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Managing Mortgage Credit Risk: What Went Wrong With the Subprime and Alt-A Markets? *

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The purpose of this study is two-fold: first, to explain the demise of subprime and Alt-A mortgage markets in the U.S. from the viewpoint of measuring and managing mortgage credit risk; and secondly, to discuss several policy lessons that can be learned from the market meltdown. To that end, three tiers of mortgage credit models are elaborated, including the scoring (or risk rank-ordering), risk-based pricing, and "sizing" (or the analytics used in determining subordination levels of credit-sensitive mortgage backed security (MBS) deals) models. Using these as conceptual underpinning, empirical evidence is surveyed to document key contributing factors to the market demise. Those that are identified include the non-availability of reliable mortgage performance data, lack of theory as well as industry best-practices in performing simulation-based mortgage risk assessments, complex and arcane structures of mortgage backed securities, and information asymmetry among the parties involved in the security transactions. The overall conclusion derived is that the participants to these market segments surpass their risk management capabilities in globalizing funding for subprime and Alt-A mortgages. The policy lessons emphasized are the importance of the infrastructure of proper risk assessment and risk-based pricing, as well as prudent and transparent MBS products along with periodic information disclosure.

Keywords:

Subprime mortgage; Mortgage-backed securities; Mortgage default; Credit risk management

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1. Introduction

A lexicon definition of “credit” is trust of others. When institutional mortgage lending started in the U.S. about 180 years ago, mortgage credit followed this literal meaning. The Terminating Building Society (TBS), the predominant lending institution at that time, was nothing but a group of trustworthy friends and relatives living close to each other. They contributed a fixed amount of money periodically, took turns in receiving the collected funds in the order of the interest to be paid, built houses with the received sums, and terminated the institution once all members were housed.[1]

The meaning of credit has changed over time in the U.S. mortgage market from a perception-based concept to a more statistical construct. In the current internet age, borrower credits are assessed electronically and on-line by distant lenders, via scorecards and other data- and model-driven measures. The subprime lending sector, which took off from the early 2000s, went even further by attempting to create a market for trading mortgage credit risk. The consequence, as well known, is that the attempt not only failed, but also has triggered a once-in-a-lifetime turmoil in the global financial system.

What went wrong, who was responsible, and what remedies can be instituted to prevent a similar credit event from occurring again? These are the questions that this study aims to shed light on.

There is already a growing volume of so-called subprime literature, which documents various causes and lessons of the on-going financial crisis.[2] The approach taken in the current study is to examine such issues in the limited scope of measuring and managing mortgage credit risk. To that end, I will first elaborate a conceptual underpinning of measuring mortgage credit risk, and secondly, provide a critical survey of relevant theoretical and empirical studies. Finally, I will discuss several policy lessons that have been learned from the subprime mortgage debacle.

The leverage in the U.S. mortgage market started burgeoning since the mid 1980s, and sharply expanded from the early 2000s. In particular, the mortgage debt outstanding (MDO), for both residential and commercial properties, surpasses any other lending sector in the U.S., both in terms of speed of growth and size of outstanding loans. The MDO growth rate in 2000-2006 was 13.5 percent per annum, 2-3 times higher than other debt sectors; and the MDO level amounted to $13.5 trillion at the end of 2006, greater than the sum

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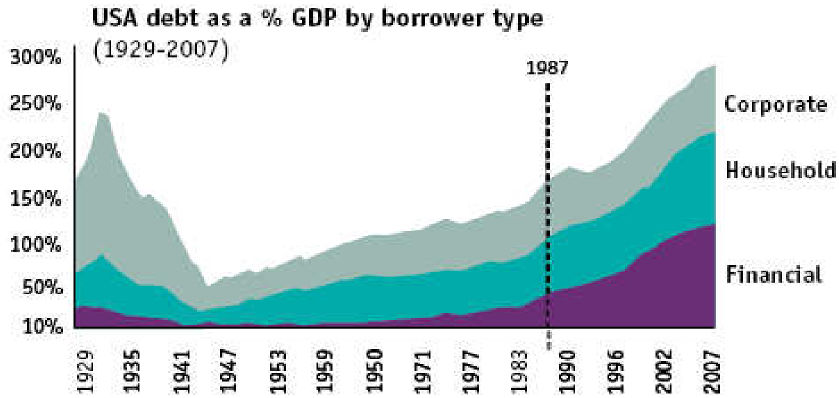
[1] See Green and Wachter (2005) and Cho (2007) for the evolution of the US mortgage·MBS markets.

[2] The growing list of the subprime studies includes Greenlaw et al. (2008), Reinhart and Rogoff (2008), Roubini (2008), Cho (2008), Gwinner and Sanders (2008), Gorton (2008), Calomiris (2008), and Jaffee (2008).

of the Treasury, corporate (non-financial), and credit card debts outstanding altogether.[3] Led by the mortgage lending sector, the total size of non-governmental borrowing in the U.S. reached about 300% of the GDP in recent years, which exceeds that of the Great Depression era (a little less than 250% as shown in Figure 1). Judging from the size of the credit market after the Great Depression, we can conjecture that the deleveraging process would be long and deep if history repeats itself again.

Figure 1 Size of Non-government Borrowing in the U.S. (% to GDP)



Source: Oliver Wyman; as reported by the UK Financial Services Authority

In order to examine the primary cause for the rise and fall of the subprime and Alt-A lending in the U.S., three classes of mortgage credit models, along with theoretical underpinning to each of them, are examined: the scoring model (Tier 1 Model), the pricing model (Tier 2 Model), and the "sizing" model (Tier 3 Model). The Tier 1 Model, developed and popularized from the mid-1990s,[4] is essentially a tool for mortgage underwriting, the process of screening out loans whose risks are not acceptable to be served by market participants. The Tier 2 Model, on the other hand, has been used in setting risk premiums for guaranteeing mortgage credit losses, both at the loan and pool-levels, which are set through negotiations between primary market lenders and guarantors of mortgage credit risk. Before the subprime debacle, only a small number of institutions, including government sponsored enterprises (GSEs; Fannie Mae and Freddie Mac), and some mortgage insurance companies and large lenders, had the internal capability that was necessary to compute these

[3] See Cho, Yang, and Lin (2009) for the figures quoted. The real estate lending in other countries has also increased in the 2000s, details of which are discussed by IMF (2008) among others.

[4] Avery et al. (1996) is one of the early studies on applying the scoring model in mortgage underwriting.

fees in a risk-based fashion. It is fair to say that before the surge of the subprime securities, the actual price setting was mostly internal (to those market intermediaries) and was often done through bargaining among involved parties rather than through a truly competitive bidding. Finally, the Tier 3 Model is used to segment mortgage pools into separate bonds (or tranches) with different levels of credit loss protection, i.e., credit-tranching done mostly in the non-agency (or non-GSE) mortgage backed security (MBS) sector. Academic research on this credit-sensitive mortgage security is rare, especially on those backed by residential mortgages.

Two particular economic trends, and more importantly, the interaction between the two, prompted the steep rise of subprime and Alt-A lending from the early 2000s: that is, the unprecedented home price growth since 1998 (until mid-2006); and the highly accommodative monetary policy, evidenced by negative real Fed fund rates (FFR) in the 2002-2005 period. Being fueled by this extremely favorable economic environment, the new issuance of subprime loans increased more than three-fold, from less than $200 billion in 2002 to over $600 billion in 2006. In the later years, about 70% of the new originations were securitized into asset backed security (ABS), some pieces of which were re-securitized into collateralized debt obligation (CDO) and CDO-squared. The whole purpose of the subprime mortgage securitization was to package and trade mortgage credit risk, with the prepayment risk being largely controlled via a penalty charged to the borrower for early repayment.[5]

There is growing evidence to suggest that reliable data did not exist even to build a robust Tier 1 model, as discussed in Section 4. Many subprime mortgage products were new to the market (e.g., 2/28 or 3/27 option ARMs[6], and 40-year ARMs), not vetted with any real stress economy, and were overlaid with other risk factors (e.g., high loan-to-value (LTV), low FICO scores, and low-/no-documentation requirements). Furthermore, neither theories nor best practices existed on some of the key components in measuring the credit risk. One example is the methodology in forming forward-looking home price scenarios. This usually involved a number of difficult measurement issues, such as defining geographical submarkets, estimating diversification benefits, and specifying a proper volatility cone. Hence, the securitization of subprime loans carried over all the problems from the earlier transaction steps: that is, the collateral (pool of mortgage loans) with a high degree of cash flow uncertainty, unreliable performance data, and the lack of industry best practices on some of key measurement analytics. On top of all these, the multiple rounds of securitization exacerbated rather than

[5] However, it is reported that subprime mortgages were prepaid quickly during the real estate boom because lenders allowed borrowers to do so by waving the penalties. This trend was reversed during the downturn as lenders have been rejecting refinancing applications, which led to high default and delinquency rates in the subprime lending sector. (Pennington-Cross and Ho (2010) and Gorton (2008))

[6] Adjustable rate mortgages

reduced the problem of information asymmetry between MBS issuers and investors on the underlying mortgage credit risk. As the economic environment turned, the “trust” among investors quickly evaporated, and the manias of 4-5 years of lending frenzy came to a crashing end from the second half of 2007.

