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ABSTRACT

During the depths of the global financial crisis of 2008-09, many holders of subprime mortgage securitizations and related derivatives were forced to mark their investments to fair values based on observable prices in mortgage index credit default swap markets. Research has generally claimed that crisis pricing of such indices cannot be explained by fundamental analysis of the underlying markets, while marking portfolios to such "irrational" benchmarks may have contributed to severe distress in the financial sector. This paper econometrically demonstrates significant fundamentally-driven components in subprime mortgage index returns throughout the crisis. Our findings suggest that such benchmarks must be considered reasonable, though imperfect, guides for determining fair value.

JEL Classification: G01, G12, G28.

Keywords: financial crisis; irrational markets; mortgage-backed securities; fair value accounting; mark to market

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1. Introduction

Should tradeable financial asset holdings be marked-to-market or held at historical cost in a crisis? Many accounting scholars believe "that reliance on prices can be counterproductive when secondary markets are stressed and illiquid" and, as such, "[p]olicy makers contemplating greater regulatory reliance on market prices ignore … findings [of irrational prices] at their peril" (Kolasinski 2011, 174). Empirical studies (Gorton, He and Huang 2006) and theoretical work (Allen and Carletti 2008; Plantin, Sapra and Shin 2008) support this view. Bernard, Merton and Palepu (1995), Goodhart (2010), and others suggest, however, that there is no better alternative to marking to observable traded prices or estimates based on traded prices of other assets. Still others find that accounting treatment is but one factor interacting with others in exacerbating crises (Ellul et al. 2015). Though the literature on "fire sales" in crises identifies many causes of irrational market price declines (Brunnermeier 2009), there are specific concerns that irreversible damage can occur if assets are valued based on prices that do not reflect (higher) fundamental values.

The Global Financial Crisis (GFC) is an important laboratory for empirical research into the question of fundamental pricing. This paper returns to one of the more well-studied markets during this period, index credit default swaps (CDS) referencing subprime U.S. residential mortgage-backed securities (RMBS), the ABX. These CDS were commonly used by investors to take positions in the United States (U.S.) RMBS market and were often significantly more liquid than the underlying cash bonds (Morgan Stanley 2008). During the GFC, accounting standards required most financial assets to be reported on a fair-value basis.[1]

As the indices traded more frequently than the underlying bonds, the index CDS were often used and sometimes indeed mandated as benchmarks to mark subprime investments to market (Senior Supervisors Group 2008).

Support for historical cost accounting for financial assets is often based on the belief that prices diverge from values justified by fundamentals during financial crashes and panics, and this has significant negative effects on systemic financial stability. Many academic studies as well as practitioner accounts of the GFC support the common financial industry and even policymaker view best articulated by the Bank of England (2008) that marking RMBS and

[1]These standards are outlined in Financial Accounting Standards Board (FASB) Statement of Financial Accounting Standards (SFAS) 157. See also SFAS 115, 139, and 159. Similarly, another accounting standard applied at many non-U.S. financial institutions during the GFC, International Accounting Standard (IAS) 39, required that fair-value accounting be applied to most financial assets with liquid markets. In late 2008, the FASB and the International Accounting Standards Board (IASB), through a series of statements, allowed for more deviations from traditional fair-value principles.

Collateralized Debt Obligations (CDO) positions to the index default swap prices may have exacerbated the crisis by forcing investors to sell RMBS and other assets to shore up capital, or otherwise make balance sheets appear worse than they really were, inciting investor panic, leading to even more fire sales at distressed prices.[5] In addition to Kolasinski (2011), Sapra (2008), French et al. (2010), and Kothari and Lester (2012) conclude from studying this period that fair value accounting should not be applied to such assets during periods of severe financial crisis.

Besides the accounting issues that impact investors' solvency measures, if crashes such as the subprime RMBS market debacle of 2008-09 are solely the result of liquidity concerns, then efforts by central banks and governments to take temporarily impaired assets onto their balance sheets would mitigate such crises at no risk. Taxpayers may benefit the market while also profiting from the capture of liquidity premia during fire sales. If, however, price declines are fundamental in nature, then GFC and COVID Federal Reserve programmes, where the U.S. Treasury takes a leveraged first-loss position on credit risky instruments (Board of Governors 2020), expose the taxpayer to undue risks when solvency rather than liquidity is the dominant problem, although such programmes may still carry second-order benefits by promoting financial stability.

Transparency in asset valuation during the crisis would be more defensible if the indices that were used to mark RMBS and CDOs to market demonstrably reflected fundamentals. Much of the recent research suggests, however, that they did not. Some degree of illiquidity effects likely combined with fundamental deterioration to cause a fire sale in these markets (Covitz, Liang, and Suarez 2013), yet scholarship generally goes further, implying complete irrationality. Stanton and Wallace (2011) find complete irrationality during the depths of the crisis, finding that "prices for … index CDS during the crisis were inconsistent with any reasonable assumption for mortgage default rates." Gorton (2009) shows that 2008 yields on the CDS were too high, so prices too low, compared to the values of other subprime bonds. Blundell-Wignall (2008) argues without evidence that liquidity drove the ABX below fundamental values. Gorton and Metrick (2012) identify overwhelming liquidity premia in the mortgage index CDS market, with no relationship between subprime mortgage CDS yields and market fundamentals. On the other hand, Longstaff (2010) and Fender and Scheicher (2009) find that these CDS prices cannot be said to have been completely disconnected from fundamentals.

We can identify four supposed negative consequences of "improper" marking to market of RMBS. Firstly, runs on the (traditional) banking system and shadow banking systems can

[5] The banking industry (Hughes and Tett 2008; Salmon 2010) and academics, including Plantin, Sapra and Shin 2008; Shleifer and Vishny 2011; Acharya, Schnabl and Suarez 2013; Ellul et al. 2015, generally support suspending marking to market during crisis.

occur as reported capital is eroded due to the price markdowns themselves (Gorton and Metrick 2012). Holding distressed assets at historical cost may avoid the appearance of insolvency, making capital raising less costly in crisis (Merrill et al. 2012).[6] One large RMBS CDS holder accused of not marking positions to market during the GFC was able to avoid raising new capital at distressed prices, unlike most other banks and investment banks (SEC 2015). Secondly, if mark-to-market is overly pessimistic, liquidations of assets to shore up capital may cause even lower and more irrational prices (fire sales) while at the same time punishing equity and possibly even debt holders. Thirdly, mark-to-market requirements may result in firms taking even more risk, as otherwise prudent risk reduction may be thwarted by those who do not want to risk sales at prices below historical cost used to mark down the remaining portfolio (Milbradt 2012). Fourthly, RMBS CDS index pricing was also used to settle lawsuits (NERA 2012). If pricing was irrational or otherwise not based on fundamental values, court judgments have been made in error, while shareholders suffered unnecessary dilution.

This paper answers the important question: Were the prices that institutions used to mark their mortgage-backed bond portfolios to fair value explainable by fundamentals? That is, were they based on liquidity and other contagion factors, or were they irrationally determined? We examine price data of the benchmark CDS indexes, the ABX.HE, and other characteristics of subprime mortgage derivatives markets. Price data alone, however, cannot reveal the whole story. In order to capture the details of the market microstructure, we sourced qualitative and quantitative analysis by contemporary investors, RMBS dealers, and bank and securities research analysts.

