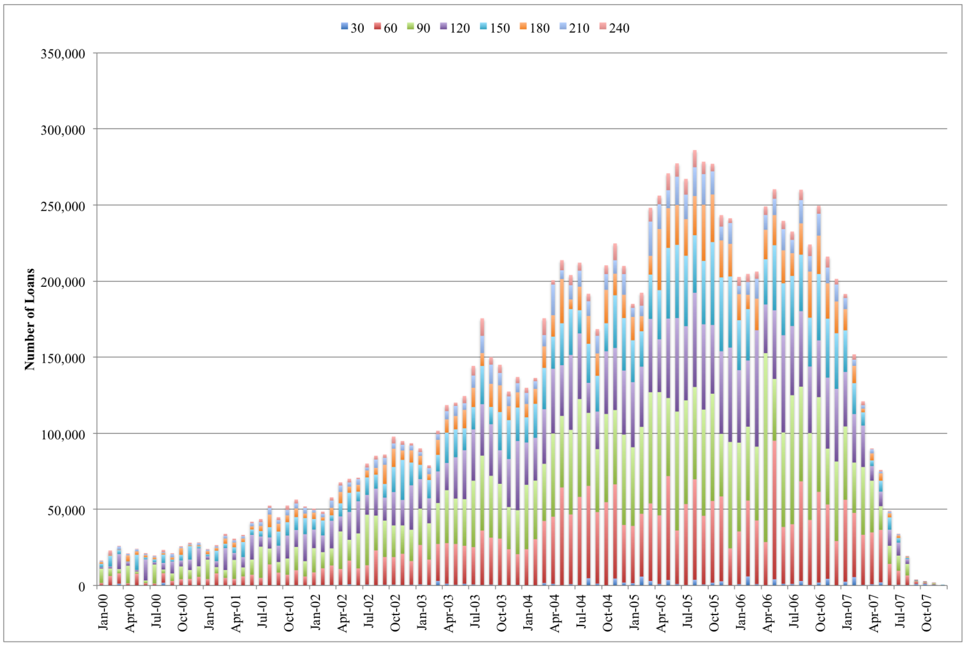


Figure 3: Pipeline volume (number of loans) by time bins (measured in days) for single family residential fixed rate mortgages securitized through private label channels. Data are represented in eleven pipeline time bins (e.g., 30 days, 60 days, 120 days, . . . , 240 days). Source: Moody's Lewtan/ABSNet for 12.997 million single family residential mortgages.

Figure 4 presents the frequency distribution over Figure 3. In contrast to the private label origination shown in Figure 3, the bulk of the GSE origination volume was in the pipeline between thirty and sixty days. Interestingly, the 30 day pipeline bin appears to represent a substantial share of mortgage originations destined for GSE securitization over the full sample period. The dislocations noticed in the mean pipeline times due to the GSE accounting scandals and to the financial crisis episode are substantially more muted in the persistence of the 30 day bin for securitization.

Overall, between 2000 and 2007, as shown in Figure 4 and Figure 3, there has been considerable variability in the timing risk of the mortgage pipeline. The securitization hazards we have identified appear importantly vulnerable to operational risks associated with the management of the GSEs, to fluctuations in the volume of mortgage origination, to the degree of competition in the investor channels, and to catastrophic shocks if government actions are not called on to intervene as in the case of the GSEs. Clearly, for participants in the mortgage origination, the warehouse lines that, as discussed, funded upwards of two thirds of mortgage origination in the pre-crisis period and about 51% of origination post-crisis, is a

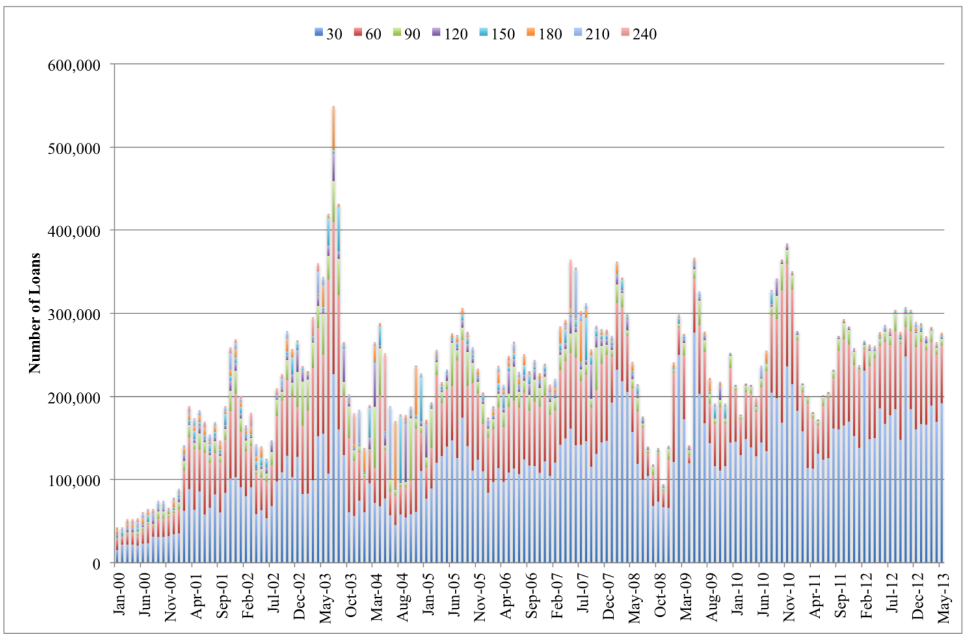


Figure 4: Pipeline volume (number of loans) by time bins (measured in days) for fixed rate single family residential mortgages securitized through GSE channels. Data are represented in eleven pipeline bins (e.g., 30 days, 60 days, 120 days, . . . , 240 days). Source: McDash Analytics, LLC data for 36.8 million single family residential mortgages securitized by a GSE.

pure bet on the liquidity of the mortgage warehouse positions to SPE investor channels either through the GSEs or through private label securitization. In both the pre and post crisis period the liquidity dynamics of the pipeline are essential to the functioning of mortgage origination in the U.S.

Another way to summarize Figures 3–4 is to take longitudinal cuts from the data, and compare securitization ratios over a given period of time. For a given origination cohort between January 2000 and December 2013, compute the the proportion of those loans that are securitized within one month. If securitization is seen as a mortality event, then this proportion is a hazard rate, which we will call securitization hazard. A market i characterized by faster arrival of SPE investor demand will in general exhibit a higher $hazard_i$ (where $i \in \{\text{GSE}, \text{PL}\}$).[23] Conversely, a low $hazard_i$ implies a low probability of securitization within 1 month. Figure 5 compares the results for private label and GSE markets.

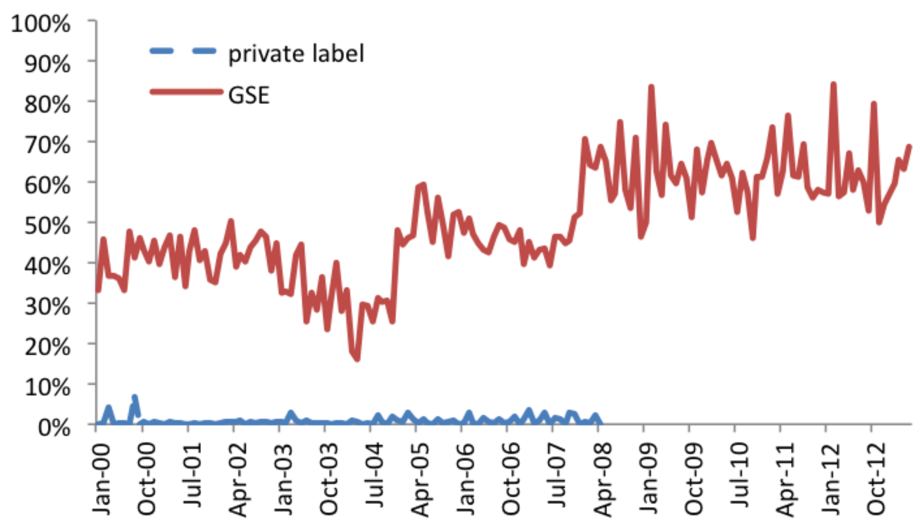


Figure 5: Time series of securitization hazard: private label and GSE

Thus the securitization hazard $hazard_i$ is a measure of liquidity flow in the pipeline i. So far we have documented a higher securitization hazard in the agency market relative to the private label market. We will now consider the price impact of these differences.

[23]The securitization hazard is an ex post measure that proxies for market liquidity, and the only characteristic of our mortgage/bond equivalents that are being priced. We only keep AAA-rated private label bonds so there are *no* other quality differences for these instruments. In fact large amounts of private label loans were conventional conforming mortgages and were, therefore, eligible for GSE securitization so "good" mortgage went through both channels. So the price differences across markets captured here are not indicative of a difference in the quality of the underlying mortgages.