The rest of the paper consists of the following five sections: a survey of the U.S. mortgage market with respect to key characteristics of mortgage·MBS products traded in different market segments (Section 2); a discussion on the three tiers of the mortgage credit model and theoretical underpinning for each tier(Section 3); a survey of the empirical findings on various risk measurement issues related to the subprime mortgage and MBS products (Section 4); policy lessons to be learned (Section 5); and, concluding remarks (Section 6).

2. Overview of Subprime and Alt-A Mortgages

2.1 Brief History

Before the 1980s, mortgage lending in the U.S. was dominated by savings and loans (S&Ls) or thrifts. The funding side of this business was also internalized in that it was predominantly provided through their deposit bases.[7] However, a series of economic events since the 1980s has fundamentally changed the mode of mortgage funding in the U.S., which has also contributed to the rise of the subprime mortgage market.

First, high inflation and the prolonged inverted yield curve in the early 1980s, coupled with stiff competition from money market mutual funds in attracting small savers, triggered the large scale failure of S&Ls in the 1980s, known as the S&L debacle. There were efforts on the part of the U.S. government to save S&Ls, with the de-regulation of deposit rate ceilings in the early 1980s being the most notable. However, such policy measures proved to be insufficient in preventing the fall of S&Ls in large numbers. The vacuum created by the failed S&Ls in mortgage funding was gradually filled by GSEs (referring to Fannie Mae and Freddie Mac) plus Ginnie Mae, the government-run funding agency, through their MBS issuance. The MBS market has grown steadily during the 1980s, and has steeply risen during the 1990s with its share in total origination reaching over 50 percent.[8] The success of this GSE-dominated funding model not only injected the needed liquidity into the

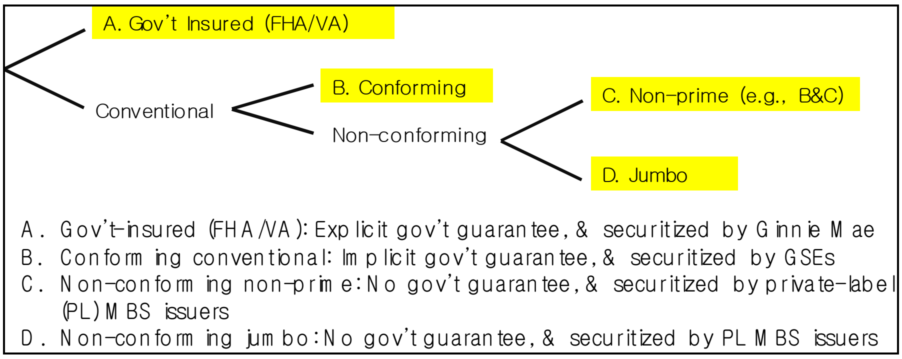
[7] See Cho (2007) for more details on the 180 years’ evolution of the US mortgage banking system.

[8] There was a policy shift that also contributed to the growth of the MBS market in the mid 1980s. That is, as a part of the Tax Reform Act of 1986, investors are allowed to form real estate mortgage investment conduits (REMIC), a tax-exempt special purpose vehicle that can hold commercial and residential mortgage loans, and issue securities; both pass-throughs and multi-class bonds, by using the loans as collateral.

primary market, which in turn, helped raise the home ownership rates, but also created a large and liquid MBS market internationally.

Secondly, as the market for MBS grew, the underwriting guidelines of GSEs, i.e., the rules as to which loans were eligible for their funding vis-à-vis which ones were not, practically segmented the U.S. mortgage market. As shown in Figure 2, conventional loans (i.e., loans without a government guarantee) were divided into two segments: those that complied with the underwriting guidelines of the GSEs; labeled as "conforming" or "A" loans, and those that did not; referred to as "non-conforming" loans. The eligibility is essentially a bundle of loan characteristics, such as the maximum allowable LTV and debt-to-income (DTI) ratios, acceptable borrower credit scores, documentation requirements, interest rate variability, and so on. The non-conforming segment is further divided into two groups; non-prime and jumbo loans. Non-prime loans, originally called "B&C" loans, are the origin of subprime and Alt-A mortgages. Jumbo loans are those that exceed the size of the GSE regulatory loan limit.

Figure 2 Segmentation of the U.S. Mortgage Market



Thirdly, the widely-publicized accounting scandals of both Freddie Mac (in 2003) and Fannie Mae (in 2004) shifted the landscape in mortgage funding once again, away from GSEs toward the private-label (PL) MBS issuers. The private funding institutions were mostly investment banks (IBs) and large commercial banks, including the Lehman Brothers, Bear Sterns, JPMorgan, Goldman Sachs, Bank of America and Wells Fargo, as well as several major mortgage lenders, such as Countrywide, Washington Mutual, and Indy Mac. In fact, the competition between GSEs and the PL MBS issuers is rooted from the early 1990s and, more often than not, it went beyond the market place. That is, the public policy debate on the role of the GSEs in the mortgage market was frequently surfaced as a hot topic for both academic studies and media coverage. [9] Some of the private MBS issuers even formed a trade organization, called the “FM Watch”, as a vehicle to lobby Congress for limiting the functions of the GSEs in the mortgage finance industry.

2.2 Mortgage and MBS Characteristics

Table 1 compares four segments of the U.S. mortgage market in terms of loan and MBS characteristics, including the prime, jumbo, Alt-A, and subprime segments. The Alt-A loans refer to those whose documentation or LTV requirements do not conform with the funding eligibility of the GSEs, while the subprime loans are issued to borrowers with poor credit histories (hence, very low FICO scores) and/or with non-conforming documentations. Compared to other segments, the subprime mortgages also exhibit a higher LTV level on average (low 80s vs. low 70s) and a higher share of second-lien mortgages.[10]

Mortgage products in the subprime market are predominantly adjustable rate mortgages (ARMs), in contrast to the prime market where fixed rate mortgages (FRMs) are the majority. The subprime ARMs also have various special features, often called “exotic” mortgages, including interest only (IO) ARMs, option ARMs (for which borrowers have several options to choose in each payment node, including a negative amortization of principal), 2/28 or 3/27 hybrids (that usually have below-market interest rates and non- or negatively-amortizing principal during the first 2-3 years of the loan life), and 40-year maturity ARMs. These exotic mortgage loans gradually increased their shares in total subprime origination between 2002- 2006.[11]

In terms of the securitization, the collateral in the conforming conventional market consists predominantly (over 90 percent) of two particular FRM products; 15-year and 30-year FRMs with level-paying fully-amortizing principals and no prepayment penalties. These “plain vanilla” FRMs had a low degree of uncertainty in projecting post-origination mortgage cash flows compared with other products. In terms of risk management, the frequency of prepayment from a given mortgage pool and the subsequent reinvestment risk

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[9] The main problem elaborated in academic studies is the moral hazard on the part of GSE caused by the ambiguous relationship with-and the implicit guarantee by the U.S. government. See Passmore (2005) for details.

[10] It is also reported that subprime loans generally exhibit high DTIs, typically over 50% at origination that can increase to over 90% after the reset of payment schedule. (Mason and Rosner, 2007)

[11] While IO-ARMs did not even exist in 2001, it amounted to 22 to 37 percent of total subprime origination in 2004 to 2006. Furthermore, the share of low-/no-documentation loans also increased from about 28 percent in 2001 to over 50 percent in 2006. (Cho, 2008) Hence, there has been a toxic combination of risk-layering that has been going on, for example, an IO- or option-ARM with no documentation requirements and issued to a borrower with an impaired credit history.

are the main risk factors to be assessed and controlled. The representative MBS products in this market include pass-through (PT) with no internal structure, and collateralized mortgage obligation (CMO) with various tranches which have different levels of call protection. Borrower default risk is usually not a concern for investors as it is controlled with external credit enhancements by GSEs and other insurance providers.