We find that a simple structural model accurately explains ABX prices during the GFC, rejecting claims of wholesale "irrationality" in the literature. We show that market participants rapidly adjusted their expectations for the RMBS beginning in early 2007, and quickly identified new models of distress and relevant fundamental factors. Regressions capturing non-linear effects of these key observable variables (without forward-looking assumptions or inputs) reveal that U.S. subprime mortgage market fundamentals explain a substantial part of the price movements in 2007-13, especially in the early years of the crisis (2008-10). As market participants often used more forward-looking inputs in their pricing decisions, our approach likely understates the effect of fundamentals. Additionally, we show that selling of ABX during 2008-09 was far from indiscriminate, and therefore not simply the result of a liquidity crisis. We conclude that ABX prices were generally rationally determined during the GFC, as evolving underlying mortgage fundamentals were associated with

[6] On the other hand, runs can also occur when investors are uncertain of what assets are held; such opaqueness can lead to panic selling. As long as firms and vehicles are solvent after write-downs, and investors believe that the write-downs are complete and accurate, capital raising might be easier than in historical cost situations.

changes in market price after controlling for likely macroeconomic factors. Such results do not support the suspension of fair value accounting during a crisis on irrationality grounds.

2. ABX.HE, The Crisis and the Existing Literature

2.1 US RMBS, credit default swaps and ABX.HE

The GFC was initially caused by the rapid fundamental deterioration of highly rated subprime and near-prime U.S. RMBS held primarily, but not exclusively, in the shadow banking sector (Krishnamurthy 2010). However, the first signs of the crisis were seen in the subprime market, with the trading of lower-rated RMBS index CDS below 75 percent of par in February 2007 on the news of the banking sector's first subprime mortgage loan write-downs (Reuters 2008).

Securitization transforms a portfolio of debt contracts into instruments that have differing risk profiles from the original underlying contracts through the use of subordination as credit enhancement.[7] A large number of mortgage loans are transferred into a special purpose vehicle (SPV, Figure 1). Payments from U.S. mortgage loans flowing into RMBS structures include scheduled interest, plus scheduled (from amortization) and unscheduled (from prepayments and liquidation proceeds) principal. Agency mortgages dominate the U.S. securitization market. Because credit risk has been minimized for agency securitizations via a guarantee issued by the government-sponsored enterprises (GSEs[8]), prepayment is modelled as the primary risk and default loss is not considered.

Non-agency mortgages, ineligible for a guarantee from any of the U.S. GSEs, were securitized into prime jumbo (high quality large loans), Alternative-A (Alt-A, the "best of the worst" loans), or subprime deals. Payments get contractually divided into the various tranches (bonds) of the securitization (Figures 1 and 2 and Table 1). The goal of the tranching is primarily to make the upper tranches, and especially the Class A tranches, unlikely to sustain any losses, irrespective of mortgage portfolio performance.[9] Though the reality is more complicated than this simple example, for the purposes of this paper one can model subprime distress by assuming that any losses up to the Class As in the securitized pool of mortgages are applied up the structure from the lowest tranche first (1 in Figure 1). One can

[7] Other credit enhancement mechanisms are used in securitization but are irrelevant in severe distress. (See Goodman et al. (2008).) The following paragraphs describing the subprime RMBS and RMBS index CDS market are loosely based on Saleuddin (2015, chs 2-3). (See Gorton (2009) for a more detailed explanation of subprime, ABX and the GFC.)

[8] The three GSEs that issue securitized RMBS are Federal National Mortgage Association (Fannie Mae), Federal Home Loan Mortgage Corporation (Freddie Mac), and the Government National Mortgage Association (Ginnie Mae). They accounted for about half the MBS issuance in the three years preceding the crisis.

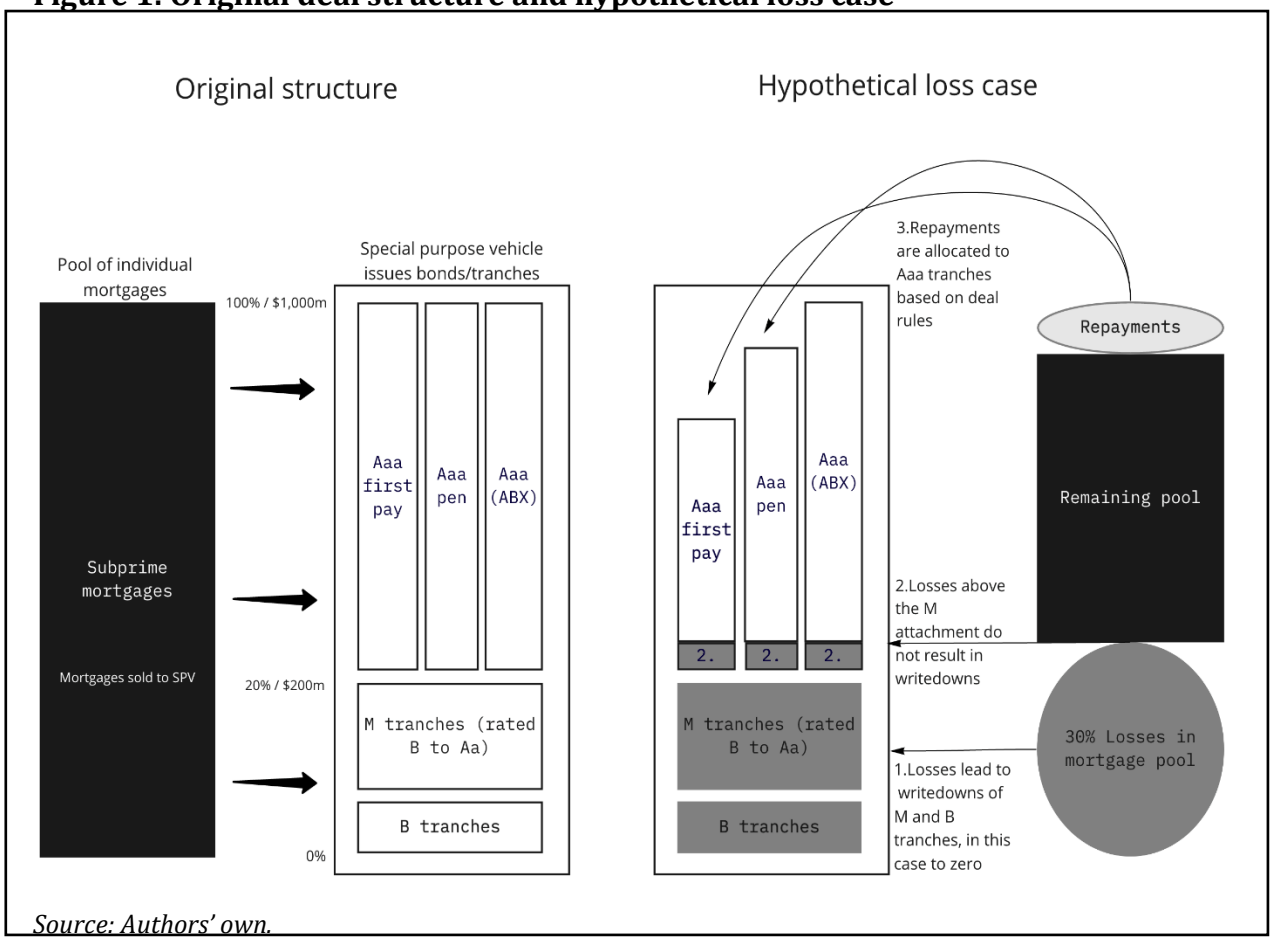
[9] As we show here, such expectations of being "loss remote" were unrealistic in hindsight.

also assume that repayments are allocated to the most senior tranches first (3 in Figure 1) in order of a prespecified priority, from "first pay" to "penultimate pay" to "last pay."[10] Due to the high expectations of repayments to the most senior Class A tranches and a low likelihood of losses being sustained, these have been historically rated AAA, implying almost zero probability of default.[11] During and after the GFC, however, losses often resulted in the write-down of all of the subordinated (M and B) tranches, resulting in an almost certain eventual default of many Class A bonds. However, generally the most senior bonds are not written down, even if the reports by the administrators of the securitization reveal that there are not enough portfolio assets to repay the bonds at their final maturity. Such impaired Class A bonds are considered near-defaulted and are rated C or CC.