4.2 The securitization hazard and mortgage-backed securities prices

In order to examine the effect of our securitization hazard on MBS pricing, we gather pricing data on both agency and private label securities for newly originated MBS through first quarter of 2007. The preferred indicator for the prices of newly issued GSE MBS is the To Be Announced (TBA) forward markets (see Vickery and Wright, 2013, for an explanation of the mechanics of this market). An important feature of TBA traded securities is their homogeneity: a security is characterized by six parameters: issuer, coupon, maturity, price, face value (or par amount) and the settlement date.[24] Agency RMBS trading is reported to the Financial Industry Regulatory Authority's (FINRA) Trade Reporting and Compliance Engine (TRACE), and pricing data is publicly available. There is one time series for each maturity and each coupon. We use prices for 30 year, fixed rate mortgage bonds, keeping the most prevalent coupon TBA as the current bond for each month. Figure 6 plots TBA prices by agency between January 1996 and May 2015.[25] This time series of TBA prices represents an index of current coupon forward prices and is our proxy for the price of newly originated GSE securities. As shown in Figure 6, the current coupon prices of Fannie Mae and Freddie Mac TBA forward contracts are always within $0.50 of each other over the whole time series. There is also considerable volatility in these price series.

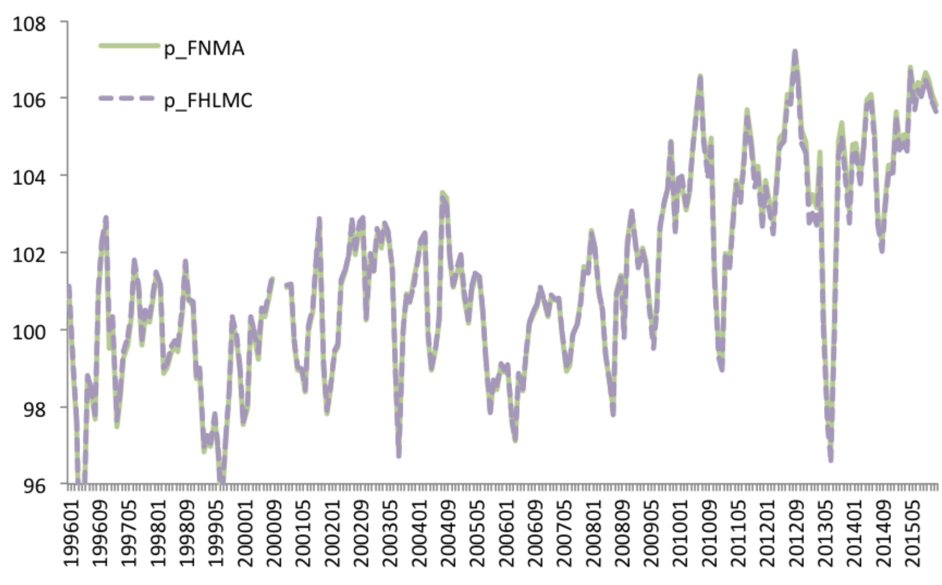


Figure 6: TBA prices by agency: 30 year, fixed rate mortgages

[24]The TBA pools are not actually homogeneous even within coupon groups. Instead, an appearance of homogeneity is enforced by revealing only the six parameters as a trading convention to enhance market liquidity (Downing, Jaffee, and Wallace, 2009).

[25]Data on Ginnie Mae securities yield very similar results; we omit them from our analysis for the sake of brevity, and will make them available upon request.

For private label securities, we use pricing data from Moody's/Lewtan website. We have bid and ask series between 2004 and 2007 for 11,079 distinct bonds from newly originated private label residential mortgage backed security (RMBS) deals. For our analysis, we use the 7,198 RMBS bonds that were rated AAA at origination and remain AAA over the period. These AAA bonds are of 5 and ten year maturities at origination, but the typical duration of these securities is significantly less due to prepayment. Figure 7 plots the average bid price for all of the outstanding newly originated AAA bonds and the corresponding TBA prices between 2004 and 2007. As shown, in Figure 7 the short maturity AAA RMBS trade at consistently lower prices than the longer maturity agency TBA forward contract prices for the same month. The relative volatilities of the two price series appear to be comparable.

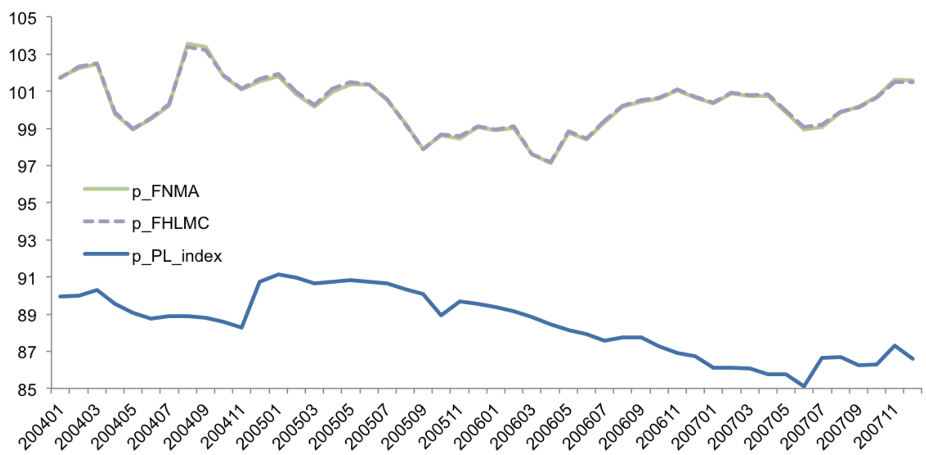


Figure 7: Private label RMBS average bid price (AAA securities) and agency TBA prices, 2004–2007. In each time period, agency TBA prices are listed at the most prevalent coupon.

While using the most prevalent coupon ensures the selection of the correct cohorts, it means that coupon changes over time in our series. Changes in coupon imply changes in prices. We address this problem by deflating TBA prices $p^{c(t)}_{TBA,t}$ (where $c(t)$ is the most prevalent coupon at time t). From the panel security prices by date and coupon $p^{c}_{TBA,t}$ for all t, c we can deflate our $p^{c(t)}_{TBA,t}$. The deflated series $p_{TBA,t}$ is obtained from the following recursive formula

$$p_{TBA,t} = p^{c*}_{TBA,t-1} \frac{p^{c(t)}_{TBA,t}}{p^{c(t)}_{TBA,t-1}},$$

where $p_{TBA,1} = p^{c(0)}_{TBA,0} \frac{p^{c(1)}_{TBA,1}}{p^{c(1)}_{TBA,0}}$.[26] We do not use a similar deflating strategy for the private label RMBS prices because these bonds are all indexed to a short term LIBOR rate.

[26]This implies that the basis for the deflator is $c(0)$

To assess whether our measures of the securitization hazard are reflected in bond prices, we consider regressions of the above bond price series on the thirty day securitization hazard, a measure of the dispersion in the timing of the securitization speed, and the 10 year constant maturity Treasury yield. Thus, for agency securities we run the following time series regression of TBA average current coupon forward prices on our securitization speed measure along with the other control covariates,

$$\begin{aligned}\Delta p_{TBA,t} = \beta_0 + \beta_h\ hazard_{GSE,t} + \beta_d\ timing\ dispersion_{GSE,t} \\ + \beta_c\ CMT\ treas\ yield(10Y)_t + \beta_y\ year_t + \varepsilon_{GSE,t}. \quad (1)\end{aligned}$$

using year indicator variables and assuming that the error terms $\varepsilon_{GSE,t}$ are i.i.d. normal.

Similarly for the AAA private label RMBS, we regress the monthly change in each bond's prices on the same set of regressors that are used for the GSE price index regressions. AAA bonds are floating, and thus indexed to LIBOR, so we control for LIBOR changes. The resulting panel regression is thus

$$\begin{aligned}\Delta p_{lt} = \beta_0 + \beta_h\ hazard_{PL,t} + \beta_d\ timing\ dispersion_{PL,t} + \\ \beta_c\ CMT\ treas\ yield(10Y)_t + \beta_b\ \Delta\ LIBOR(3m)_t + \beta_y\ year_t + \varepsilon_{lt}. \quad (2)\end{aligned}$$

where the error terms ε_{lt} are again assumed to be i.i.d. normally distributed. We also include individual bond-level fixed effects and year indicator dummies.

We report the results of the GSE TBA regressions in Table 2. One limitation with the TBA data is that the reported trading prices are for forward contracts organized by the six pool indicative parameters for a given coupon and trading date. Thus, sample size is limited to the one reported price per date, since the pools have not yet been delivered, and there is no time series price heterogeneity across different pool identification numbers because the pools do not yet exist.[27] Despite this limitation, the TBA data are the industry standard for "new origination prices."