Table 1 Description of RMBS Categories

	Prime	Jumbo	Alt-A	Subprime
Mortgage characteristics				
Lien Position	1st Lien	1st Lien	1st Lien	Over 90% 1st Lien
Weighted Average LTV	Low 70s	Low 70s	Low 70s	Low 80s
Borrower Credit History	No credit derogatories	No credit derogatories	No credit derogatories	Credit derogatories
Conforming to Agency Criteria	Conforming	Conforming by all standard but size	Non-conforming due to documentation or LTV	Non-conforming due to FICO, credit history, or documentation
Loan-to-Value (LTV)	65-80%	65-80%	70-100 %	60-100%
Securitization attributes				
MBS Products	Pass-through CMO	ABS	ABS, CDO CDO-squared	ABS, CDO CDO-squared
Collateral	Predominantly FRMs (15-/30 yrs)	Mixed with ARMs and FRMs	Mixed with ARMs and FRMs	Predominantly ARMs w/ "exotic" features
Credit Enhancement	External CE	Internal, "6-pack" CE	Internal, "6-pack" CE	Internal, XS/OC
Risk Indicators	Prepay-OAS G-fee	N/A	Credit-OAS (being developed)	Credit-OAS (being developed)
Issuers	GSEs	Private Label issuers	IBs & large CBs	IBs & large CBs

Source: Gorton (2008); Cho (2008)

Aside from GSEs, there are two other sources of external credit enhancement (CEs) in the U.S. mortgage market. They are the FHA (Federal Housing Administration) as the public mortgage insurance (MI) provider, and the private mortgage insurance companies (for high-risk loan segments, such as above 80 percent LTV loans). The industry of providing external CEs in the primary mortgage market in fact has a long history, beginning in the 1930s when FHA insurance was first introduced to protect the investors for the long-term FRM. After a successful operation by the FHA, the private mortgage insurance industry was created in the 1950s with authorization laws enacted in all 50 states in the U.S. Since then, both private and public MI contracts from these institutions have been serving as an important market-maker in the prime MBS business as they practically screen out the default-driven cash flow uncertainty for MBS investors. Nonetheless, their risk assessment was mostly rule-based, rather than model-based, until the introduction of mortgage scoring techniques in the mid 1990s.

Unlike their prime market counterpart, subprime MBS deals are backed primarily by ARMs with special features, resulting in a high degree of cash flow uncertainty. Furthermore, aside from the default and prepayment options, products such as 2/28 option ARMs have an additional option embedded, in the form of possible refinancing decisions by lenders at the time of reset (hence, an asset to lenders, but a cost to borrowers). That is, subprime lenders can waive the prepayment penalty to existing borrowers at, or right after, the reset, only if market conditions (home price appreciation, in particular) favor doing so. (Gorton, 2008) Due to this added possibility, the cash flow projection and risk assessment for subprime mortgage collateral were highly challenging from the outset.

3. Pricing Mortgage Default Risk-Theoretical Underpinning

A mortgage contract can be viewed as a composite financial asset with three underlying components: a scheduled (or contracted) payment of principal and interest, and two competing options of (borrower's) default and prepayment. There has been a reasonably long history of academic research in estimating fair values of such embedded options in the Mertonian distance-to-default model framework.[12] (Foster and Van Order (1984), Kau and Keenan (1995), Buist and Yang (1998), Deng, Van Order and Quigley (2000), and Calhoun and Deng (2002)) Originally developed to explain defaults on corporate debt, the model's key exposition is that when the asset value of the collateral (or the home value) drops below the unpaid (loan) balance (UPB), the default option is in the money, and the borrower will have an economic incentive to put (transfer) home to lender at par value of unpaid loan balance. Hence, negative home equity (i.e., over 100% effective LTVs), or its likelihood, is the key indicator of mortgage default under this strand of the model.

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[12] The model, originally developed by Merton (1974) and extended later on by Longstaff and Schwartz (1995) and others, is also termed as a structural model for corporate loan defaults. Given that the volatility of asset value is given at loan origination, a standard option pricing model can be used to estimate PD at a particular point in time post origination. The reduced-form model, on the other hand, is developed by Jarrow-Turnbull and others, which estimates PD by assuming a particular distribution of default intensity (e.g., a Poisson distribution).

However, the Merton model falls short in accurately assessing the default likelihood due to two reasons. First, it is mute about payment shock-driven mortgage defaults, which represent the primary cause of default for ARMs in general and the subprime ARMs in particular. Borrower's liquidity, as measured by the DTI ratio, is shown to be more predictive in assessing default risk of this sort (Ambrose et al. (2005) and Pennington-Cross and Ho (2010)). Secondly, the two embedded options are American in nature (i.e., the borrowers having a chance to exercise in each and every payment node, or 360 if it is a monthly-paying 30-year loan contract) rather than European (the borrower's exercise being allowed only in a particular time point). [13] Therefore, it is usually intractable to come up with a closed form solution to price the mortgage default risk, and instead, numerical techniques, such as a Monte Carlo simulation are generally used in real world applications.

In terms of estimating a fair value of mortgage default risk, one can consider a general net present value (NPV) approach; that is, the present value (PV) of a stream of mortgage insurance premiums over time for guaranteeing credit losses should be set to cover the PVs of all anticipated expenses involved, including expected credit losses, required rate of return to holding capital reserve, and other intermediation costs. [14] A more conventional method in academic literature (Chacko et el. (2007) and Duffie and Singleton (2003)) is the risk-neutral valuation approach. Under this, the risk premium for guaranteeing credit risk is directly estimated with the following objective function:

$$\sum_{t=0}^{T} \frac{E_0[M_{t,p}]}{\prod_{j=1}^{t}(1+r_j)} - \sum_{t=0}^{T} \frac{M_t}{\prod_{j=1}^{t}(1+r_j+spread)} = 0 \qquad (1)$$

where M refers to scheduled payment of the mortgage principal and interest (at future time t with economic path p), r_j is a time-varying short rate, and E[·] is an expectation operator. 'spread' is the risk premium to be estimated via a trial-and-error process, given other factors in (1) being pre-determined. In a real world application, equation (1) can be estimated with a large number of future economic paths, p, and 'spread' can be computed as an average across those multiple paths.

[13] Besides these shortcomings, the option theoretic model of mortgage default also ignores important institutional features of a mortgage contract, such as the non-recourse of credit losses and the leverage enhancement through a second mortgage. On the latter issue, refer to LaCour-Little (2007).

[14] Given the lack of a liquid market, the best-practice valuation of mortgage asset is conventionally called a cost approach; that is, the spread to be equated with the best estimate of credit losses obtained with all available data and econometric models at the time of pricing.

The key variable to be estimated in(1) is $E_0 [M_{t,p}]$,which is further specified as:

$$E_0[M_{t,p}] = (1 - PD_{t,p}) \cdot M_t + PD_{t,p} \cdot (1 - SEV_{t,p}) \cdot M_t \tag{2}$$

where PD represents the probability of default (at time *t* under path *p*), and SEV is the loss severity rate in case of default(i.e.,loss rate after liquidating the collateral of defaulted loan).Provided that $PD_{t,p}, SEV_{t,p} > 0$, 'spread' is ensured to be positive. *PD*, in turn, can be econometrically estimated as follows:[15]

$$PD^i_{t,p} = f(ltv_{t,p} / pneq_{t,p}, dti_{t,p}, fico, X; \beta^i) + e^i \tag{3}$$

The explanatory variables on the right hand side include LTV ratio (*ltv*), DTI ratio (*dti*), consumer credit score (*fico*), along with a series of other loan, borrower, and collateral characteristics (*X*). Note that *ltv* and *dti* are dependent upon time path, while fico and *X* are not. This does not mean that the latter variables are constant over time. However, due to the problem in measuring these inter-temporally, the usual practice in estimating *PD* is done under the assumption that they are invariant over time. '*pneq*' represents the probability of negative equity, which is as an interval estimate of the likelihood of negative home equity. Hence, it is a superior measure to *ltv*, which represents a point estimate of the equity level. β and e are parameters to be estimated.

Equation (3) can be estimated either as a multinomial logistic regression model or as a proportional hazard model. Deng et al. (2000) also controlled unobserved heterogeneity in fitting this model. The left-hand side variable in equation (3) actually takes various forms; namely, a lifetime *PD* (until loan maturity), early payment default (e.g., a probability of foreclosure or "serious delinquency" within certain years from origination), early payment delinquency of different levels (e.g., a probability of more than 60 days of delinquency within 2 years from origination), and transition from one state of delinquency to another (a probability of 90+ days of delinquency to foreclosure). Some variations of the above model are often used purely as a rank-ordering tool for coming up with mortgage underwriting criteria. (Avery et al. (1996)) In applying the scoring approach, the mortgage industry lagged behind the credit card sector, which has been using the model developed by Altman and others in the 1960s.