Investors and hedgers commonly adjusted their exposure to subprime credit and market risk by being long or short credit default swaps (CDS) referencing four standardized portfolios, the ABX.HE indices. Traditionally, CDS on corporate credit can be thought of as credit insurance, offering the protection buyer a cash payment (the Floating Amount) based on the auction price of an underlying credit instrument (bond or loan) conditioned on the triggering of a Credit Event, usually a failure to pay a contracted debt payment, or a bankruptcy. In return, the protection seller receives an ongoing coupon payment (like an insurance premium) as long as a Credit Event has not occurred. The spread is fixed for the term of the contract, so the contract can be traded on a price basis.

[10] Again, the reality is somewhat more complex, yet adding complexity would not alter the results of this paper.
[11] The major ratings categories are Aaa/AAA, Aa/AA, A, Baa/BBB, Ba/BB, B, Caa/CCC, Ca/CC and C. We use the generic labels AAA, BBB and BBB- ratings here. All but the Ca/CC, C and Aaa/AAA have modifiers from 1 (highest) to 3 (lowest quality) or -, flat, and +. For example, BBB- is the rating category above BB+ one below BBB (flat). BBB- and above is considered investment grade. Non-investment grade is any rating BB+ and lower. C is considered default or near default. D and WD are used by some agencies to designate a default.

Figure 1: Original deal structure and hypothetical loss case



Source: Authors' own.

Table 1: Actual Structure

Morgan Stanley ABS Capital I Trust 2006-WMC2							
Bloomberg ticker	Original issuance	Original credit support	Original S&P rating	ABX Constituent	Current Factor	Write-down or repay date	Current S&P rating
MSAC 2006-WMC2 A1 Mtge	581,960,000	18.7%	AAA		0.0912		CC
MSAC 2006-WMC2 A2FP Mtge	500,000,000	18.7%	AAA		0.0329		CC
MSAC 2006-WMC2 A2A Mtge	340,525,000	18.7%	AAA		Repaid	Feb09	NR (Repaid)
MSAC 2006-WMC2 A2B Mtge	115,885,000	18.7%	AAA		0.1296		CC
MSAC 2006-WMC2 A2C Mtge	335,030,000	18.7%	AAA	06-2 PEN*	0.3561		CC
MSAC 2006-WMC2 A2D Mtge	242,825,000	18.7%	AAA	06-2 AAA	0.3561		CC
MSAC 2006-WMC2 M1 Mtge	89,803,000	15.3%	AA+		0	Feb10	NR (Written down)
MSAC 2006-WMC2 M2 Mtge	72,884,000	12.5%	AA	06-2 AA	0	Aug09	NR (Written down)
MSAC 2006-WMC2 M3 Mtge	45,552,000	10.7%	AA-		0	Jun09	NR (Written down)
MSAC 2006-WMC2 M4 Mtge	41,648,000	9.1%	A+		0	Apr09	NR (Written down)
MSAC 2006-WMC2 M5 Mtge	40,346,000	7.6%	A	06-2 A	0	Feb09	NR (Written down)
MSAC 2006-WMC2 M6 Mtge	36,442,000	6.2%	A-		0	Dec08	NR (Written down)
MSAC 2006-WMC2 B1 Mtge	35,140,000	4.8%	BBB+		0	Oct08	NR (Written down)
MSAC 2006-WMC2 B2 Mtge	27,331,000	3.8%	BBB	06-2 BBB	0	Sep08	NR (Written down)
MSAC 2006-WMC2 B3 Mtge	26,030,000	2.8%	BBB-	06-2 BBB-	0	Aug08	NR (Written down)
MSAC 2006-WMC2 X Mtge	71,585,987				0	Jul08	Written down
MSAC 2006-WMC2 P Mtge	100				1		
MSAC 2006-WMC2 R Mtge	-				N/A		
Legal final maturity of 2036					NR = not rated		

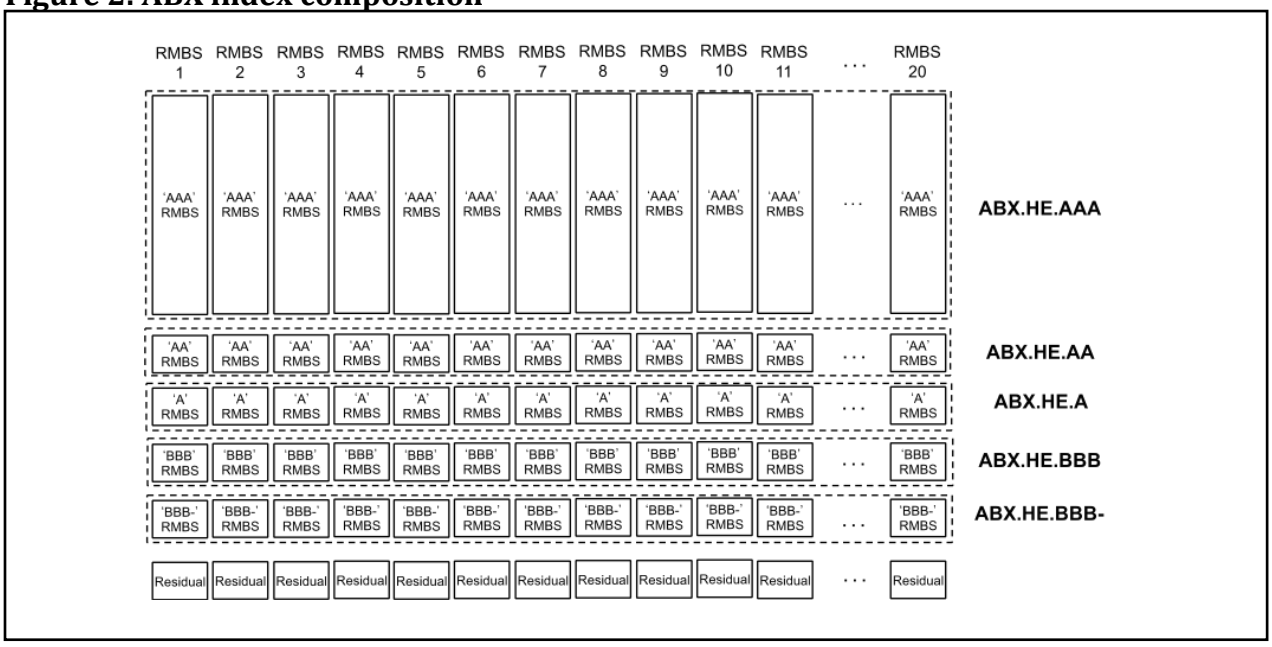
*Notes: Shaded bonds are ABX 2006-2 constituents. All B and M tranches are fully written down and defaulted as per Figure 1 stylized example. Full write downs began in July 2008 and ended in February 2010. One "fast pay" Class A tranche has fully repaid (A2A). It is highly likely, given there is not enough remaining assets to repay all of the other Class As, that some of these tranches will default at legal final maturity (also as shown in Figure 1). This explains the current CC (near-default) rating of the remaining Class As. *PEN AAA was the sixth index, added during the crisis but was not as active as the AAA that is shaded.*
Sources: Bloomberg, IHS Markit, sec.gov.

Credit Events and Floating Amounts for ABS CDS differ from those on corporate CDS in that there is no single Credit Event where the Floating Amount is determined. Instead, as tranche/bond payments are missed and/or write-downs occur in the underlying bonds, these losses are paid to the CDS protection buyer.[12] Such specialized language is needed to indicate when payment occurs as most highly rated securitized bonds do not default until they have not paid a legally required amount of interest or principal, even if the pool performance implies that they will default with 100% likelihood at a later date. Bankruptcy or failure to pay a contracted amount rarely occurs in senior (Class A) subprime bonds until the legal final maturity, which could be as much as 30 years from the time of the realized loss in the underlying pool (3 in Figure 1).