As shown in Table 2, the thirty-day securitization hazard at month t has an economically important effect on TBA forward prices and it is statistically significant at the 10 percent level or less for both the Fannie Mae and the Freddie Mac specifications. Unfortunately given the small time series sample size, the dispersion of the securitization times for mortgages in month t is not shown to be statistically at standard cut-off levels. In our preferred

[27] There is very limited data on the trading prices of individual bond pools because after origination they trade rarely except in a highly illiquid stipulated coupon (STP) market.

specification reported in columns (3) and (6), the ten year constant maturity treasury yield is statistically significant in the Freddie Mac specification, however, it is significant at the 10 percent level in the Fannie Mae specification. The coefficients for all three of the time series covariates and across all of the specifications appear to have quite similar effects on the deflated trading prices of both the Fannie Mae and the Freddie Mac TBA contracts. Overall, despite the high level volume of GSE mortgages that are securitized within thirty days of origination, as shown in Figure 4, the securitization hazards for individual mortgages do appear to affect TBA forward prices such that higher securitization hazards are associated with higher prices. This results suggests that there is an important association between liquidity in the mortgage pipeline and the prices of TBA forward contracts, our proxy for GSE prices.

	Fannie Mae securities			Freddie Mac securities		
	(1)	(2)	(3)	(1)	(2)	(3)
	Δp_t	Δp_t	Δp_t	Δp_t	Δp_t	Δp_t
Thirty day securitization hazard at month t	2.781***	3.120**	2.985*	1.797	2.099*	3.152**
	(3.06)	(3.38)	(2.44)	(1.96)	(2.25)	(2.73)
Dispersion in securitization time at month t	0.004	0.007	0.006	-0.001	0.002	-0.002
	(0.90)	(1.56)	(1.28)	(-0.31)	(0.41)	(-0.48)
Ten year constant maturity treasury yield		-0.152	-0.314		-0.143	-0.541***
		(-1.66)	(-1.93)		(-1.54)	(-3.47)
Constant	-1.816***	-1.435*	-0.172	-1.097	-0.722	1.472
	(-3.26)	(-2.40)	(-0.16)	(-1.95)	(-1.18)	(1.42)
Year fixed effects	No	No	Yes	No	No	Yes
Observations	107	107	107	105	105	105

t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2: The table presents the regressions of the month-t thirty-day securitization hazard for mortgages originated at the beginning of month t on the change in the prices for Fannie Mae and Freddie Mac To-Be-Announced (TBA) forward contracts for the delivery of current coupon, thirty year fixed rate mortgages between months t-1 and t. The table shows the outcome of the time series regression outlined in equation 1 for reported TBA forward contract prices between 1999 and March 2007. Observations include up to the first quarter of 2007 for consistency with the private label data. All regressions control for the cross-sectional dispersion of times to securitization, computed as the standard deviation of times to securitization for the given cohort month, and time fixed effects.

Table 3 reports the results of the panel regression of private label RMBS prices on our measure of the thirty day securitization hazards for private label mortgages. As shown in Table 3, the thirty day securitization hazard has an economically important positive effect on RMBS bond prices and it is statistically significant at better than the 1 percent level in all of the specifications. Similarly, the dispersion of the securitization times has a smaller negative effect on price changes and it is also statistically significant at the 1 percent level. The ten year constant maturity treasury yield is now statistically significant at the 1 percent level and higher treasury yields are associated with lower RMBS bond prices. Again, the coefficients for all three of these time series covariates are quite stable over all three specifications. Overall, the securitization hazards for individual private label mortgages do appear to strongly positively affect RMBS bond prices. Again, this result suggests that there is an important association between liquidity in the mortgage pipeline measured both by the hazard levels and the dispersions in the timing of loan-level securitization in a given month and the changes in RMBS bond prices.

Of course, these associations do not really provide a causal explanation for the mechanisms by which the mortgage origination flows are affected by the repo contracting structure that is widely used to fund mortgage originations in both the GSE and the private label channels. What is of particular interest in comparing Tables 2 and 3 is that there are important differences in the effects of the securitization hazards on TBA and RMBS bond price dynamics. Overall, the hazards are faster for mortgages securitized through the GSE channel than are the hazards for mortgage securitized through the RMBS private label channel and these liquidity proxies have economically important effects on the bond price dynamics in their respective markets. We now turn to a model of how the repo contracting structure and these differing empirical regularities in the ex post realization of the operation of the GSE and the private label channels are also likely to lead to important differences in the market fragility of these two channels.

5 A model of repo-funded mortgage origination

As previously discussed, under a MRA, the repo seller uses its revolving lines to fund mortgages that it originates in its own name. For every borrowed dollar on the line, the repo buyer simultaneously perfects an interest in the mortgage that is subject to a commitment on the part of the repo seller to reimburse the repo buyer for the mortgage collateral within a designated number of days. The repo seller is subject to a haircut on each dollar of loan balance originated.[28] Since the repo seller does not have a perfected interest in the mortgage, the repo seller's transaction with the SPE investor is done through a bailee letter.[29] The

[28] The haircut is charged as a percentage of balance, such that less than 100% of the loan would be funded, or owned, by the warehouse lender.

[29] The sale under a "bailee letter" is a sale in which the investor is notified about the repo buyer's security interest in the related mortgage loan, thus preserving the repo buyer's perfected interest, and directs the sale proceeds to be delivered to the repo buyer. It also contains the repo buyer's release of its security interest

	(1)	(2)	(3)	(4)
	Δp_{lt}	Δp_{lt}	Δp_{lt}	Δp_{lt}
Thirty day securitization hazard at month t	0.141***	0.128***	0.0932***	
	(5.71)	(5.21)	(3.39)	
Dispersion in securitization time at month t	-0.000179***	-0.000823***	-0.000584***	-0.000707***
	(-4.97)	(-18.82)	(-8.25)	(-14.33)
Change in 3m LIBOR	0.000608	0.00338	0.0112	0.00644
	(0.08)	(0.44)	(1.44)	(0.83)
Ten year constant maturity treasury yield		-0.0199***	-0.0290***	-0.0221***
		(-26.02)	(-31.58)	(-27.59)
			(1.90)	
year=2004 × hazard_PL				0.0701
				(1.42)
year=2005 × hazard_PL				-0.212***
				(-5.74)
year=2006 × hazard_PL				0.375***
				(9.51)
year=2007 × hazard_PL				0.314***
				(6.96)
Constant	0.0104***	0.139***	0.163***	0.142***
	(4.54)	(25.52)	(25.20)	(24.85)
Year fixed effects	No	No	Yes	No
Bond fixed effects	Yes	Yes	Yes	Yes
Observations	1,435,486	1,435,486	1,435,486	1,435,486

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: The effect of the securitization hazard on the bid prices for private label RMBS bonds. The table shows the outcome of the panel regression outlined in equation 2 for all tranches, l, that were rated AAA at origination by Standard&Poor's, stayed AAA bonds, and were traded between February 2004 and March 2007. The dependent value is the first difference in bid price for the given bond between month t-1 and month t. Observations include up to April 2007 to exclude the impact of the repo market shutdown that took place from Q2 2007 onwards. This regression controls for monthly change in 3m LIBOR rates.

sale proceeds from the sale to the SPE investor is then paid to the repo buyer. Upon receipt of the sale proceeds, the repo buyer releases its interests in the mortgage/trust deed and the promissory note to the SPE investor. The net proceeds from the sale (purchase price of the collateral from the SPE minus interest charges from the repo buyer) are then reimbursed to the repo seller's credit line.