Once *PD* (as well as *SEV*) is estimated, then the risk-neutral insurance premium, 'spread,' can be obtained. Furthermore, expected credit losses under a particular economic path (for a given mortgage type *i*) and economic capital (*EC*) can be defined as follows:

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[15] *REC* should also be estimated, but more often than not a historical recovery rate (or a loss severity rate) is used.

$$E_0[Loss_p^i] = \sum_{t=0}^{T} \frac{PD_{t,p}^i \cdot SEV_{t,p}^i \cdot M_{t,p}^i}{\prod_{j=1}^{t}(1 + r_j + spread)} \tag{4}$$

$$EC = E_0[Loss^i_{StressPath}] - E_0[Loss^i_{MeanPath}] \tag{5}$$

The type of stress path to use is a crucial decision, not only in computing *EC*, but also determining subordination levels (i.e., the level of loss protection for each tranche in credit-sensitive MBS products, such as CDO and CDO^2). Nonetheless, there is not much theoretical guidance as to defining stress scenarios except the general requirement that they are "extreme but plausible." (Moretti et al., 2008) A particular scheme of "left-tail scenarios" employed by Cho, Yang, and Lin (2009) in pricing credit-sensitive MBS products is shown below:

- AAA tranche to withstand $E_0[Loss^i_{1st\ Percentile}]$
- AA tranche to withstand $E_0[Loss^i_{2nd\ Percentile}]$
- A tranche to withstand $E_0[Loss^i_{5th\ Percentile}]$
- BBB tranche to withstand $E_0[Loss^i_{11th\ Percentile}]$
- BB tranche to withstand $E_0[Loss^i_{23rd\ Percentile}]$
- B/NR tranche to withstand $E_0[Loss^i_{50th\ Percentile}]$

An important consideration prior to implementing the above measurement framework, with or without a liquid market for trading mortgage credit risk, is quality loan performance data and robust empirical models for key input variables. Without them, the risk spread and indicators obtained are at risk of being purely arbitrary.

4. Empirical Findings

4.1 Comparison of PD – Tier 1 Model

ARM products, in general, exhibit lower prepayment risk (due to periodic rate resets), but higher default risk (due to payment shocks caused by interest rate adjustments) than FRM products.[16] Many ARM contracts also have lower initial interest rates which are called teaser rates, to compensate the borrowers who take interest rate risk and lure borrowers, enhancing the affordability in initial loan repayments. It is also believed that more mobile borrowers tend to self-select themselves into ARM contracts. (See Brueckner and Follain (1988),

[16] See Calhoun and Deng (2002) and Lin, Cho, Yang (2008) for empirical evidence.

Brueckner (1993), LaCour-Little (2007), and Fortowsky et al. (2009) among others on consumer choice of mortgage products.)

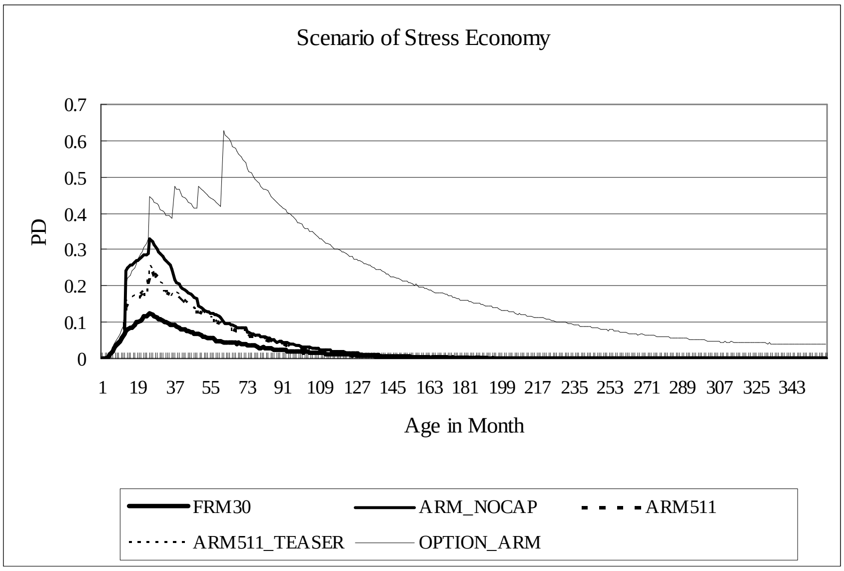
However, these reported ARM attributes are not readily applicable to the typical subprime ARM (or hybrid) products, such as 2/28 or 3/27 option ARMs. They were new to the market (introduced in the early 2000s), and their product characteristics were very much different from the conventional ARMs or hybrid mortgage loans, in terms of negative amortization of principal, amount of payment shock at the reset, and other cash flow features. Furthermore, subprime ARMs in general, impose prepayment penalties, which can also increase the default risk (Quercia, Stegman and Davis, 2005).

Two recent studies specifically estimate PD for the subprime 2/28 option ARMs and made comparisons to FRMs (Ambrose, LaCour-Little, and Huszar (2005), and Pennington-Cross and Ho (2006)). In particular, using the sample that covered 1998-2005, Pennington-Cross and Ho report that the 2/28 ARMs have a higher PD than subprime FRMs in the first two years, but default rates for the two products become very similar after the reset. Also, loan terminations for 2/28s steeply increase at the first reset, most of which represent prepayments rather than defaults. However, recent delinquency data indicates that subprime ARMs now (as of the end of 2008) exhibit much higher delinquency rates than subprime FRMs; close to four times higher. These results are consistent with the argument put forth by Gorton (2008) in that the 2/28 products have an embedded option on the part of mortgage lender as to refinancing at the time of reset. That is, they waived prepayment penalties and refinanced existing loans under the favorable market environment in 2002-2006, but not any more during the downturn when many cash-poor borrowers were pushed to default.

As a more recent study, Lin, Cho and Yang (2008) performed a Monte Carlo simulation analysis with three correlated stochastic variables; mortgage interest rate, home price, and household income, to estimate the PDs of five different mortgage products, including 2/28 option ARMs. Their results also confirm that the PD of option ARMs highly surpasses those of other products; about four times higher, with the maximum PD exceeding 60% under a stress scenario.[17] (See Figures 3 for the estimated PD trend under the stress scenario.)

[17] The stress scenario is defined as two standard deviation units left tails for all three economic variables used.

Figure 3 Estimated PD Trend under the Stress Scenario



Source: Lin, Cho, and Yang (2008)

4.2 Risk-Based Pricing – Tier 2 Model

As mentioned in Section 3, a closed-form solution via a backward propagation is generally not feasible for pricing mortgage credit risk, and the pricing tends to rely on a forward simulation with an anticipated distribution of state variables (e.g., a Monte Carlo simulation with forward-looking home price distribution).[18] Furthermore, to implement portfolio-level pricing, one has to control diversification benefits as well, either across geographical areas or product types.

In that vein, a proper specification of home price volatility is critical, but not much analysis has been done in that regard. Related to that topic, Yang, Lin, and Cho (2009) specify two alternative home price models with different volatility specifications.

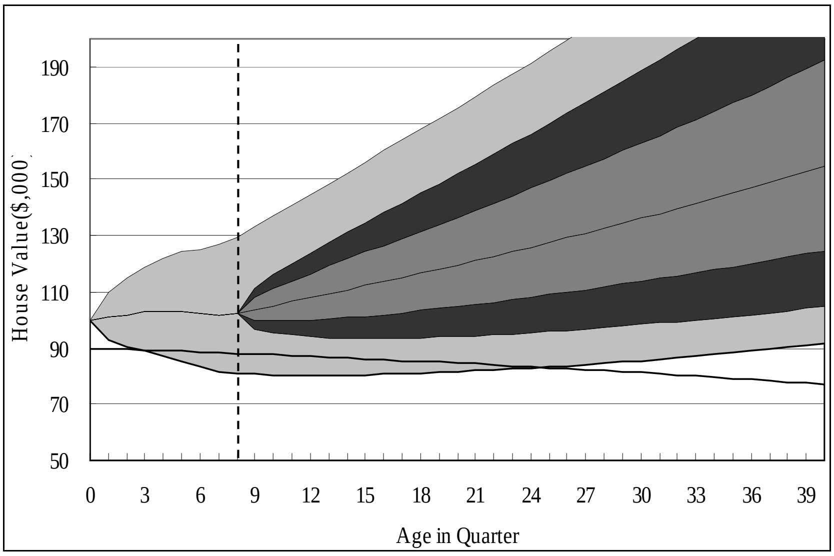
- The bottom-up approach with local-market home price forecasts that have:
  A. Average dispersion between individual properties and local home price index, and
  B. Forecasting error in projecting local home price trends.

[18] See Buist and Yang (1998) and Lin, Cho, and Yang (2008) for three correlated state variables used in the mortgage pricing.

- The top-down approach with national home price forecasts that have (see Figure 4 for the composition of the home price simulation cone):
    - C. A plus average dispersion between local vs. national HPIs, and
    - D. A forecasting error in projecting national home price trends.