CDS were written on the ABX.HE indexes, each referencing tranches of subprime RMBS. Each ABX index was an arithmetic average of 20 tranches, all of the same initial rating and of the same "vintage," a six-month window based on date of issue. There were four vintages, 2007-2 (early 2007 issuance), 2007-1 (H2 2006 issuance), 2006-2 (early 2006 issuance) and 2006-1 H2 2005 issuance). For each vintage, the indices were grouped by original rating: AAA, AA, A, BBB and BBB- (Figure 2). The ABX.HE 2007-1 AAA CDS, for example, referenced the last pay AAA-rated tranches (leftmost AAA in Figure 1) of the 20 subprime securitizations in the index issued in the second half of 2006 (Figure 2). This paper is concerned almost exclusively with the highest rated (Class A) AAA tranches, though also addressing behavior of the (lowest rated) BBB and BBB- tranches. Before and throughout the crisis, the AAA CDS were significantly more liquid than the underlying cash bonds. Table 1 shows an actual securitization in ABX 2007-2, highlighting the tranches that ended up in the various indices.

[12] Write-down reimbursements also can occur, where previous write-downs need to be repaid to the CDS seller. Such a structure of possible two-way payments makes such a CDS, pay-as-you-go (PAUG), rather than having one settlement upon a Credit Event.

Figure 2: ABX index composition



Notes: RMBS are sourced from the 25 largest issuers from the previous six-month period, with the final 20 securitizations chosen by the top dealers.
Source: Fitch Ratings.

ABX prices are calculated theoretically by estimating write-downs (and principal and interest shortfalls) as:

$$ABX\ CDS\ Price = \frac{1}{\sum Factors} * \sum_{i=1}^{20} Factor_i * (\ 100 + PV_i\ (fixed\ amount) - Exp\ [PV_i\ (writedows, shortfalls)])$$

Factor = Remaining principal of each of the 20th assets as a percentage of original amount

Fixed amount = initial CDS coupon

Write-downs and shortfalls = floating amounts

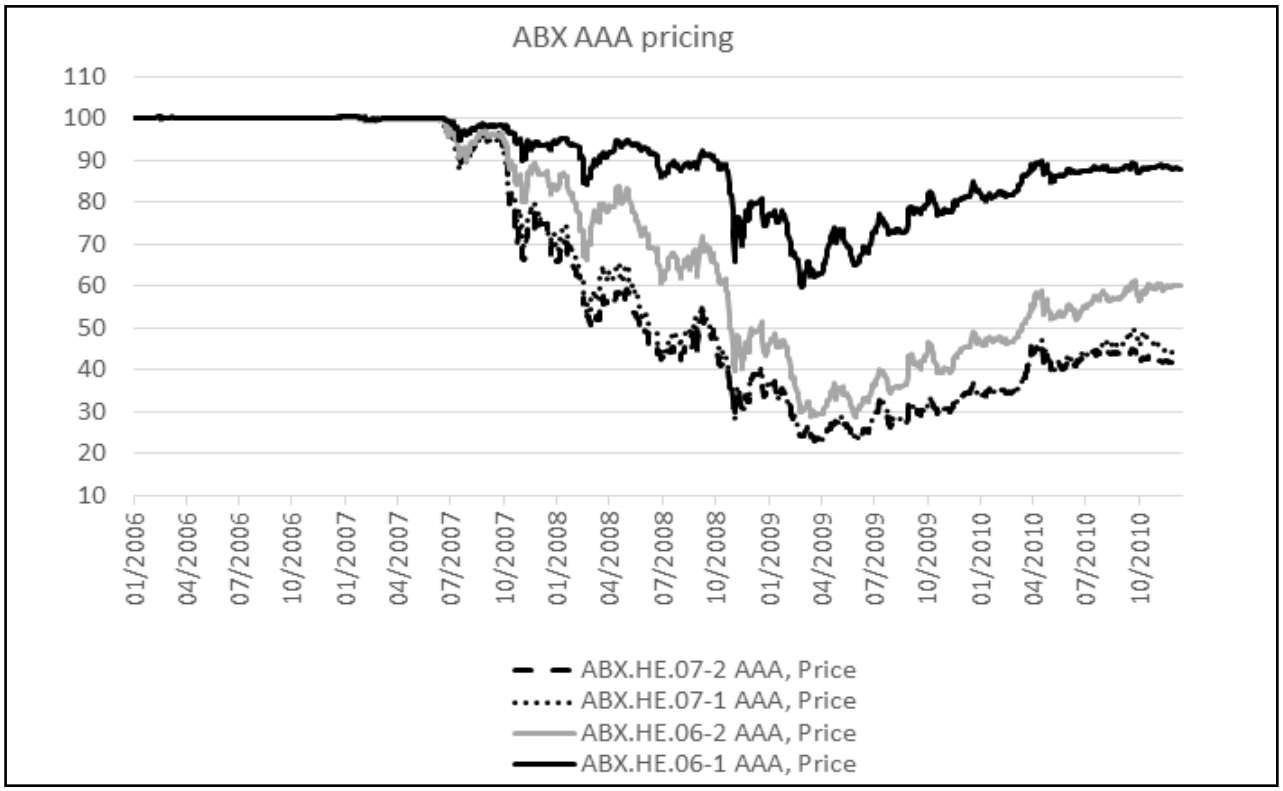
If transacting a tranche at a price of 95, the protection buyer would pay 5% up front on the remaining notional plus the running coupon. The factor adjusts for prepayments and write-downs reducing the notional amount of the tranches and therefore the CDS. Of course, prices

may deviate from rational expectations of the above parameters. The question of how much deviation occurred in 2008-10 is addressed below.

2.2 The subprime crisis

The late-boom (2006-07) U.S. subprime mortgage originations almost immediately failed once housing prices stagnated making it difficult for overextended borrowers to refinance their teaser rate mortgages (Gorton 2009). The ABX indices fell rapidly once the extent of the deterioration in subprime portfolios became widely known (Figure 3). By the middle of 2007, delinquencies and foreclosures, indicators of future pool losses, rose to unprecedented levels. Did ABX prices drop too far? There certainly are several reasons why they may have, such as limits to arbitrage (Shleifer and Vishny 197). Prices can deviate from fair value when buyers who could normally purchase securities when prices get "too low" are somehow limited in their capacity to do so, often because of lack of funding. Certainly, funding markets for all assets, but especially subprime, were failing catastrophically at the time (Gorton 2009; Gorton and Metrick 2012). Most every financial asset market also collapsed in the following years 2008-09, hinting that perhaps ABX prices were driven solely by the same macro and liquidity concerns that affected all markets.

Figure 3: ABX.HE AAA CDS prices, 2006-2010



Source: IHS Markit.

With hindsight it does appear that ABX prices got "too low" during the depths of the crisis, bottoming out in early 2009 (Figure 3). Clearly the market's fears were not fully realized. Again with hindsight, it is easy to identify the results of the mightiest infusion of liquidity in history (as well as the rescue for both banks and homeowners)—global markets stabilised, and employment and house prices trended higher until 2020. The U.S. government and the Federal Reserve stepped in with fiscal policies and both conventional and unconventional monetary policy. Additional specialized programs supported distressed homeowners as well as mortgage investors (Board of Governors 2020). Legal settlements established large programs for relief from overwhelming mortgage debt (Mortgage Settlement Monitor 2020). While in hindsight it is clear that some AAA tranches recovered and even repaid full principal after a coordinated rescue and the largest and longest credit boom in history, this is not in itself evidence that the market was irrational at the time, since the government response was uncertain at best. In order to declare that pricing was irrational, it needs to be shown that ABX prices were not based on a reasonable assessment of the fundamentals of the underlying mortgage markets.