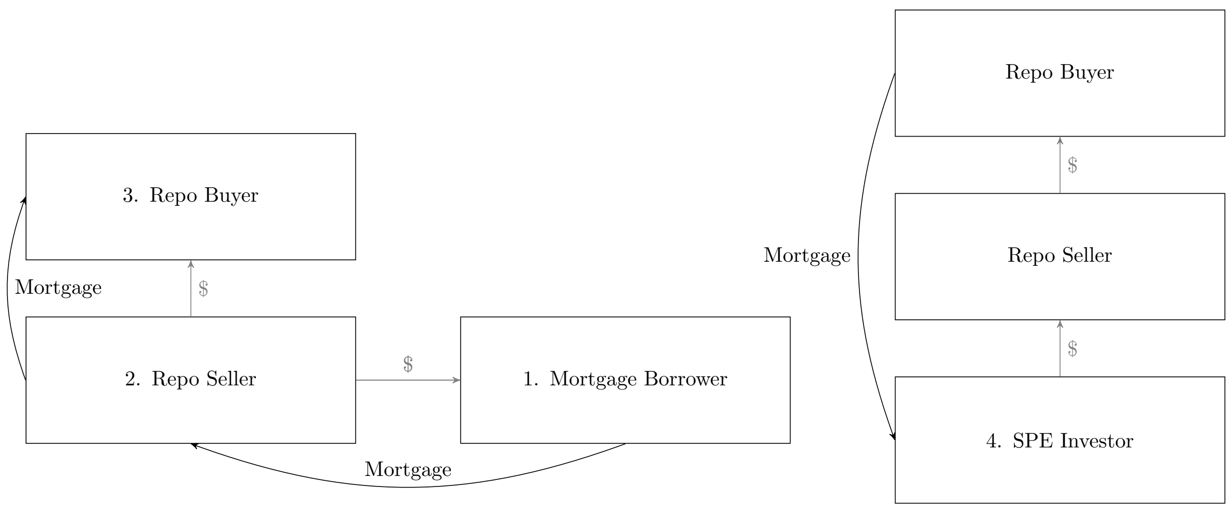
Subfigure (a) in Figure 8 presents the repo setup discussed above, where the mortgage collateral (the mortgage/trust deed and promissory note) flows from the borrower to a perfected interest on the repo buyer's balance sheet. The funding flows move from the repo buyer who provides dollars minus a haircut to the repo seller to fund the loan to the borrower. Under the MRA, it is the responsibility of the repo seller to find a willing SPE and sell the mortgage to an SPE investor. The allowed time for the repo seller to accomplish this sale without additional penalties is stipulated in the MRA. This timing, or liquidity, risk is the fundamental risk of warehouse lending to the repo seller since they are at risk of interest charges (margin calls) on tardy sales as well as losses associated with cancellations on their lines and total collateral losses in the case of bankruptcy. The repo buyer's risks are associated with possible duration mismatch risks associated with their funding strategies and potential losses associated with collateral liquidations. Surprisingly, the underwriting risk is borne by the repo seller.

Through the setup phase, the repo seller obtains short term finance to fund the mortgage borrower. This intermediate step creates an imbalance between the assets and liabilities of the repo seller, who holds a liability from the mortgage debt but does not hold the corresponding trust deed. Once the repo is unwound the mismatch is corrected.

Subfigure (b) in Figure 8 presents the unwind of the repo position that occurs after the sale under the bailee letter to the SPE investor. At the sale into the SPE, the SPE investor pays the repo buyer for the purchased mortgages in exchange for the transfer of the interest in the mortgage/trust deed and the promissory note from the repo buyer. The repo buyer then deducts interest charges (margin) on the borrowed balances and reimburses the net proceeds from the sale to the line of credit held by the repo seller. The hold-for-sale mortgage positions of the repo seller and the hold-for-investment balances of the repo buyer are then cleared.

We discussed in Section 4 how pipeline performance differs between the private label and GSE investors: there are important differences in the pipeline timing exposures to the repo buyers and seller when transacting with one or the other of these investors. The repo buyer is

upon receipt of payment. See Warehouse Lending from A to Z, Part One and Two, Mortgage Banking Association Webinars by Sophie B. Schubert, Joe Lathrop, Tom Kelly, Esquire, September 17, 2013 and September 24, 2013.



(a) Repo setup (b) Repo unwind

Figure 8: Schematic for warehouse lending under master repurchase agreements. Figure (a) presents the repo setup, where: (1) a mortgage borrower obtains a mortgage funded by a mortgage originator; (2) the repo seller, mortgage originator, funds the loan with repo collateralized by the mortgage note; (3) the repo buyer, warehouse lender, holds the mortgage repo collateral against the draw on the line of credit (the draw amount is valued at the loan balance minus a haircut). Figure (b) shows the repo unwind where: (4) the repo seller must sell the loan to an SPE investor to unwind the repo position. The proceeds from this sale flow directly to the repo buyer who releases the mortgage/trust deed to the SPE and reinstates the line of credit (minus the haircut) to the repo seller for subsequent transactions, and pays the residual to the repo seller.

placing a bet on liquidity when funding the seller. We highlight this aspect of market timing by incorporating random SPE arrival into a model of market liquidity. The SPE investor demand arrives at uncertain times, which creates a significant risk for the repo seller.

The results reported in Section 4.2 document important differences in the pre-crisis securitization hazards for newly originated mortgages that were sold through the private label and GSE securitization channels. The liquidity of either channel is determined by possible supply and demand imbalances between borrower demand for and originator supply of new mortgage originations and the willingness of mortgage securitizers, the SPEs, to invest in these mortgages. Because the prices of the securitized bonds in these two channels and the assets that collateralize them (the mortgages) are affected by the respective liquidity in the channel, it is likely that deviations of the respective bond prices from their fundamental values are also correlated with the differential funding constraints in the channels (see, for example, Grossman and Miller, 1988; Brunnermeier and Pedersen, 2009).

As in Section 4.2, we interpret empirical securitization hazards as proxies for market illiquidity where a securitization hazard of less than one implies a more illiquid market. This interpretation gives us the means to calibrate a model in which we explore the properties of the two differing securitization channels. In particular, our focus will be on the effect of funding the GSE and private label securitization channels using repo contracts that are bets on the speed of securitization and are priced via haircuts. In addition to the securitization hazards, following Brunnermeier and Pedersen (2009) we will also consider the effect of the volatility of asset values (σ) on repo haircuts using empirical measures derived from the bond price dynamics of the two respective securitization channels. These two proxies for market liquidity, the empirical securitization hazards and fundamental bond price volatility allow us to characterize expected differences in the role of repo haircuts in stabilizing or destabilizing the functioning of these two securitization channels.[30]

Comotto (2012) suggests that haircuts potentially amplify market pro-cyclicality because they can act either as offsets or accelerators of market imbalances. Brunnermeier and Pedersen (2009) emphasize the role of the repo buyers' asset value information in determining whether haircuts will stabilize the market (i.e., cushion the effect of market imbalances). In our model, repo buyers could be uninformed about asset values, but still face a fragile market due to the securitization hazards and the volatility of asset values that characterize the two securitization channels.

[30]We also assume that the volatility of the fundamental value of the mortgage bonds is perfectly correlated with the volatility of the fundamental value of the underlying mortgage collateral.

5.1 Demand imbalances between mortgage borrowers and SPE investors

Borrowers demand new mortgage loans and this exogenous demand brings a supply of mortgage collateral to the repo market. For the repo market to clear, the SPE investors must have symmetric demand for the outstanding supply of mortgage collateral. In the long run, the demand for mortgage related collateral matches the supply, but in the short run, an excess supply of mortgage related repo collateral can build up. We proxy for the imbalances between supply and demand using our measures of the securitization hazards for newly originated mortgages since we know from the results of Section 4.2, that the securitization hazards are priced in the traded mortgage bonds.

Stanton and Wallace (2011) examine the price of credit default swaps on mortgage-backed securities. They find that market prices were far away from fundamentals during the crisis, and suggest that short-sale activity was a potential source of market imbalance. In our model, imbalances in the repo market arise from exogenous frictions to mortgage investor demand by SPEs and the concomitant increases in the supply of mortgage repo collateral on the repo buyers' balance sheets and increases in the repo related funding liabilities on the repo sellers' balance sheets. These excess mortgage repo balances can build over time if they are not immediately met by the SPEs' mortgage investment demand because only the SPEs can act to clear the market. In the short-run, endowment related mortgage demand shocks on the part of borrowers can lead to a larger supply of mortgage related repo collateral held by repo buyers and funded by repo sellers.

The key feature of our model is that market illiquidity, $\Lambda_{i,t}$, defined as the difference between fundamental value, the risk adjusted present value of the cash flows, $(v_{i,t})$, and market price, $(p_{i,t})$, arises from shocks to the mortgage demand endowments of borrowers and the SPE investor who also experiences an investment timing friction. The magnitude of those shocks are proxied by our measure of the time varying securitization hazards of newly originated mortgages.[31] Market imbalances are temporarily absorbed by repo sellers, who perform an arbitrage function (Gabaix, Krishnamurthy, and Vigneron, 2007) using funds from the repo buyers, as in Figure 8, until the securitization investor, the SPE, arrives in the market.

[31] Without loss of generality we will focus on economies where the initial excess demand is negative. Thus in equilibrium, repo sellers hold long positions in periods 0 and 1, implying illiquidity Λ is positive. We do this without loss of generality as repo haircuts on short and long positions are symmetric.