Their results indicate that the top-down approach is shown to be a good approximation to the bottom-up approach (the two solid lines for Figure 4), which is more conceptually sound, but demanding computationally. It is also shown that omitting different volatility terms (A through D in the above) can produce significant biases in the *PD* estimation. In particular, deleting A, and deleting A and C together in the second approach, yield much lower PD trends(over loan ages),as seen in the two dotted lines in the middle and bottom of Figure 4. On the other hand, omitting D does not produce a comparable level of bias. As another result to note, Yang et al. also show that the degree of diversification benefit from a nationally-diversified mortgage portfolio is high, resulting in a significantly lower stress PD and, hence, a smaller capital reserve requirement than a geographically-concentrated one, ceteris paribus.[19]

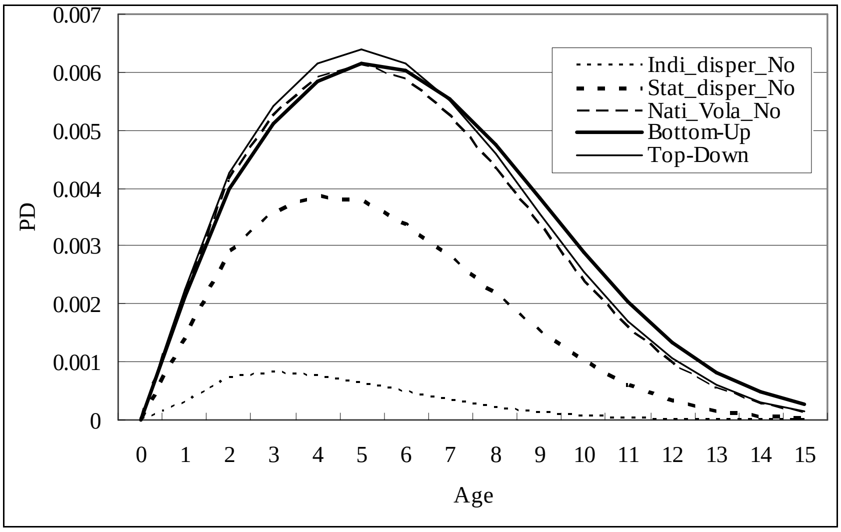
Figure 4 Top-Down Volatility Specification



Source: Yang, Lin, and Cho (2009)

[19] See Calem and LaCour-Little (2003) on diversification effects in managing mortgage portfolios.

Figure 5 PD Estimates under Different Home Price Volatility Specifications



Source: Yang, Lin, and Cho (2009)

In terms of EC, Lin, Cho and Yang (2008) report the following results obtained via a Monte Carlo simulation analysis. As shown in Table 2, the EC estimated based on Equation (5) is much higher for option ARM products; 17%, as compared to 3.68% for FRMs.

Table 2 PD and Capital among Products

Product	PD (Base)	PD Multiplier (Base)	PD (stress)	PD Multiplier (Stress)	Economic Capital	Basel II Regulatory Capital	RC Multiplier	EC as % of RC
FRM30	1.63%	1.00	7.35%	1.00	3.68%	6.19%	1.00	0.59
ARM_ NOCAPS	2.27%	1.39	17.95%	2.44	9.75%	7.59%	1.23	1.28
ARM511	1.69%	1.04	13.00%	1.77	7.04%	6.34%	1.02	1.11
ARM511_ TEASER	2.74%	1.68	13.67%	1.86	6.97%	8.50%	1.37	0.82
OPTION ARM	4.98%	3.06	32.10%	4.37	17.02%	11.83%	1.91	1.44

Note: Economic capital is computed assuming LGD 60 percent for PD (Stress) and LGD 45 percent for PD (Base Case)

4.3 Securitization via Credit-Tranching – Tier 3 Model

From a risk management point of view, there are three main pillars that have been propping up the prime-MBS market. First, prepay-tranching, i.e., the segmentation of a mortgage pool into multiple tranches with different levels of prepayment risk, done by a family of collateralized mortgage obligation (CMO) products, has gained investor confidence. In particular, PAC[20]-CMO, which was first introduced in the mid-1980s, was the milestone product in gaining confidence from the investment community. Secondly, the mortgage finance industry embraced the concept of option adjusted spread (OAS), first developed by the Salomon Brothers in 1986 as a primary tool for measuring risk-adjusted returns from CMO tranches. To date, the prepay-OAS statistics are widely used in the performance-tacking reports issued by the prime MBS dealers.[21] Thirdly, the monthly disclosure by MBS issuers to investors, on every 4th business day of each month, shows marked-to-market risk indicators for each MBS deal. As mentioned earlier, the mortgage loans used as collateral were also "plain vanilla" products with low cash flow uncertainties.

The subprime MBS, on the other hand, is structured to control default risk, i.e., "credit-tranches" with different degrees of loss protection. The credit-tranching itself is generally deemed as a vehicle to reduce the problem of "lemons" in the MBS trading: that is, due to information asymmetry between lenders/issuers and investors in assessing embedded risks of the deal, tranching can reveal risk-return trade-offs that investors can expect (DeMarzo (2005), Downing, Stanton and Wallace (2005), and Oldfeld (2000)). However, this notion is premised upon perfect and symmetric information, and a noisy estimation of underlying loan performance (PD via a Tier 1 Model) will carry through the next stages, all the way to determining the size of each tranche and coming up with its risk-adjusted return measure.

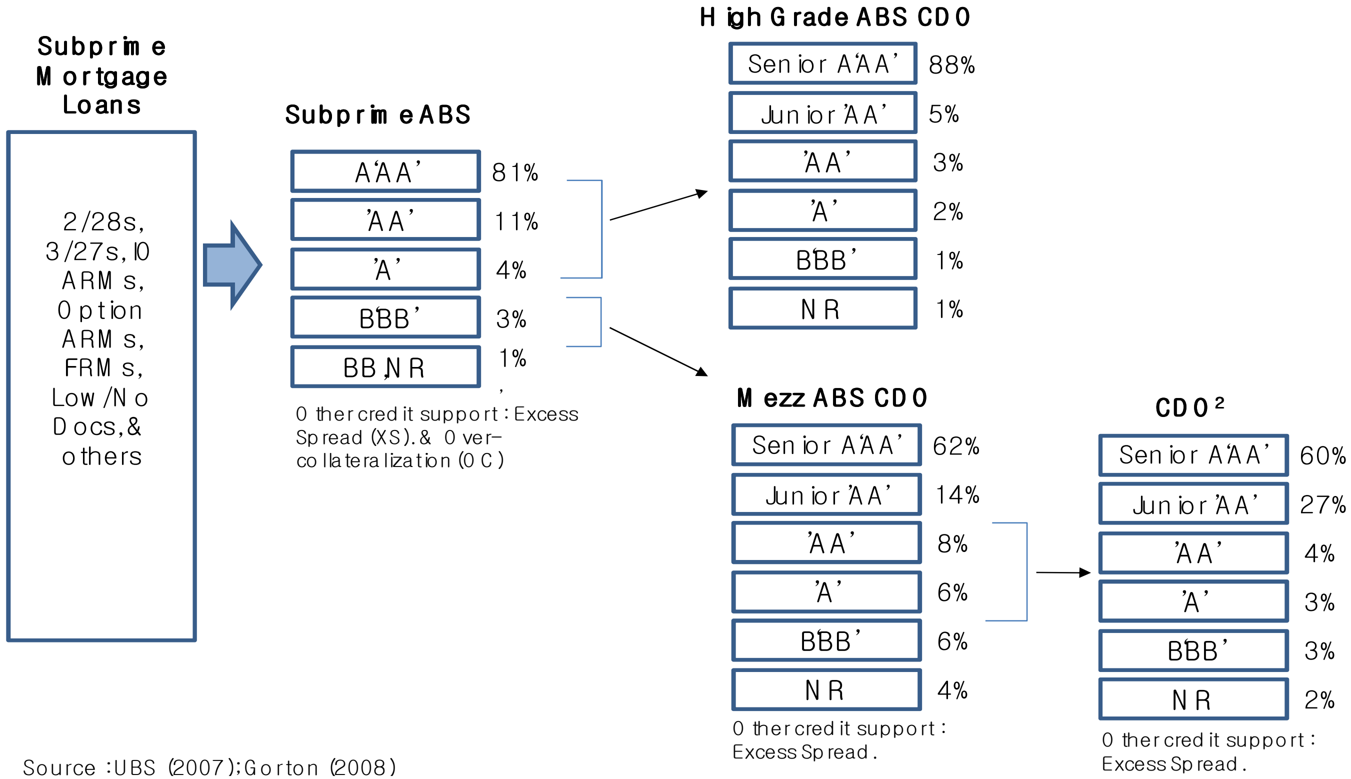
In particular, the subprime MBS involves multiple rounds of securitization, as shown in Figure 6. The first round is to package a pool into an ABS deal. There are three ways to control the embedded default risk via structuring the deal: subordination (to be discussed later), excess spread (XS), and over-collateralization (OC).[22] The typical subordination in the ABS trading takes the so-called "6-pack" structure; that is, the senior (or AAA) tranches in the deal are protected by 3 mezzanine tranches and 3 junior tranches.