2.3 Irrationality in the literature

We have identified four lines of argument in the literature involving ABX market participants—traders, hedgers, and investors—behaving irrationally or affected primarily or exclusively by liquidity constraints. Stanton and Wallace (2011) claim that there were no reasonable parameters in a simple ABX model that resulted in rational pricing during the depths of the GFC based on credit fundamentals. A second approach, as exemplified by Fender and Scheicher (2009), slightly differs in that it claims there was no wholesale rejection of fundamental value models. However, these authors find that declining global risk appetite and liquidity effects outweigh any fundamental concerns.

A third approach evaluates ABX yields, calculated implicitly from market prices. Gorton (2009) studies the yield difference between ABX and cash subprime bonds and finds that ABX yields were much too high in comparison to cash bond yields, implying that ABX prices were "too low." Gorton and Metrick (2012) examine the relationship between ABX spreads and other credit spreads, but they do not examine the role of fundamentals in ABX pricing. They find that ABX yields and other financial asset yields are not correlated. Stanton and Wallace (2011), also using this third approach, find that changes in ABX are not correlated with observable fundamental credit metrics. The fourth approach by Ellul et al. (2015) shows that an accounting rule change away from fair market requirements resulted in less selling in MBS markets, hinting that lower prices were a direct result of the fair value rules, and not based on credit fundamentals.

There are limitations to the literature on ABX irrationality to date. Considering the first approach, Stanton and Wallace's (2011) simple model of irrationality assumes incorrectly

that all non-defaulted mortgages repay in full at the end of one year, and that all prepayments occur before the default rate is applied. To reasonably approximate reality, the default rate would need to apply for the life of the bond and repayment rates, and default rates and loss given default would have to match contemporary observed or expected levels. In section four of this paper we extend their simple model and use more reasonable assumptions to provide simple yet robust results that fit observed pricing.

Issues with the second and third approach are many, but they distill down to two points: (1) Pre-2007 econometric models and data cannot be, and were not, used to estimate losses to the underlying RMBS during and after the GFC, and (2) ABX junior tranches under stress cannot be analyzed in the same way as senior tranches or corporate CDS. We cover each of these in the next two subsections.

2.4 Models of ABX distress, a regime change

There are two main types of models used by practitioners to estimate future default losses in RMBS. Before 2007, an "econometric model" was most common (Goodman et al. 2008).[13] Such models were driven by macro and microeconomic factors such as house price appreciation, interest rates (affecting affordability as well as refinanceability) and unemployment. The models were fit using historical data and used to predict portfolio repayments and losses. These models often assumed a strong relationship between house price appreciation measure (HPA) and prepayment. As long as HPA was positive, default losses were forecast to be minimal and prepayments very high: often between 30% and 40%, pre-GFC. With declining HPA, such models can fail catastrophically (Rodriguez 2007). Even a small decline in borrowers' equity makes refinancing impossible. The now negative HPA will no longer be a relevant factor affecting (the now low) prepayments and will not become a factor again until the mortgages are back above the A level where they can be refinanced. Therefore, not only did negative HPA cause an immediate halt to prepayments, default losses were rising as mortgage coupons were rising, refinancing was impossible, and repossessed houses hit the market causing a negative feedback loop. The old models no longer applied.

Subprime bonds originating in mid-2005 to mid-2007 constituted the majority of those still outstanding when the GFC hit and were much less creditworthy than subprime bonds issued previously (Goodman et al. 2008; Acharya et al. 2011; Demyanyk and van Hemert 2011; Moody's 2018). The majority of loans in 2006-07 subprime deals had low "teaser" interest rates that rose to unaffordable levels after two to three years, with the end result that after the teaser period, the loan would refinance, if HPA would allow it, or default. Surprise negative HPA was, in fact, the discontinuity that caused the subprime failure. Before late

[13] "Econometric models" in this context refer to a very specific use of house price appreciation, interest rates, and other economic variables to model defaults and prepayments.

2006, positive HPA drove prepayments. By 2007, negative HPA caused the whole market to fail. By late 2007, it was clear to most participants that, due to house price falls that had already occurred, HPA was irrelevant for prepayment rates (Credit Suisse 2008). Only a tremendous increase in prices would have allowed for any prepayments at all, so changes in HPA around the new lower level would have no effect. The past could no longer be used as a guide for future performance and, as such, the old econometric models were quickly abandoned. HPA became an explicit assumption, rather than formed by an econometric model (Credit Suisse 2007; JPMorgan 2008; Deutsche Bank 2008b).

When the crisis hit, some variables were (theoretically and, in the eyes, of participants, practically) no longer relevant, such as HPA and interest rates for prepayment. Expected HPA began to be used to calculate current and future LTVs to determine the likelihood of default and loss severity (Barclays Capital 2009). Small changes in HPA were unimportant (Deutsche Bank 2007).[14]

New forward-looking "migration" models (Goodman et al. 2008) replaced econometric ones early in the crisis. These models priced RMBS and ABX using expectations of default rates and loss severity based on (negative) expected HPA, jurisdictional differences, and very recent observations of portfolio performance characteristics such as delinquencies and insolvencies. The relationships between delinquent loans and further distress such as insolvency, deeper delinquency, and default as well as regional idiosyncrasies regarding losses given default (LGD, also known as loss severity) were monitored closely, and observed relationships between these variables became the bases for the new models. Variables such as current delinquency were used as predictors of further delinquency, "cures" (the debtor resuming payments), and further distress. It was also quickly realized that further prepayments in deals where mortgages were "underwater" (LTVs higher than 100%) would be near zero for some time (Credit Suisse 2008).

2.5 ABX BBB

A four-year CDS that costs 95% (as ABX 06-2 BBB did in 2008) would show a yield of around 10,000-20,000 basis points depending on methodology and precise assumptions. That spread has little relation to the expected return. At such low prices, mezzanine tranches were providing almost no information about the riskiness of the subprime securitizations. For example, JPMorgan (2008) estimated that the BBB and BBB- tranches would barely survive the year before default losses would need to be paid out, and so were trading as "interest only" (IO). A protection seller could receive 100–ABX price today, earn a few quarterly coupons, but be required to pay 100 within one year or two, depending on the exact timing

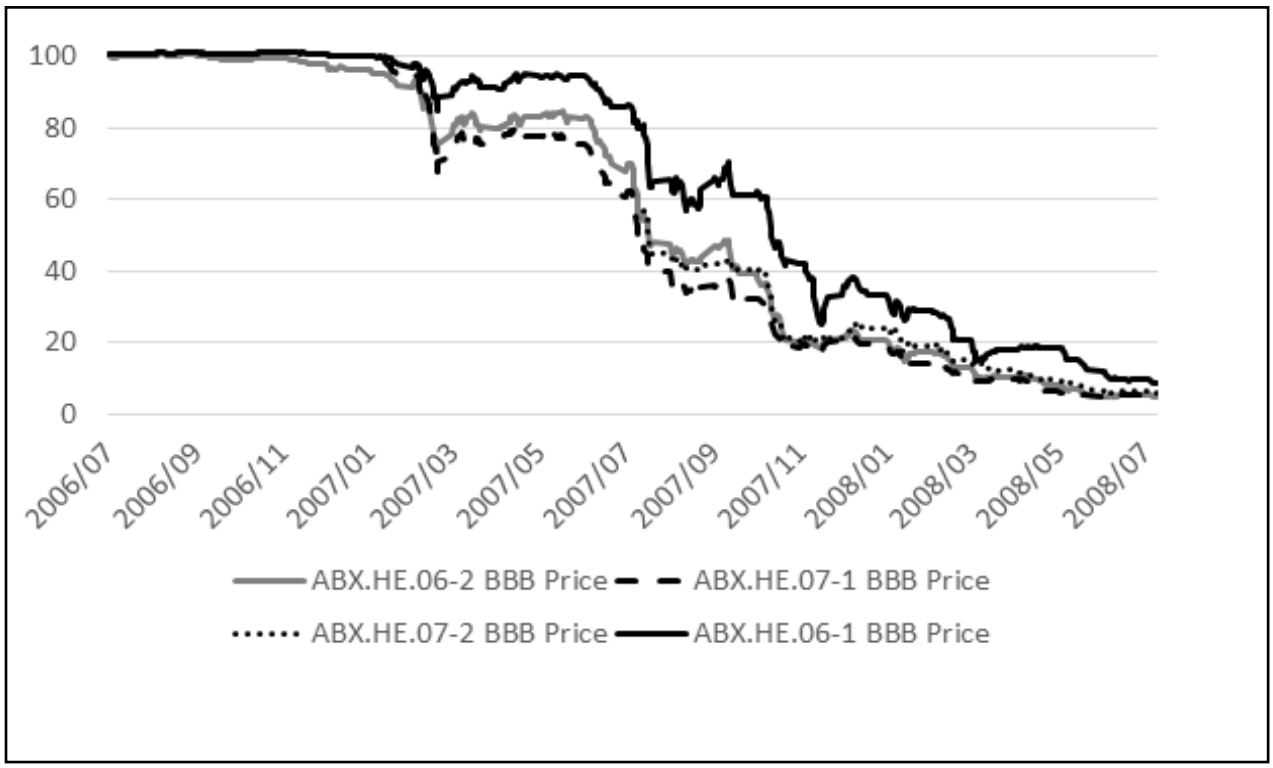
[14] Other parameters often used as risk measures pre-crisis have always been known to be so lagging as to be useless, such as ratings. One year into the crisis, ABX 06-2 AAAs were still rated high investment grade on average (Fender and Scheicher 2009). Currently, the average rating is B- (Moody's 2018).