The mortgage asset is risky. As in Brunnermeier and Pedersen (2009), we assume that changes in the mortgage asset's fundamental value, $v_{i,t}$, follow an ARCH process,

$$\Delta v_{i,t+1} = \sigma_{i,t+1}\varepsilon_{i,t+1}, \qquad \text{where} \tag{3}$$

$$\sigma^2_{i,t+1} = \kappa_i + (\theta_i \, \Delta v_{i,t})^2. \tag{4}$$

Here, θ_i is an autocorrelation parameter, κ_i represents a baseline volatility, and $\varepsilon_{i,t+1} \sim$ i.i.d. $N(0,1)$. We condition the Brunnermeier and Pedersen (2009) model with empirical estimates for $\kappa_{\text{GSE,PL}}$ and $\theta_{\text{GSE,PL}}$ using an ARCH(1) model and mortgage bond price data for the GSE and private label securitization channels. In the absence of data to calibrate the model, the results about fragility can only be linked to whether market agents are uninformed (cannot distinguish between $p_{i,t}$ and $v_{i,t}$). We show that markets can be less fragile, even if agents are uniformed, if $\theta_i < 0$. We provide empirical evidence that this is the case for GSE markets, while private label markets exhibit positive levels of autocorrelation leading to greater market fragility.

We use a three-period model, $t \in \{0, 1, 2\}$. In the last period, the value of the asset $v_{i,2}$ is realized and all positions are liquidated whereas before that the asset is traded and trades are funded. There are two traders $k_i \in \{0, 1\}$, consisting of one borrower ($k_i = 0$ arriving at $t = 0$) and one SPE investor ($k_i = 1$ arriving at $t \in \{0, 1\}$). The borrower and SPE investor start with $W^{k_i}_{i,t}$ cash and \$0 mortgages. Each of them is subject to an endowment shock of a mortgage. For the borrower, $k_i = 0$, the shock $z_{i,0}$ is deterministic and happens at $t = 0$. For the SPE investor, $k_i = 1$ and $t \in \{0, 1\}$, the total shock is also deterministic and clears the market, i.e., $z_{i,1} = -(z_{i,0})$.[32] Figure 9 represents the supply and demand events in a timeline.

The ex post probability of arrival of the SPE investor's demand within time 0 is determined by the securitization hazard of the channel. The excess supply of loans in the market is determined by $1 - hazard_{i,0}$, which determines the proportion of loans that remain to be securitized and thus must continue to be funded through the repo. The main point is that a lower hazard rate implies a larger aggregate excess supply $Z_{i,0}$. We capture this risk of excess supply using a uniform distribution

$$Z_{i,0} \sim U[1 - hazard_{i,0} - s_i, 1 - hazard_{i,0} + s_i]$$

[32] We represent $z_{i,1}$ as a negative supply shock, which is equivalent to a positive demand shock, for notation convenience.

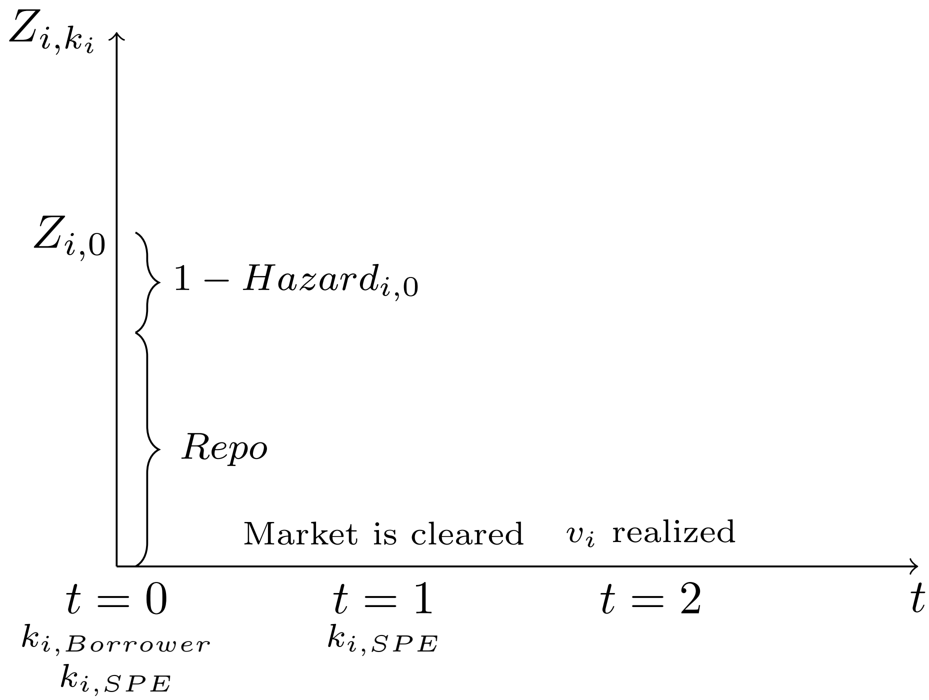


Figure 9: Model timeline. The schematic represents the evolution of mortgage supply and demand as driven by the arrival of the borrower and SPE investor from $t = 0$ onwards.

where s_i is a dispersion parameter and the $hazard_{i,0}$ differs between the private label and GSE market, as discussed before. By construction we have that $Z_{i,1} = 0$, i.e., the market clears at time 1.

Each of the two agents (borrower and SPE) will issue a net demand schedule $y_{i,t}^{k_i}$ ($y_{i,t}^{k_i} < 0$ denoting supply) in order to maximize a CARA utility function over final wealth

$$U(W_{i,2}^{k_i}) = E\left[-e^{-\delta W_{i,2}^{k_i}}\right].$$

($y_{i,t}^{k_i} = 0$ if k_i is not present in the market at time t, e.g., if the SPE demand has not arrived in the market or if the borrower has exited). Their wealth evolves according to

$$W_{i,t+1}^{k_i} = W_{i,t}^{k_i} + (p_{i,t+1} - p_{i,t})(y_{i,t}^{k_i} + z_i^{k_i}), \tag{5}$$

where $y_{i,t}^{k_i}$ is their demand schedule and $z_{i,t}^{k_i}$ is the endowment shock.[33]

Through the risk aversion of market agents, the securitization hazard of newly originated mortgage supply and the bonds collateralized by that supply will be priced. Our model explains the results in section 4.2 as follows.

Proposition 1. Equilibrium prices are given by $p_{i,0} = v_{i,0} - 2\delta(y_{i,0}^0 + 1 - hazard_{i,0})\sigma_1^2$. It follows that prices are increasing in the securitization hazard, i.e., $\frac{\partial p_{i,0}}{\partial hazard_{i,0}} > 0$.

The proof is given in Section A, but the main intuition is that agents are risk averse. SPE wealth is subject to an endowment shock that affects the variance of the payoff distribution, which makes the parameters of that endowment shock priced. Because the excess supply risk is priced, the securitization hazard has price impact.[34]

Prices in this model are determined by the risk averse agents, the borrower and the SPE investor. As mentioned before, as soon as SPE investor demand is fully present the market clears. Otherwise, another market agent would be necessary to temporarily clear the market. Now we will look at the effect of the securitization hazard on repo markets through its effect on the repo haircuts.

[33] Given the absence of aggregate risk we normalize the interest rate to zero in order to simplify calculations. The results would only differ if we were modeling the rollover option.

[34] Note that securitization dispersion is not priced, which is related to our use of a uniform distribution. In our CARA specification, skewness in the distribution would be needed to generate an effect of securitization dispersion.

5.2 The securitization hazard and the repo haircut

In the short run, the agent who arrives to fund the mortgage demand shocks from borrowers will fund through a repo transaction, and so we call him the repo seller. Because he is risk neutral (he maximizes his expected final wealth $E[W_2]$). His wealth evolves according to

$$W_{i,t+1} = W_{i,t} + (p_{i,t+1} - p_{i,t})x_{i,t} \tag{6}$$

where $x_{i,t}$ is his demand schedule. Repo sellers smooth out temporary market imbalances by buying mortgage assets from borrowers at time t and holding these assets until $t + 1$.

The repo buyer provides collateralized funding for the repo seller's trades. In order to successfully complete the repo unwind phase (see Figure 8), the repo seller must repay the loan that was provided to them. The repo buyer sets a haircut $h_{i,t}$ in order to ensure that the loan will be repaid with a given probability, i.e., in order to control the Value at Risk (VaR) on the portfolio they are funding. In our setting haircuts target a VaR of $1 - \pi_i$ (for a small value of π_i, e.g., $\pi_i = 1\%$)

$$\pi_i = \mathbb{P}(p_{i,1} - (p_{i,0} - h_{i,0}) < 0|\mathcal{F}_{i,t}). \tag{7}$$

For Brunnermeier and Pedersen (2009) the key determinant of haircuts is whether the repo buyer is informed ($\mathcal{F}_i 0 = \{p_{i,0}, v_{i,0}\}$) or uninformed ($\mathcal{F}_{i,0} = \{p_{i,0}\}$). We will assume the latter, so that the repo buyer cannot distinguish between price and value, and will assume price follows the stochastic process given in 4 when solving (7). This gives

$$\begin{aligned}\pi_i &= \mathbb{P}(\sigma_{i,1}\varepsilon_{i,1} + h_{i,0} < 0|\mathcal{F}_{i,0}) \\ &= 1 - \Phi\left(\frac{h_{i,0}}{\sqrt{\kappa_i + (\theta_i\,\Delta p_{i,0})^2}}\right)\end{aligned}$$

We obtain the following haircut formula:

$$h_{i,0} = \Phi^{-1}(1 - \pi_i)\sqrt{\kappa_i + (\theta_i\,\Delta p_{i,0})^2}. \tag{8}$$

Equation 8 shows that haircuts are driven by the second moment in the distribution of mortgage asset values. In particular, haircuts are increasing in baseline volatility κ_i of mortgage bond prices and in the autocorrelation parameter, θ_i^2, of price volatility.