[20] Planned amortization class

[21] See Appendix 1 for a conceptual discussion on OAS.

[22] OC refers to the fact that the total amount of mortgage loans backing an ABS deal exceeds the total bond to be paid; that is, the asset (of the deal) being greater than the liability. XS, on the other hand, means that total interest collected from the pool is greater than the interest paid to investors.

Figure 6 Securitization of Subprime Mortgages



Source: UBS (2007); Gorton (2008)

The second layer is the re-securitization of ABS tranches into CDO deals, and the high-grade ABS CDO and the mezzanine ABS CDO as shown in the figure.[23] There is one more layer of securitization, via pooling mezzanine CDO tranches into CDO^2 (or CDO-squared), due to the problem in marketing these middle tranches. That is, while the senior CDO tranches were favored by conservative investors (e.g., pension funds) and the junior tranches by aggressive investors (e.g., hedge funds and foreign investors), the middle pieces did not pull a strong demand. Hence, the MBS issuers re-packaged the mezzanine tranches and re-created senior and junior tranches with different subordination levels from the original CDOs.

The ABS CDO market has grown from virtually non-existent in 2001 to $261 billion in new issuances in 2006 (including subprime and other ABS deals). This rapid growth was achieved without any industry-wide best practices for measuring and disclosing risks embedded in the deals. As mentioned earlier, the industry practice was different in the prime MBS market in that it has been utilizing OAS as a key measurement tool along with the monthly disclosure requirements of mark-to-market risk factors by MBS issuers to investors. The subprime ABS CDOs, which grew the most rapidly of any segment of the CDO market since the early 2000s, has declined since mid 2007 with virtually no new issuances in 2008.

Longstaff and Rajan (2008), the only study identified on CDO pricing, document that the use of CDOs can produce a substantial diversification benefit in the case of corporate bonds. In particular, by using the market transaction data between 2003- 2005, they show that on average, 65 percent of the CDO risk spread is due to firm-specific idiosyncratic default risk, 27 percent to clustered industry or sector default risk, and 8 percent to catastrophic or systemic default risk. However, it remains to be seen whether or not a similar diversification benefit can be expected from the re-securitization of mortgage bonds via CDO and CDO^2, which is not likely given the high degree of similarities among subprime mortgage loans in the pool. Nonetheless, diversification across geographical areas and/or across different mortgage products would be one possible option for risk reduction by having a CDO-like structure.

As a final point, bond ratings have a paramount importance in gauging embedded credit risks in CDO and CDO^2 deals. The main purpose of bond rating is to measure the likelihood of full payment of interest either on a timely or ultimate basis, and ultimate payment of principal to noteholders. Specifically, each tranch, starting from AAA, has protection from credit losses

[23] The CDO deals illustrated in Figure 6 represent “cash flow CDOs.” Another type of CDO that has been widely traded is “synthetic CDOs,” the structured finance vehicles that use credit derivatives (e.g., credit default swap (CDS)) to achieve the same credit risk transfer as cash flow CDOs, without physically transferring the assets. There are also “hybrid CDOs” that combine the features of both.

with subordinated principals allocated to all tranches below it. As shown in Figure 6, the AAA tranch is protected by all tranches below it (AA to NR, (non-rated)), whose principals equate to the stress losses expected. Therefore, the rating agencies should have sound frameworks for the Tier 1 Model, as well as a portion of the Tier 2 Model (to generate scenario-specific losses). Also, transparency in their rating practice should also have been a useful market-maker for CDO and CDO^2, which in all likelihood did not appear to happen during the boom period. On this topic, Cho, Yang and Lin (2009) model the cash flow waterfall of ABS and CDO deals backed by mortgage loans, and report preliminary results on tranche-level risk-return indicators.

5. Lessons Learned

There were two unprecedented economic trends that promoted the asset market booms in the U.S. since the late 1990s; the sustained strong home price growth in the 1998-2006 time period, and the highly accommodative monetary policy, especially in the early 2000s. The level of home price appreciation, which was several multiples higher than prior boom periods in terms of total appreciation, created a perception of a long run price growth among market participants, creating a mania for investment. That, in turn, increased the demand for subprime mortgage products, such as option ARMs, which were quite frequently used for purchasing investments or second homes rather than primary residences. The crashing end of that boom came when the national price index started declining from mid-2006.[24]

The monetary policy in the early 2000s is another systematic factor that contributed to the real estate boom since the late 1990s. In particular, the real FFR was negative (below the inflation growth rate) between 2002 and 2005, as shown in Figure 7. During this period, the spread between 1-year and 10-year treasuries was floating around 250-300 basis points, inviting the so-called "yield curve play" among institutional investors: that is, borrowing in a short-term money market by issuing ABCPs and other products with short maturities, and using the mobilized funds to invest in long-term securities, such as subprime MBS. There is a growing evidence that the Wall Street IBs have played this game; that is, they not only served as issuers of CDOs and CDO^2s, but also as active investors thereof, either through affiliated hedge funds or direct portfolio acquisitions of the securities.[25]

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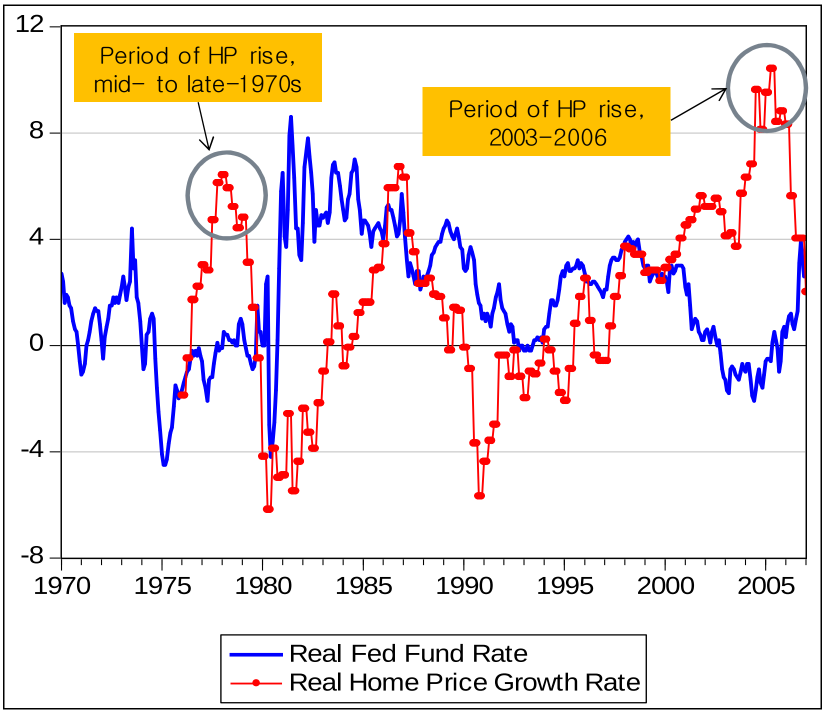
[24] There is a growing literature on the relationship between housing and speculative mortgage demand, including Wheaton and Nechayev (2008), Coleman, LaCour-Little, and Vandell (2008), and Avery, Brevoort, and Canner (2007). In addition, the relaxation of the capital gains tax on housing sales in 1997 is also quoted as a contributing factor to the rise of leveraged investment on housing in the 2000s.

[25] For example, UBS had a larger subprime MBS portfolio than the sum owned by their hedge funds. (UBS (2008))

Before the 2000s, there was only one incident in the last 40 years where the real FFR was negative for a time span of 2-3 years in the mid- to late-1970s. At that time, the national home prices also rose steeply in the middle of that prolonged negative short rate period. The difference between this period and the present crisis, however, is the fact that the price boom in 2003-2006 started in the middle of already accumulated strong growth from 1998, while the boom in the 1970s began from the depressed home price movement in the early 1970s. Hence, the self fulfilling nature of the boom in home prices is presumed to be much stronger in the recent incident.[26]

With this as background, I will discuss three particular lessons to be learned from the subprime mortgage debacle below; that is, the importance of reliable loan performance data, need to develop conceptual guidance in measuring mortgage credit risk, and a process and products for transparent mortgage securitization.

Figure 7 Interaction between Home Price and Interest Rate



Data Sources: Federal Reserve Bank; OFHEO

[26] As a relevant point, Shiller (2008) also reports that the home price boom in the 2000s is unprecedented in the last 100 years of history in the U.S. housing market.

5.1 Ramification (1): Compiling Reliable Mortgage Performance Data

A question to ask is whether the participants in the subprime and Alt-A markets had reliable data to fit a robust PD model; the Tier I Model, for the mortgage products traded, such as option ARMs, 2/28s, 3/27s, and 40-year ARMs. The answer now would be positive, as we have seen ample cases of default and delinquency from those products, but it must have been infeasible before late 2006, when the markets started collapsing.