of the (fully-expected) write-downs. The IRR of such a trade was in the low double digits in percentage terms if expectations were realized, not 10,000s of basis points.

The changes in price of most junior tranches in 2008-09 reflected the possibility of one more or one fewer coupon *rather than any overall changes in riskiness in the underlying subprime assets.* The BBB indices were insensitive to losses in excess of those that would wipe out the tranche. Once losses were expected to eventually wipe out the tranche and result in no principal payment (requiring losses of usually less than 5% of an RMBS), the only cash flows that would be expected to be paid in the future would be interest payments, and even then only until complete write-down. Even large positive revisions to loss expectations to subprime could not have affected tranches about to be completely written down in all scenarios. That is, traders could have vastly altered their assumptions regarding the underlying RMBS markets and, therefore, the senior ABX tranches, without it significantly affecting the BBB market's returns, which were based on almost certain and total write-down.

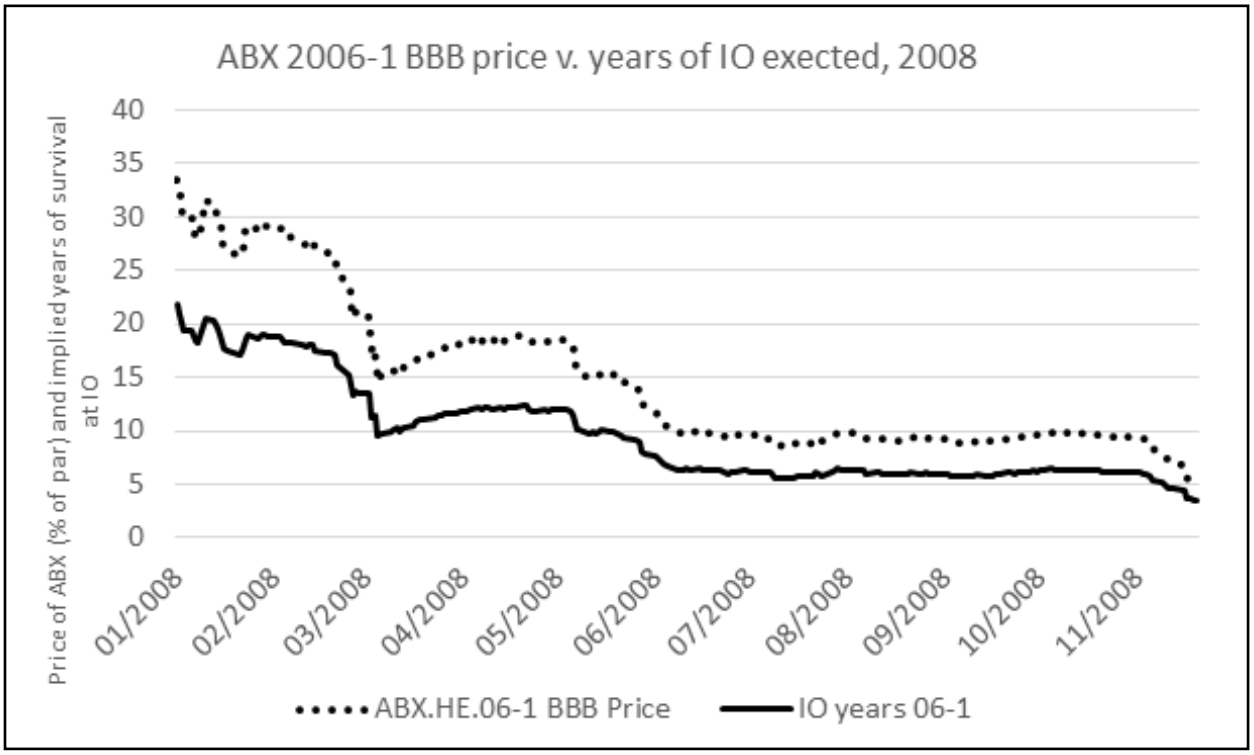
In fact, most of the BBB and BBB- ABX indices never recovered from their quick approach to near-zero prices (Figure 4). Prices remained close to zero even as AAA subprime indices rebounded post-crisis. Only one BBB- and two BBB bonds out of the 80 ABX deals retain any principal, with the rest written down to zero (factors sourced from Bloomberg in October, 2020). By October 2007, the remaining final write-down date was three years hence for ABX 06-1 and 06-2 BBB- and two years hence (June 2009) on average for ABX 07-1 and 07-2 BBB-. Considering the IO component was the only positive cash flow likely to be earned by most index investors (other than small amounts possible in 06-1 and 06-2), it can be said that ABX BBB prices reacted rationally to the subprime crisis in a timely manner. By the middle of 2008, as revisions to the write-down dates occurred, prices changed (Figure 5). That the yields appeared to behave "strangely" is not proof of pricing irrationality. In this paper we focus on the price changes of the most senior tranches, which would better reflect the changes in fundamentals, whether backward or forward looking.