A static illiquidity shock $\Lambda_{i,0} < 0$ is not sufficient to force prices down. If the market is illiquid at time 0 and $\Lambda_{i,0} < 0$, but at the same time fundamental value v_i increases, the illiquidity shock is offset. However, *ceteris paribus* an illiquidity shock $\Lambda_{i,0} < 0$ does lead to a fall in price. That is the scenario assumed in the following result, which shows how the securitization hazards will affect haircuts.

Proposition 2. Suppose $\Delta p_{i,0} < 0$. Then haircuts $h_{i,0}$ are decreasing in the securitization hazard, $hazard_{i,0}$.

An illiquidity shock $\Lambda_{i,0} < 0$ leads to $\Delta p_{i,0} < 0$ if asset value is nonincreasing over the same period. Proposition 2 does not apply if the illiquidity shock is compensated by a rise in asset values, which is not a typical case since the market tends to be more liquid when asset values are rising.

Propositions 1 and 2 refer to our price regressions from section 4.2, and how prices and haircuts are driven by the securitization hazards. If mortgage asset price volatility is constant ($\theta_i = 0$) then the securitization hazard has no effect. The main intuition that drives the results in Brunnermeier and Pedersen (2009) comes from the same source, i.e., that there is autocorrelation in the variance of asset values (i.e., the variance of prices, given agents are uninformed). Our price data allow us to assess the degree of autocorrelation in mortgage bond price volatility, $Var_0(\epsilon_{i,1})$, and will give us further insight into the relative stability of the two securitization channels.

The model described in equation 4 can accommodate both the case of constant volatility (v is a random walk) and that of first order autocorrelation. We test the hypothesis of ARCH effects using Engle's Lagrange multiplier test for the presence of autoregressive conditional heteroskedasticity in TBA and private label RMBS bond price volatility. We cannot reject the null of no ARCH effects at 10% significance on either Fannie Mae, Freddie Mac or private label data. To estimate equation 4, we first assume that $\Delta v_i = \Delta p_i$ which is equivalent to assuming that repo buyers are uninformed. We estimate separate specifications for the GSE and the PL data of the form:

$$\Delta p_{i,t+1} = \gamma_{i,0} + \varepsilon_{i,t+1} \tag{9}$$

$$Var_t(\varepsilon_{i,t+1}) = \sigma^2_{i,t+1} = \beta_{i,0} + (\beta_{i,1}\, \Delta p_{i,t})^2 \,. \tag{10}$$

Constraining $\gamma_{i,0} = 0$ in the ARCH model gives the desired estimates $\beta_{i,0} = \kappa_i$ and $\beta^2_{i,1} = \theta^2_i$ for equation 4. We present the results in Table 4.

ARCH	(1) $\Delta p_{FNMA,t+1}$	(2) $\Delta p_{FHLMC,t+1}$	(3) $\Delta p_{PL,t+1}$
$\beta_{GSE,1}$ (θ_{GSE})	0.414^{*}	0.299	1.211^{***}
	(2.05)	(1.05)	(4.85)
$\beta_{GSE,0}$ (κ_{GSE})	0.378^{***}	0.391^{***}	0.209^{**}
	(3.38)	(3.93)	(3.06)
Observations	38	38	38

z statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: the table reports results for the ARCH regression specified in (4) using the Stata command for an ABARCH(1) regression. In order to estimate this time series regression on the private label data panel we collapse the cross section using a simple average of all the tranches on that date. We restrict the data to the time window common to the two datasets – February 2004 to March 2007 (38 observations). The variable used here is the deflated price series.

Table 4: ARCH(1) estimated within each market, February 2004–March 2007

As mentioned before, haircuts are increasing in baseline volatility κ_i and in the degree of autocorrelation, θ_i^2. The results from Table 4 show countervailing effects $\kappa_{GSE} > \kappa_{PL}$ and $\theta_{GSE}^2 < \theta_{PL}^2$, and so it is not obvious which market should exhibit larger haircuts. From our data we construct the time series of first differences in prices for each channel (Fannie Mae, Freddie Mac or private label). Using the parameters from Table 4 we compute the expected time varying haircut values, which we present as a proportion of the price level in Figure 10.

The average haircuts as a percentage of par are 2.57% for Fannie Mae and 2.52% for Freddie Mac, vs. 1.74% for PLS.[35] Overall this indicates haircut percentages that are on average lower in private label markets (due to the higher κ_{PL}) however, they are much more volatile, due to the large autocorrelation coefficient, θ_{PL}^2, as opposed to the negative coefficient in GSE markets. This larger volatility in private-label haircuts suggests that the PL securitization channels are more unstable. In section 5.3 we will explore this hypothesis.

[35] Unfortunately, we do not have data on the realized repo haircuts in the PL and the GSE channels. Somewhat related data that was obtained from Gary Gorton for PL structured RMBS debt in the pre-crisis bi-lateral repo markets shows realized repo haircuts of 0% from January through March of 2007 for these products. These haircuts then rose very rapidly to 45% of par from July 2007 through February 2009. This period, of course, corresponds to a period when the PL securitization channel failed, securitization hazards of 0, as shown in Figure 1.

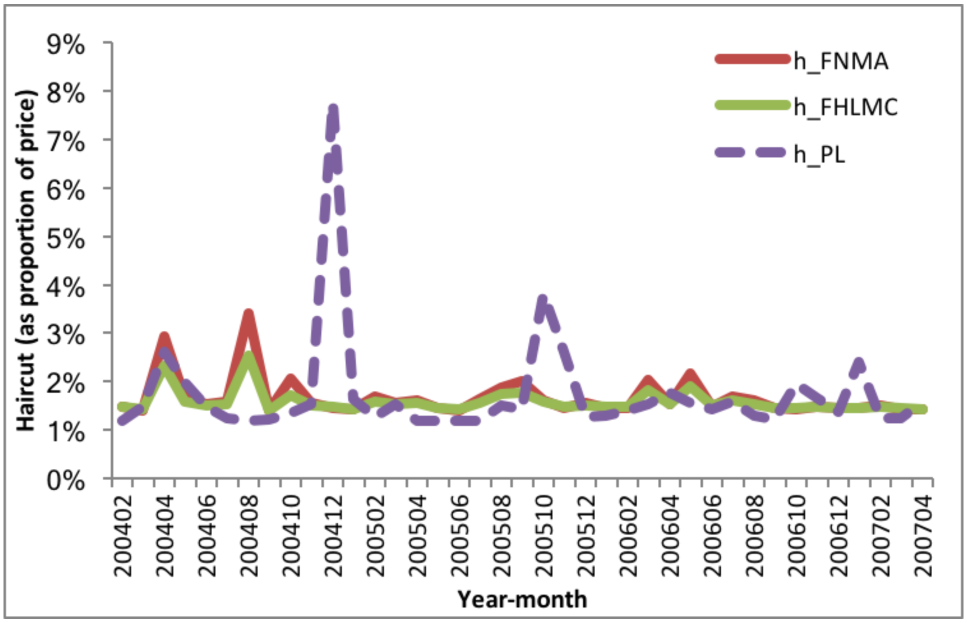


Figure 10: Expected haircut percentages given bond prices and the results for κ_i and θ_i from Table 4, using a VaR constraint of $\pi_i = 1\%$ - February 2004–March 2007

5.3 Autocorrelation in asset volatility and pro-cyclicality of haircuts

In our model, a decrease in prices that is not related to a negative shock to fundamentals is due to market illiquidity. Our focus in this section is on how the haircut $h_{i,0}$ within a channel responds to market illiquidity $\Lambda_{i,0}$. Of course, when haircuts are tightened (increased) by market illiquidity rather than being loosened, the channel is more prone to liquidity crashes. Given our model, the repo funding of a securitization channel is fragile if the endogenous response of haircuts exacerbates episodes of market illiquidity as opposed to mitigating them.[36]

A market is fragile if $\frac{\partial h_{i,0}}{\partial \Lambda_{i,0}} < 0$. Fragility increases with the slope of the haircut: the same drop in liquidity is amplified even more where θ_i^2 is larger. We illustrate this with a two-period example. Suppose a given pipeline has parameters $\kappa = 1$ and $\theta^2 = 1$. For simplicity of calculations hold the asset value constant at $v_{-1} = v_0 = 100$, and suppose $p_{-1} = 100$ (so that $\Lambda_{-1} = 0$). If at time 0 the market continues to be liquid, i.e., $\Lambda_0 = 0$, then the haircut in dollars is $h_0 = 1$. Suppose instead there is a net supply shock leading to illiquidity $\Lambda_0 = -1$, and hence to $p_0 = 99$ (using the simplification that asset value is fixed, $v_0 = v_{-1} = 100$).