As shown in Table 3 below, there is a wide variation among 90+ day delinquency rates across prime and subprime mortgage products in recent years, ranging between 24% for subprime ARMs, 8.7% for subprime FRMs, 5.4% for prime ARMs, and 1.1% for prime FRMs. However, in 2006 Q1, the bad loan shares are virtually identical between FRMs and ARMs in each market segment; the delinquency rates decline between 2002 and 2006 in all product segments, more so in the subprime market. The rates sky-rocket between 2006 and 2008, in particular for subprime ARMs which show a 270% total growth during that two-year period.

Table 3 90+ Day Delinquency Rates

	A. 2002 Q4	B. 2006 Q1	C. 2008 Q1	03 to 06	06 to 08
Subprime ARM	10.0%	6.5%	24.1%	-34.9%	269.8%
Subprime FRM	11.0%	6.5%	8.7%	-40.9%	34.1%
Prime ARM	1.1%	0.9%	5.4%	-17.1%	490.2%
Prime FRM	0.8%	0.9%	1.1%	11.0%	22.0%

Source: Freddie Mac (2009)

The ramification is that the historical loan performance data up to 2006 must not have been a proper guide in differentiating the performance of subprime ARMs, which take about 90% in that market segment, vis-à-vis other products.[27] Hence, the performance data available before the market run in 2006-2007 is not reliable in fitting the basic credit model; the Tier 1 Model, which has spillover effects on the subsequent credit models as discussed in Section 3.

There are other reasons to believe that the data up to 2006 is not a good guide. First, many subprime products introduced in the 2000s never experienced a real stress economy, making it virtually impossible to benchmark relevant performance indicators (e.g., stress PD, stress loss, and the risk-neutral spread as in equation (1)) under any extreme economic environment before it actually happened. Secondly, many Alt-A products did not collect data on several key

[27] The empirical findings reported by Pennington-Cross and Ho (2010) confirm this observation.

variables on the right-hand side due to low documentation requirements, which exacerbated the data problem for measuring credit risk.

5.2 Ramification (2): On Developing Theories and Industry Best-practices

As discussed in Section 4, one of the key measurement issues that remained unresolved in pricing subprime mortgage risk is how to form a forward-looking home price distribution to be used in the simulation. Unlike interest rate modeling, which has a long tradition since the 1970s, conceptual guidance for projecting home prices still has a number of loose ends, such as the type of forecasting model to use (e.g., autocorrelated vs. random walk model), ways to segment geography (metropolitan areas vs. states vs. whole country), ways to measure and reflect diversification benefits (across geographical areas vs. across mortgage products) as well as correlation between home prices and interest rates, the volatility specification to be used (e.g., the top-down vs. bottom-up approach), and so on.[28] Each approach has pros and cons, as a theory and feasible industry practice. It is fair to say that the literature in this regard is in its infancy in offering theories and guiding industry practices.[29]

The study discussed in Section 4; Yang, Lin, and Cho (2009), represents an early research effort by showing effects of different sources of home price volatility on estimating PDs and the probability of negative home equity. Related to this line of research, defining forward-looking stress scenarios in the housing market and setting the corresponding capital reserve levels are other conceptual issues to be enlightened with future research. As mentioned earlier, “extreme but plausible” roughly defines the level of conceptual guidance in defining stress scenarios right now, and so, the extant literature should be further elaborated via more full-blown theoretical and empirical research in the context of the mortgage market.

Another important area for further research is the role of household income and DTI in measuring and pricing mortgage credit risk. The literature on mortgage defaults to date has primarily focused on the equity level, at origination and ex post, and its share to remaining loan balance. However, as shown in the subprime debacle, payment shock is a highly critical factor in determining PDs for ARMs in general and the subprime products in particular. As this is mostly determined by interest rate and income processes, properly modeling these variables in the measurement of mortgage risk should receive

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[28] There are other measurement issues in executing the pricing simulation, such as correlation across state variables (e.g., between home prices and interest rates) and use of second liens. See LaCour-Little (2007) for these issues.

[29] In terms of the industry practice, the forward-looking home price distributions are widely varied among subprime MBS issuers up until the early 2007. (Merrill Lynch (2006) and Lehman Brothers (2006) stand as notable examples)

more attention going forward. In particular, as ARMs and hybrid mortgage products are generally advantageous over FRMs in terms of enhancing home purchase affordability for first-time home buyers and young borrowers, further research on income-driven variables is warranted for more robust estimations of PDs and other default indicators.

5.3 Problem (3): On Restoring Mortgage Securitization

It is reasonable to expect that highly complicated mortgage securities, such as CDOs and CDO^2s will not be seen again in the market, at least in the near future, if not permanently. The problem with such securities, as emphasized in this study, is the fact that it is virtually impossible to accurately measure and fairly price the embedded credit risks due to data problems and lack of conceptual guidance as well as industry best practices. As a result, there is a disconnection between the performance of underlying assets (mortgage loans) and the prices of those securities. The key lesson to be learned is that the security market should not leap ahead without proper infrastructure of measuring risks of underlying assets; that is, proper data, theories, and best-practices as discussed in the earlier sections.

Nonetheless, the credit-tranching itself, as shown in structuring the ABS in Figure 6, still has an important role, in my view, in alleviating the information asymmetry between investors and security issuers as to the credit risks of underlying mortgage loans. Provided that the proper infrastructure of the risk assessment is well-established, the credit-structured securities can work as useful liquidity facilities in the mortgage market as well as other borrowing sectors. The recent Term Asset-Backed Securities Loan Facility (TALF) program instituted by the Federal Reserve is a good example of utilizing prudent and transparent ABS structures for again, mobilizing global funds, in order to foster consumer and small business lending in the U.S. and other countries.

Finally, a mechanism, such as monthly disclosure done in the prime MBS market, which can reduce information asymmetry between security issuers and investors, will be required. Related to this point, evidence is growing to indicate that the subprime and Alt-A mortgage lenders took incrementally higher credit risks over time since the early 2000s with similar credit loss assumptions (Calomiris (2008). This was done partly because there was no similar mechanism in the subprime security market that could convey the risk of underlying mortgage asset periodically. Hence, as a final point, the moral hazard problem in the mortgage securitization process, similar to the one observed in the subprime mortgage market, can be alleviated by instituting disclosure and other monitoring tools that can make the security trade a more transparent and level-playing-field between security issuers and investors.

6. Concluding Remarks

This study aims to shed light on two main analytical issues: first, the type of infrastructure that is needed in properly measuring mortgage credit risk, and secondly, the specific problems that are observed with the subprime, and to a more limited extent, Alt-A mortgage markets in managing credit risks embedded in the mortgage and MBS products traded. Also discussed are several policy lessons learned, including the importance of the data and modeling infrastructure and the need to make MBS trading more prudent and transparent. As discussed in the prior section, I expect and hope that we will see more theoretical and empirical studies on the various issues discussed to help guide industry practice.

In closing, we can pose one question to ourselves as to the rise and fall of the subprime mortgage markets; that is, could it have been avoided? Although different pundits would offer different answers, it is worth noting the claim made by the late Edward Gramlich in 2007. In particular, he argued that the crisis could have been averted had one existing regulation been applied properly in screening risky mortgage loans. That is, the “high-cost loans” as required to be monitored by the Home Owner Equity Protection Act (HOEPA) of 1994 were inadequately defined. The law requires mortgage lenders to perform special tests for high-cost mortgage loans, and those with an interest rate more than “eight percentage points” above the benchmarking Treasury rates. For high-cost loans, several practices are banned, including balloon payments in the first five years, severe payment shocks after origination, and prepayment penalty periods that last longer than five years. The problem is that with the existing 8% threshold, only 1% of the subprime loans could have been covered. Had it been 5% (3%), about 50% (virtually all) of the subprime loans would have been covered. Hence, in hindsight, the unprecedented credit losses of the subprime mortgage products and the credit crunch that ensued in those market segments could have been avoided, at least in the viewpoint of credit risk management.

References

Ambrose, B., M. LaCour-Little and Z. R. Huszar. (2005). A Note on Hybrid Mortgages, *Real Estate Economics*, **33**, 4, 765-782.

Avery, R., R. Bostic, P. Calem, and G. Canner. (1996). Credit Risk, Credit Scoring, and Performance of Home Mortgages, *Federal Reserve Bulletin*, **July**.

Avery, R., K. Brevoort, and G. Canner. (2007). The 2006 HMDA Data, *Federal Reserve Bulletin,* **Summer**.

Brueckner, J.. (1993). The Demand for Mortgage Debt: Some Basic Results, *Journal of Housing Economics,* **3**, 251-262.

Brueckner, J., and J. Follain. (1988). The Rise and Fall of the ARM: An Econometric Analysis of Mortgage Choice, *Review of Economics and Statistics*, **70**, 1, 93-102.