Figure 4: ABX BBB CDS prices, All vintages, July 2006 to July 2008

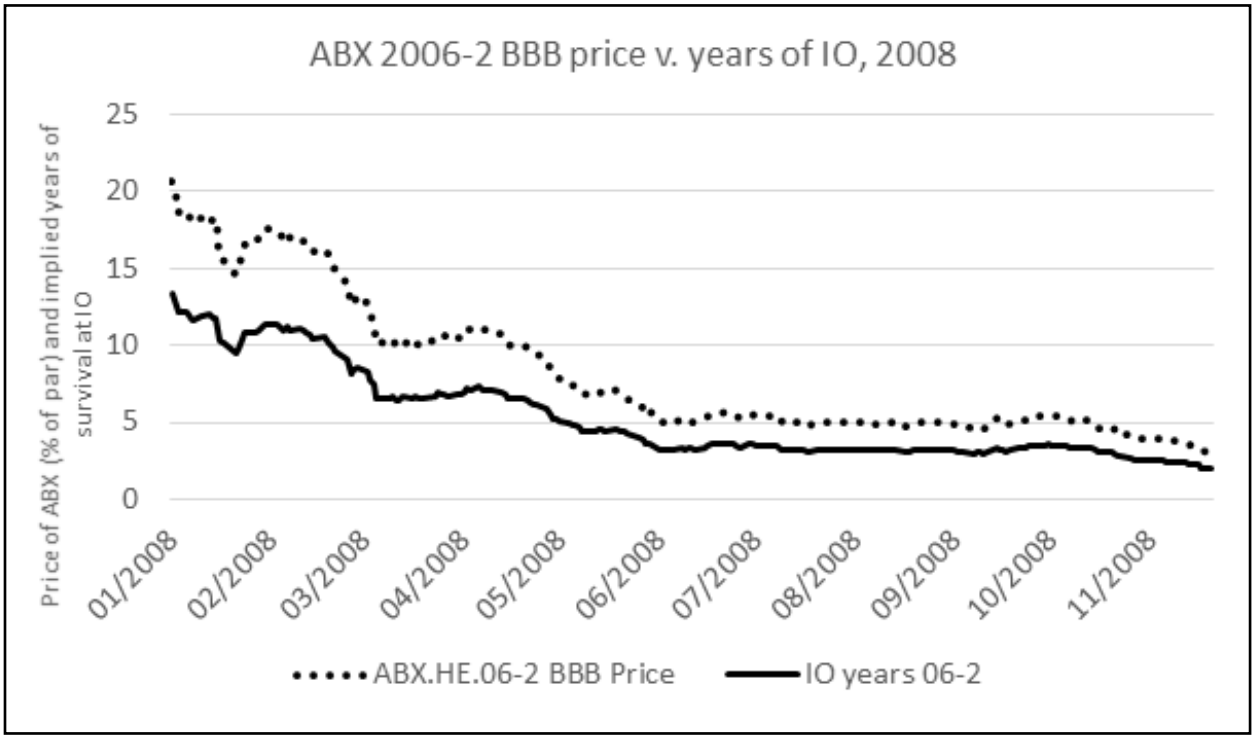


Source: IHS Markit.

Figure 5: ABX 2006-1 and ABX 2006-2 BBB prices v. years of IO expected, 2008



Sources: IHS Markit, authors' calculations.



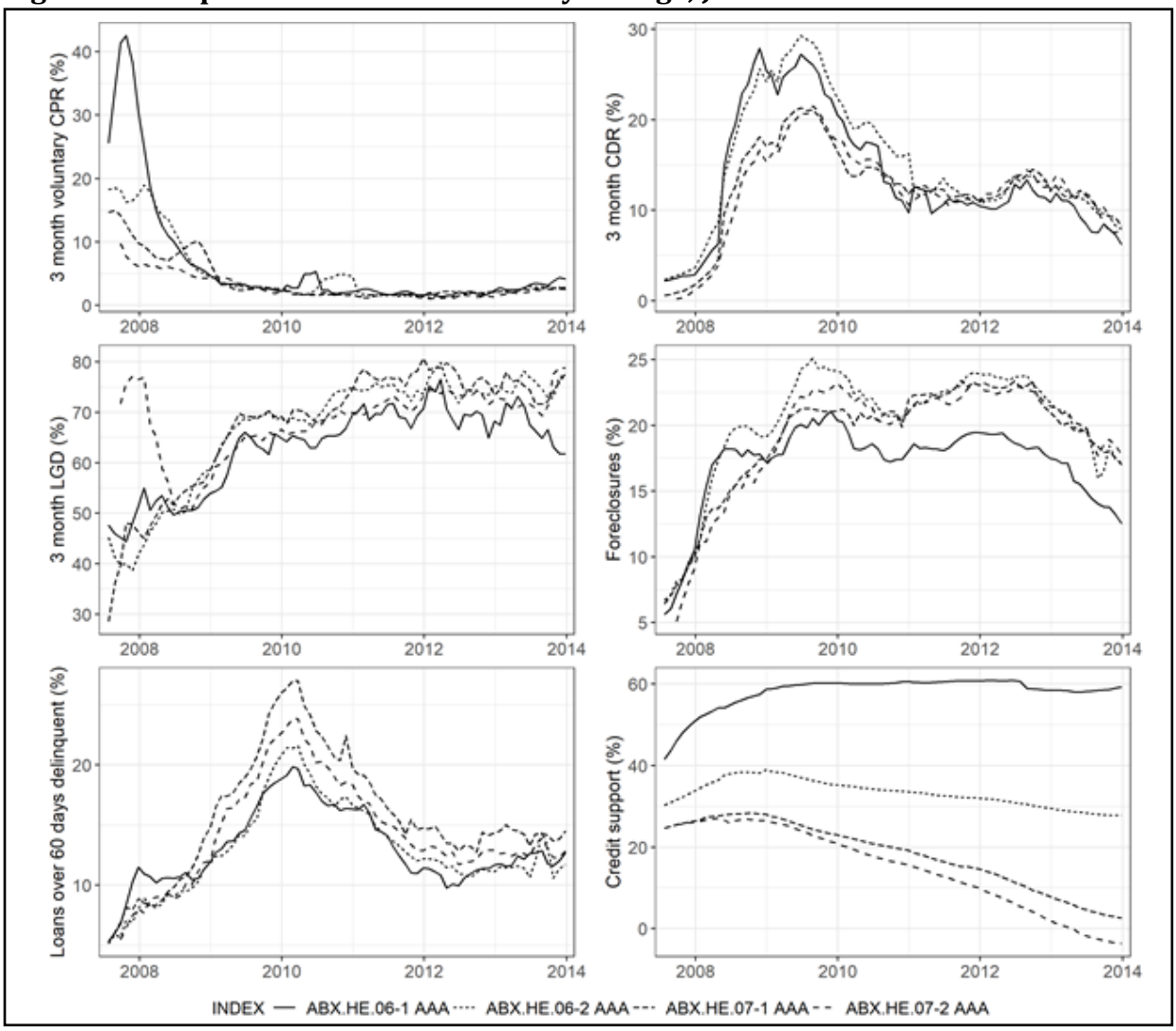
Sources: IHS Markit, authors' calculations.

3. Data

This section describes the data used for our econometric analysis. We obtained prices directly from the official mark-to-market source for ABX, IHS Markit. All the relevant measures of credit quality, loss experience, and deal and tranche characteristics were sourced from Bloomberg. Market and macroeconomic data are from Eikon. The data is at the monthly frequency, which matches the frequency of available RMBS remit data. The sample runs from July 2007 to December 2013. The starting point of the sample is conditioned on the availability of sufficient remit data through Bloomberg for most bonds to construct the necessary proxies for credit quality. The end date is determined by the fact that ABX prices start exhibiting very little variance after this point. According to our data, for example, the 07-2 AAA index had price changes in every month in 2013, but the price was largely static from March 2014 onwards. Prices stabilized as losses became more likely to wipe out some Class A tranches (primarily in later vintages), or more likely to be repaid in full (primarily in the earlier vintages), or some combination.

Unlike equities or corporate debt, structured securities such as RMBS do have some fundamentally important factors that can be used to discern value. Mortgages with LTVs close to and above 100% and higher delinquencies are more likely to cause distress to the securitized portfolios, all else being equal. Each month, a certain percentage of delinquencies migrate from 30 days to 60 days to 90 days to 180 days. Foreclosure often begins after 90 days. If LTVs are low, losses to the pool, even if defaults rise, are unlikely. To model the expected losses and therefore the prices of subprime bonds and CDS, traders and investors generally use a range of variables such as those shown in Figure 6: foreclosures, delinquencies, defaults, and prepayments. More elaborate models project future migration rates on macroeconomic assumptions.

Figure 6: ABX portfolio characteristics by vintage, June 2007-December 2013



Notes: The three-month CDR is annualized.
Source: Bloomberg.