[36] Brunnermeier and Pedersen (2009) refer to this property of haircuts as "stability."

Then the shock leads to a new haircut value of $h_0 = 1.41$, as opposed to $h_0 = 1$, and so repo sellers will face tighter funding when the market is illiquid.

In our example, consider another market where $\theta'^2 = 0.1$. In this market the haircut response is much milder: instead of increasing by 0.41 (i.e., from $h_0 = 1$ to $h_0 = 1.41$) it would increase by 0.05 (i.e., from $h'_0 = 1$ to $h'_0 = 1.05$). The impact of illiquidity depends on the functional form of the repo haircut, as we illustrate now graphically. Figure 11 presents two hypothetical examples depicting both cases, one where markets are fragile and one where they are not.

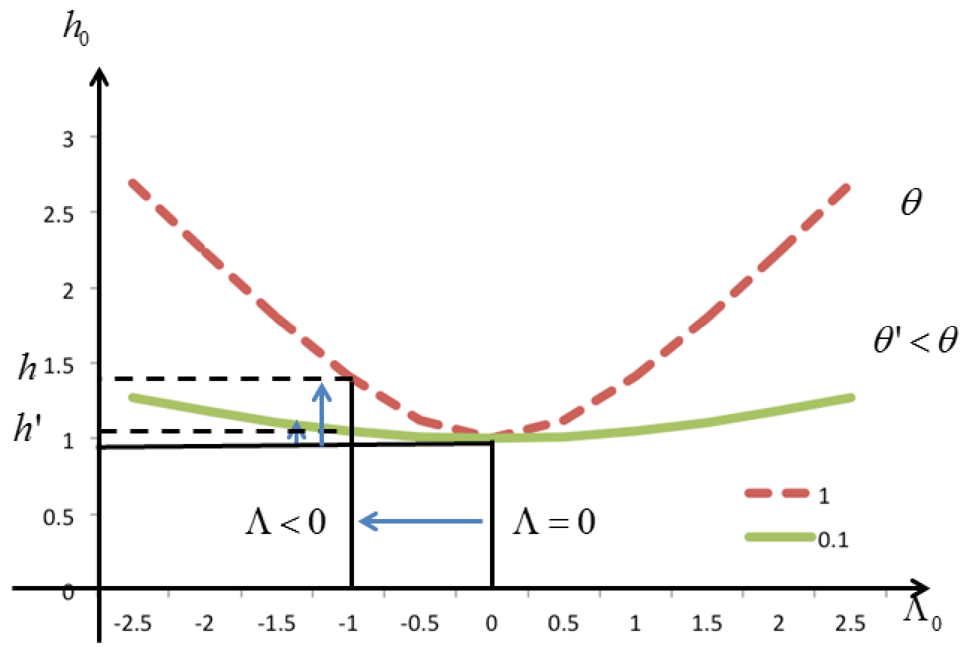


Figure 11: Illiquidity and market fragility. The graph shows generic forms for haircut h_0 as a function of market illiquidity Λ_0. For ease of representation we chose the convention $p_{-1} = v_{-1} = v_0$. We focus on episodes of illiquidity where $\Lambda < 0$, i.e., the left-hand half of each curve.

Figure 11 describes two cases where haircuts rise in response to illiquidity, which is the case in the example above. This is what we call a fragile market.[37] This will depend on the size of θ^2, as we summarize in the following (*ceteris paribus*) result:

[37] A market that is not fragile would see a different haircut response, i.e.,

$$\frac{\partial h_0}{\partial \Lambda_0} \geq 0. \tag{11}$$

Lemma 1. Given an illiquidity shock $\Lambda_{i,0}$ such that $\Delta p_{i,0} < 0$, it holds that

$$\frac{\partial h_{i,0}}{\partial \Lambda_{i,0}} \leq 0, \tag{12}$$

i.e., haircuts will increase in response to the illiquidity shock and markets are fragile. The higher θ_i^2, the higher the haircut sensitivity to illiquidity, i.e., $\frac{\partial h_{i,0}}{\partial \Lambda_{i,0}}$ is decreasing in θ_i^2.

Based on our regression estimates, lemma 1 characterizes the difference in fragility across the GSE and private label markets. Figure 12 summarizes these results by plotting the haircut function that results from our empirical estimates of the volatility parameters.

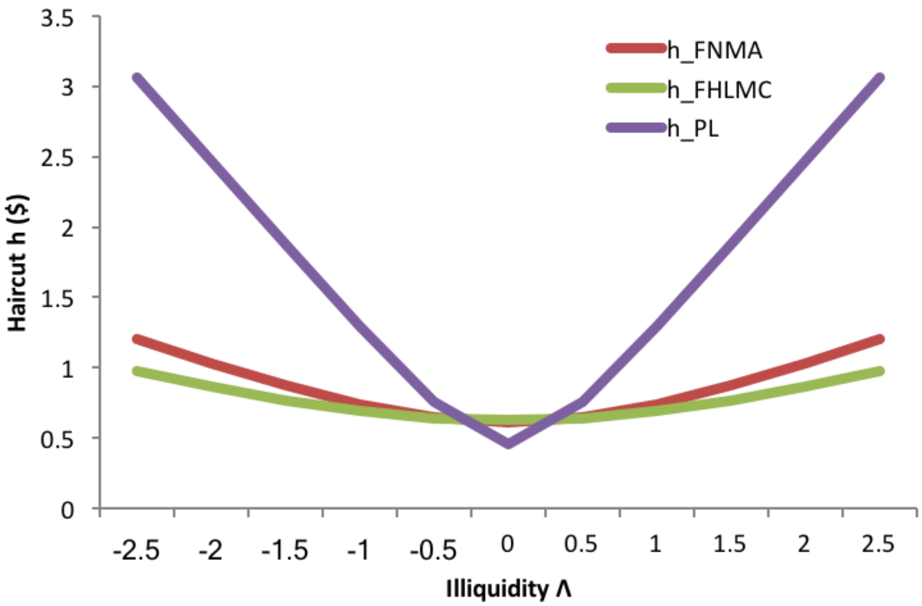


Figure 12: Haircut response to market imbalance. This graph plots the haircut function resulting from formula 8, using the parameters estimated for each market segment from Table 4 and a VaR constraint $\pi_i = 1\%$. For a fixed value of $p_{i,-1}$, we generate increments in $p_{i,0}$ of \$0.50 and subtract $p_{i,-1}$ from them. To each value of this difference will correspond a haircut value. For ease of representation we chose the convention $p_{i,-1} = v_{i,-1} = v_{i,0}$ as shown in Figure 11. We focus on illiquidity shocks where $\Lambda < 0$, i.e., the left-hand half of each curve.

Figure 12 shows a downward-sloping haircut function in GSE markets (in the region $\Lambda < 0$) with a small slope. The negative autocorrelation coefficient that we find for GSE TBA price dynamics suggests that the GSE market is less fragile than the PL markets. This holds even under the assumption that repo buyers and sellers are uninformed about true asset values ($p_{i,t} = v_{i,t}$). In contrast, this same assumption always leads to market fragility in the Brunnermeier and Pedersen (2009) model. As shown in Figure 12, the PL securitization channel exhibits extreme slope, suggesting that the repo funding structure of this channel is highly fragile.

6 Conclusions

We develop a model of repo-funded mortgage origination under trade imbalances. We highlight important differences across GSE and private label securitization channels using a measure of the securitization hazards for newly originated mortgages. In an equilibrium model of mortgage funding, we find that the securitization hazards are priced and we verify this empirical finding using trading prices for the GSE TBA forward contract and the private label mortgage-backed securities markets. Our model of the repo-funding of mortgage origination is sufficiently flexible to accommodate both constant volatility and first order autocorrelation in TBA and private label RMBS bond price volatility. We test for these dynamics using traded bond price dynamics from the PL and GSE securitization channels. We find important differences in the degree of autocorrelation in bond price volatility across the channels and these differences give rise to important differences in the level and volatility of the implied repo haircuts. Overall our results indicate haircut percentages that are on average lower in private label markets however, they are much more volatile, due to the large autocorrelation coefficient in bond price volatility. This larger volatility in private label haircuts suggests that the PL securitization channels are more fragile, in the sense that PL repo pricing dynamics will be pro-cyclical and thus susceptible to liquidity spirals and market breakdown. In contrast, the GSE repo price dynamics are found to be less fragile because they are not pro-cyclical.