Buist, Henry and Tyler Yang. (1998). Pricing the Competing Risks of Mortgage Default and Prepayment in Metropolitan Economies, *Managerial Finance*, **28,** 9/10, 110-128.

Calem, P., and M. LaCour-Little. (2003). Risk-Based Capital Requirements for Mortgage Loans, *Journal of Banking and Finance*.

Calhoun, C.A. and Y. Deng. (2002). A Dynamic Analysis of Fixed - and Adjustable-Rate Mortgage Terminations, *Journal of Real Estate Finance and Economics*, **24**, 1/2, 9-33.

Calomiris, C. (2008). The Subprime Turmoil: What's Old, What's New, and What's Next, *Presented at the 2008 Kansas City Fed Economic Policy Symposium*, Jackson Hole, Wyoming.

Chacko, G., S. Sjoman, H. Motohashi, and V. Dessain. (2007). Credit Derivatives: A Primer on Credit Risk, Modeling, and Instruments, Wharton School Publishing, Upper Saddle River, New Jersey.

Cho, M. (2008). Subprime Mortgage Market: Rise, Fall, and Lessons for Korea, *KDI School Working Paper 08-08.*

Cho, M. (2007). 180 Years’ Evolution of the US Mortgage Banking System: Lessons for Emerging Mortgage Markets, *International Real Estate Review*, **10**, 1, 171-212.

Cho, M, T. Yang, and C. Lin. (2009). Pricing Failure of Subprime ABS-CDO Deals: What Went Wrong? , Presented at the 2009 ASSA Meeting, San Francisco, U.S.A..

Coleman, M., M. LaCour-Little, and K. Vandell. (2008). Subprime Lending and the Housing Bubble, *Journal of Housing Economics*, **17**, 272-290.

DeMarzo, P. (2005). The Pooling and Tranching of Securities: A Model of Informed Intermediation, *Review of Financial Studies*, **18**, 1-35.

Deng, Y., J. M. Quigley and R. Van Order. (2000). Mortgage Termination, Heterogeneity, and the Exercise of Mortgage Options, *Econometrica*, **68**, 2, 275-307.

Downing, C., R. Stanton, and N. Wallace. (2005). An Empirical Test of a Two-Factor Mortgage Valuation Model: How Much Do Home Prices Matter? , *Real Estate Economics*, **33**, 4, 661-710.

Duffie, D. and K. Singleton. (2003). Credit Risk. *Princeton University Press*. Princeton, New Jersey.

Fortowsky, E., M. Lacour-Little, E. Rosenblatt, and V. Yao. (2009). Housing Tenure and Mortgage Choice, *Journal of Real Estate Finance and Economics*, forthcoming.

Foster, C. and R. Van Order. (1984). An Options-Based Model of Mortgage Default, *Housing Finance Review*, **3**, 4, 351-372, 1984.

Freddie Mac. (2009). *Freddie Mac Update,* **January**.

Gorton, G. (2008). The Panic of 2007, Presented at the 2008 Kansas City Fed Annual meeting, Jackson Hole, *U.S.A.*.

Gramlich, R. (2007). Subprime Mortgages: America's Latest Boom and Bust, The Urban Institute Press, Washington, D.C.

Green, R., and S. Wachter. (2005). The American Mortgage in Historical and International Context, *Journal of Economic Perspectives*, **19**, 4.

Greenlaw, D., J. Hatzius, A. Kashyap, and H. Shin. (2008). Leveraged Losses: Lessons From the Mortgage Market Meltdown, *US Monetary Policy Forum Paper No. 2*, Rosenberg Institute, Brandeis International Business School and Initiative on Global Markets, University of Chicago Graduate School of Business.

Gwinner, W., and A. Sanders. (2008). The Subprime Crisis: Implications for Emerging Market, *World Bank.*

International Monetary Fund (IMF). (2008). *Global Financial Stability Report,* **October**.

Jaffee, D. (2008). The US Subprime Mortgage Crisis: Issues Raised and Lessons Learned, *Mimeo*.

Kau, J. B. and D. C. Keenan. (1995). An Overview of the Option Theoretic Pricing of Mortgages, *Journal of Housing Research,* **6**, 2, 217-244, 1995.

LaCour-Little, M. (2007). The Home Purchase Mortgage Preferences of Low- and Moderate-Income Households, *Real Estate Economics*, **35**, 3, 265-290.

Lehman Brothers. (2006). Introducing Credit OAS for Residential Mortgage Securities, *Fixed Income Research*.

Lin C. C., M. Cho, and T. T. Yang. (2008). Default Risk and Relative Values of "Exotic" Mortgage Products: A Multi-Factor Simulation Approach, Working Paper presented at 2008 AREUEA Annual Meeting.

Longstaff. F., and A. Rajan. (2008). An Empirical Analysis of the Pricing of Collateralized Debt Obligations, *The Journal of Finance,* **LXIII**, 2, 529-563.

Longstaff, F., and E. Schwartz. (1995). Valuing Risky Debt: A New Approach, *Journal of Finance*, 789-821.

Mason, J., and J. Rosner. (1997). How Resilient Are Mortgage Backed Securities to Collateralized Debt Obligation Market Disruptions?, Manuscript presented at the Hudson Institute.

Merrill Lynch. (2006). Valuing Subordinate ABS, *Global Securities and Research*.

Merton, R. (1974). On the Pricing of Corporate Debt: the Risk Structure of Interest Rates, *Journal of Finance,* **29**, 449-470, 1974.

Moretti, M., S. Stolz, and M. Swinburne. (2008). Stress Testing at the IMF, *IMF Working Paper 08-206.*

Oldfeld, G. (2000). Making Markets for Structured Mortgage Derivatives, *Journal of Financial Economics,* **57**, 445-471.

Passmore, W. (2005). The GSE Implicit Subsidy and the Value of Government Ambiguity, *Real Estate Economics*, **33**, 3.

Pennington-Cross, A. and G. Ho. (2010). The Termination of Subprime Hybrid and Fixed Rate Mortgages, *Real Estate Economics*, **38**, 1, forthcoming.

Quercia, R., M. Stegman, and W. Davis. (2005). The Impact of Predatory Loan Terms on Subprime Foreclosures: The Special Case of Prepayment Penalties and Balloon Payments, *mimeo,* University of North Carolina.

Reinhart, C., and K. Rogoff. (2008). Is the 2007 US Sub-Prime Financial Crisis So Different?, An International Historical Comparison, *mimeo.*

Roubni, N. (2008). The Current US Recession and the Risks of a Systemic Financial Crisis, *Written Testimony to the US House of Representatives,* February 26, 2008.

Shiller, R. (2008). *The Subprime Solution: How Today's Global Financial Crisis Happened, and What to Do About It?,* Princeton University Press, Princeton, New Jersey.

UBS. (2008). Shareholder Report on UBS's Write-Downs, *UBS AG*, **April**.

Wheaton, W., and G. Nechayev. (2008). The 1998-2005 Housing 'Bubble' and the Current 'Correction': What's Different This Time?, *Journal of Real Estate Research*, **30**, 1, 1-26.

Yang, T., C. Lin, and M. Cho. (2009). Collateral Risk in Residential Mortgages, *Journal of Real Estate Finance and Economics,* forthcoming.

Appendix 1 Option Adjusted Spread (OAS) and Its Application

The U.S. mortgage finance industry has embraced the concept of option adjusted spreads (OAS) since the mid-1980s. OAS specifically controls: (1) the shape of the forward-looking yield curve in discounting MBS cash flows, (2) the timing and amount of prepayments in different future time periods, and (3) the appropriate benchmark to use in computing the spread at a particular time period. As such, it is viewed as a more theoretically-sound measure than the alternative risk-adjusted return measures, e.g., the nominal spread (a static risk premium of a security over a single risk-free rate), and Z-spread (or zero-volatility spread that controls the yield curve effect, but not the volatility in the state variable nor the propensity of prepayment under different economic scenarios).

Specifically, OAS is measured via a trial-and-error process by using a large number of simulated paths (N) of economic variables, such as interest rates, through loan maturity (T), and time-varying risk-free rate (r). Assuming a known market value on the left-hand side, the formulae below represents a typical framework for measuring OAS, s therein. In the case of using a large number of simulated economic paths, obtaining s can be computationally involved.

$$Market\ Price = \frac{1}{N}\sum_{i=1}^{N}\ \sum_{k=1}^{T}\frac{E[CF_{i,k}]}{\prod_{j=1}^{k}(1+r_{i,j}+s)}$$

$CF_{i,k}$ refers to the cash flow at time period k corresponding to the economic path i, and E[.] represents the expectation operator. The obtained OAS is the residual spread in that it is the remaining risk premium after netting the prepayment risk, i.e., OAS = Z-Spread – Option Cost. See Davidson et. al (2003), Chapter 13, for further details. OAS is widely used in the MBS performance reports issued by the prime MBS dealers.