In their discussion of why haircuts exist, Dang et al. (2013) consider three aspects: counterparty credit risk,[38] asset risk and liquidity constraints. Our equilibrium hinges on the liquidity constraint of the repo buyer, and our specification of the asset value is about risks surrounding the asset. Moreover, the fact that the asset volatility parameter depends on pipeline attributes (either the GSE or PL SPE) is somewhat related to the view that the counterparty matters to repo pricing. Our model is not one of counterparty risk, but rather of the repo funding structure of the pipeline and the riskiness of the repo bet on securitization timing.

[38] Another way to incorporate counterparty risk is through the reputation channel. Weymuller (2013) finds that reputation acts as a pro-cyclical force.

Our analysis highlights the stability features of the GSE funding pipeline, which is faster and provides less fragile liquidity. The issue that remains is whether this provision of stable liquidity is welfare enhancing. Having provided a view of the value of the liquidity provision, the next step is to understand the (mis)pricing of this liquidity function in order to achieve a successful outcome for the current regulation initiatives aimed at the GSEs.

References

Acharya, Viral V., Philipp Schnabl, and Gustavo Suarez, 2013, Securitization without risk transfer, *Journal of Financial Economics* 107, 515–536.

Brunnermeier, Marcus, and Lasse Pedersen, 2009, Market liquidity and funding liquidity, *Review of Financial Studies* 22, 2201–2238.

Chen, Jiakai, 2015, Off-balance sheet financing and bank capital regulation: Lessons from asset-backed commercial paper, Working paper, U.C. Berkeley.

Comotto, Richard, 2012, Haircuts and initial margins in the repo market, Working paper, European Repo Council, ICMA.

Consumer Finance Protection Bureau, 2016, TILA-RESPA integrated disclosure: Guide to the loan estimate and closing disclosure forms.

Covitz, Daniel, Nellie Liang, and Gustavo A. Suarez, 2013, The evolution of a financial crisis: Collapse of the Asset-Backed Commercial Paper market, *Journal of Finance* 68, 815–848.

Dang, Tri Vi, Gary Gorton, and Bengt Holmström, 2013, Haircuts and repo chains, Working paper, Yale University.

Downing, Christopher, Dwight Jaffee, and Nancy Wallace, 2009, Is the market for mortgage-backed securities a market for lemons?, *Review of Financial Studies* 22, 2457–2494.

Felton, Andrew, 2008, The impact of the GSE accounting scandals on the increase in risky mortgages, Working paper, Federal Deposit Insurance Corporation.

Gabaix, Xavier, Arvind Krishnamurthy, and Olivier Vigneron, 2007, Limits of arbitrage: Theory and evidence from the mortgage-backed securities market, *Journal of Finance* 62, 557–595.

Gorton, Gary, and Andrew Metrick, 2010, Haircuts, *Federal Reserve Bank of St. Louis, Review* 92.

Gorton, Gary, and Andrew Metrick, 2012, Securitized banking and the run on repo, *Journal of Financial Economics* 104, 425–451.

Grossman, S., and M. Miller, 1988, Liquidity and market structure, *Journal of Finance* 38, 617–633.

Inside Mortgage Finance, 2015, Guide to mortgage origination channel strategies.

Krishnamurthy, Arvind, Stefan Nagel, and Dmitry Orlov, 2014, Sizing up repo, *The Journal of Finance* 69, 2381–2417.

OFHEO, 2003, Systemic risk: Fannie Mae, Freddie Mac and the role of OFHEO, Working paper, Office of Federal Housing Enterprise Oversight.

OFHEO, 2004, Report of findings to date: Special examination of Fannie Mae, Working paper, Office of Federal Housing Enterprise Oversight.

Schroeder, Jeanne L., 1996, Repo madness: The characterization of repurchase agreements under the bankruptcy code and the UCC, *Syracuse Law Review* 46, 1000–1049.

Schweitzer, Lisa, Seth Grosshandler, and Willian Gao, 2008, Bankruptcy court rules that repurchase agreements involving mortgage loans are safe harbored under the bankruptcy code, but that servicing rights are not, *Pratt's Journal of Bankruptcy Law* May–June, 357–360.

Singh, Manmohan, and James Aitken, 2010, The (sizable) role of rehypothecation in the shadow banking system, Working paper, International Monetary Fund.

Stanton, Richard, and Nancy Wallace, 2011, The Bear's lair: Indexed credit default swaps and the subprime mortgage crisis, *Review of Financial Studies* 24, 3250–3280.

Vickery, James I., and Joshua Wright, 2013, TBA trading and liquidity in the agency MBS market, *Economic Policy Review* 19.

Weymuller, Charles-Henri, 2013, Leverage and reputational fragility in credit markets, Working paper, Harvard University.

A Derivation of equilibrium

Let $q_{i,0} = 1 - hazard_{i,0}$ for ease of notation.

t=1 The securitization SPE determines its demand $y_{i,1}^{k_i}$ by solving

$$\max \mathbb{E}_1[-e^{-\delta W_{i,2}^{k_i}}] \text{ s.t. } W_{i,2}^{k_i} = W_{i,1}^{k_i} + (p_{i,2} - p_{i,1})(y_{i,1}^{k_i} + z_{i,k}). \tag{13}$$

Now $p_{i,2} = v_{i,2} = v_{i,1} + \sigma_{i,2}\varepsilon_{i,2}$ where $\varepsilon_{i,2} \sim N(0,1)$ gives a standard CARA-normal problem conditional on a realization of $z_{i,k}$. Using $z_{i,k} \sim U[q_{i,k} - s_i, q_{i,k} + s_i]$ we embed the goal function into a uniform distribution,

$$\mathbb{E}_1[-e^{-\delta W_{i,2}^{k_i}}] = \frac{1}{2s}\int_{q_{i,0}-s}^{q_{i,0}+s} -e^{-\delta\left(W_{i,1}^{k_i}+(v_{i,1}-p_{i,1})(y_{i,1}^{k_i}+z)\right)+\frac{\delta^2}{2}(y_{i,1}^{k_i}+z)^2\sigma_{i,2}^2} dz.$$

This is a convex maximization problem, which we solve by taking the FOC

$$\int_{q_{i,0}-s}^{q_{i,0}+s} e^{-\delta\left(W_{i,1}^{k_i}+(v_{i,1}-p_{i,1})(y_{i,1}^{k_i}+z)\right)+\frac{\delta^2}{2}(y_{i,1}^{k_i}+z)^2\sigma_{i,2}^2}(-\delta(v_{i,1} - p_{i,1}) + \delta^2(y_{i,1}^{k_i} + z)\sigma_{i,2}^2)dz = 0.$$

Solving the integral by substitution and taking logarithms we obtain the condition

$$-\delta(v_{i,1}-p_{i,1})(q_{i,0}+s)+\frac{\delta^2}{2}(y_{i,2}^{k_i}+q_{i,0}+s)^2\sigma_{i,3}^2 = -\delta(v_{i,1}-p_{i,1})(q_{i,0}-s)+\frac{\delta^2}{2}(y_{i,1}^{k_i}+q_{i,0}-s)^2\sigma_{i,2}^2.$$

Rearranging we obtain $p_{i,1} = v_{i,1} - 2\delta(y_{i,1}^{k_i} + q_{i,0})\sigma_{i,2}^2$ and taking partial derivatives yields proposition 1. By market clearing $\sum_k y_{i,1}^{k_i} = -x_{i,1} = 0$, and since $Z_{i,1} = 0$ it follows that $p_{i,1} = v_{i,1}$. In fact, whenever the market is complete we have $v_{i,t} = p_{i,t}$.
The risk neutrality of the repo seller makes him indifferent in terms of demand, so that clearing the market is a profit-maximizing strategy.

t=0 If the market is already complete ($hazard_{i,0} = 1$) we have $v_{i,0} = p_{i,0}$. Otherwise the FOC for borrower $k = 0$ and SPE $k = 1$ present in the market is solved in the same way to obtain

$$p_{i,0} = v_{i,0} - \delta(y_{i,0}^{k_i} + q_{i,0})\sigma_{i,1}^2.$$

Once prices are set, the equilibrium is given by applying the repo sellers' funding constraint $h_{i,t}x_{i,t} \leq W_{i,t}$.