In Figure 6, the voluntary CPR (prepayment rate, annualized) refers to voluntary unscheduled principal payments measured as a share of the pool and very different from involuntary "repayments" that flow through the RMBS structure due to recoveries on defaulted mortgages. CDR refers to the annualized default rate—effectively the share of defaulted mortgages as a percentage of the pool balance. Loss severity is the loss of remaining mortgage principal after a default.

Our aim was to create a highly parsimonious model while still utilizing the primary variables used by practitioners at the time of the GFC. While investors and traders would examine the input variables at the deal/tranche level (or even at the individual mortgage level, we summarize the credit performance of the ABX.HE indices using the measures aggregated over the 20 deals in each index. The first of these is average 60+ day delinquencies, which

includes loans that are delinquent by more than 60 days, including real estate owned, and foreclosures. The second variable is average credit support: the balance of more junior tranches relative to the tranches underlying ABX.HE AAA indices (expressed as a share of total outstanding balance). Table 2 shows summary statistics of these figures, alongside ABX.HE AAA prices, for the sample period used in the regressions: July 2007 to December, 2013.[15] The data is at a monthly frequency, which matches the frequency of RMBS remits.

[15] Before July 2007, Bloomberg does not contain sufficient data for many of the bonds underlying the ABX indices. After December 2013, ABX prices start expressing relatively little variance.

Table 2: Summary of ABX-related variables used in regressions

Index	Period	Variable	mean	median	sd	min	max
ABX.HE.06-1 AAA	2008-2010	Δlog(price) x 100	-0.12	0.30	4.29	-11.48	9.77
	July 2007 - December 2013		0.01	0.12	1.90	-7.52	3.05
ABX.HE.06-2 AAA	2008-2010		-0.70	0.59	5.40	-12.31	10.51
	July 2007 - December 2013		0.03	-0.17	4.21	-12.64	7.87
ABX.HE.07-1 AAA	2008-2010		-0.82	-0.61	5.06	-12.29	9.93
	July 2007 - December 2013		-0.26	0.20	4.14	-17.50	7.02
ABX.HE.07-2 AAA	2008-2010		-0.83	-0.42	4.92	-11.91	9.84
	July 2007 - December 2013		-0.10	0.29	4.54	-22.47	7.85
ABX.HE.06-1 AAA	2008-2010	Δ60+ Delinquencies	0.33	0.32	1.16	-3.24	3.80
	July 2007 - December 2013		0.15	-0.22	1.19	-1.39	4.11
ABX.HE.06-2 AAA	2008-2010		0.56	0.61	1.26	-1.74	4.00
	July 2007 - December 2013		0.02	-0.16	0.84	-0.84	2.52
ABX.HE.07-1 AAA	2008-2010		0.71	0.63	1.09	-1.11	3.25
	July 2007 - December 2013		0.00	-0.29	0.91	-1.13	2.44
ABX.HE.07-2 AAA	2008-2010		0.77	0.86	1.12	-1.26	2.76
	July 2007 - December 2013		0.06	-0.26	1.10	-1.04	3.90
ABX.HE.06-1 AAA	2008-2010	(100-Credit support)	41.38	40.00	2.43	39.35	48.05
	July 2007 - December 2013		42.29	41.03	5.05	39.13	58.99
ABX.HE.06-2 AAA	2008-2010		63.64	63.71	1.93	60.95	66.63
	July 2007 - December 2013		69.10	68.63	2.00	64.92	72.25
ABX.HE.07-1 AAA	2008-2010		75.58	75.18	3.19	71.87	81.39
	July 2007 - December 2013		87.27	87.37	7.20	73.33	97.41
ABX.HE.07-2 AAA	2008-2010		77.56	76.46	4.03	73.08	84.85
	July 2007 - December 2013		92.09	93.15	7.76	74.36	100.00

Notes: Credit support has been set to min (Credit support, 0) for the purposes of the regressions and the valuation model—i.e. we set credit support to zero once the tranche starts taking losses. This assumption only affects the end of the sample for the 07-2 vintage and does not affect our results.
Source: Bloomberg.

$\Delta Delinq60plus_{t,i}$ is the change in loans that are delinquent (not having made required repayments) for 60+ days, including foreclosures, and real estate owned.

This is interacted with $\left(100 - Credit\ support_{i,t}\right)$, where credit support represents the amount left in securities representing lower tranches of the RMBS pool which act as a buffer for losses. We use 100-Credit support to make the interaction term easier to interpret: according to intuition, higher delinquencies should have a negative impact on ABX prices, as should *lower* credit support. We largely follow Stanton and Wallace (2011) in our choice of

controls for macroeconomic and financial market drivers of ABX.HE prices.[16] These are: the log difference in U.S. non-farm payrolls ("employment"); the change in the LIBOR-OIS spread; the monthly return of the S&P financials index; the log change in the U.S. house price index; the change in the VIX index; and the change in the difference between 10-year U.S. government bonds and three-month U.S. treasury bills ("term premia"). Table 3 shows summary statistics of these variables.

Table 3: Summary statistics of control variables

Period	Variable	mean	median	sd	min	max
2008 - 2010	Δlog(Employment) x 100	-0.15	-0.13	0.24	-0.60	0.41
July 2007 - December 2013		0.13	0.13	0.06	-0.02	0.27
2008 - 2010	ΔLIBOR-OIS	-1.62	-0.61	31.28	-91.18	118.99
July 2007 - December 2013		1.35	-0.08	7.92	-8.55	48.10
2008 - 2010	Δlog(S&P financials) x 100	-1.61	0.25	11.26	-43.40	16.49
July 2007 - December 2013		0.26	1.46	6.10	-18.52	10.90
2008 - 2010	Δlog(HPI) x 100	-0.47	-0.55	0.55	-1.78	0.87
July 2007 - December 2013		0.19	0.38	0.53	-1.01	0.99
2008 - 2010	ΔVIX	-0.03	-1.30	10.26	-19.16	47.24
July 2007 - December 2013		-0.12	-0.46	5.27	-12.56	20.41
2008 - 2010	Δterm premia	0.06	0.01	0.37	-0.88	0.97
July 2007 - December 2013		0.01	0.01	0.26	-0.73	0.58

Notes: The log differenced variables have been scaled to make it easier to read the regression tables.
Source: Eikon by Refinitiv.

4. A Simple Pricing Model

Before presenting our regression results, in this section we extend Stanton and Wallace's (2011) one-period simple model to five annual periods (t = 5) to reveal that 2008-09 pricing cannot be immediately dismissed as irrational. This extension of their model is required as the original model assumed 100% prepayment at the end of year one on all non-defaulted assets, as well as a (large) prepayment at the beginning of the year, reducing the effective default rate. Such optimistic assumptions are likely to inflate the model-implied ABX prices.

[16] The main difference, due to data availability over our longer sample horizon, is that we use the change in S&P financials sub-index instead of the short interest in U.S. banks.

The five-year model for loss to the tranche (assuming 100% repayment after five years) is:

$$Loss = \min\left\{\frac{(\sum_t D(1-R)(1-Y)^t)-S}{1-H-S}, 0\right\}.$$

Y is equivalent to a constant annual prepayment rate (CPR). This must be the voluntary repayment rate, as the involuntary payments (from loan liquidations) are covered in R as per below. D is the constant annual default rate (CDR or CADR), annualized.[17] R is the recovery rate on defaulted mortgages, with 1 – R, called the loss given default (LGD) equal to the loss to the mortgage pool given a loan defaults. S is the attachment point of the tranche, after which point, portfolio losses begin to affect the tranche. H is the percentage amount of tranches senior to the tranche in question. The distance between the attachment point of S and 1-H-S is called the tranche thickness.

Losses start to affect the RMBS tranche after the first percent of losses until the tranche has experienced a total loss, which is when 1-H-S losses have hit the mortgage bond. Note this model remains conservative, as it assumes 100% CPR at the end of year five. Due to the complexities of paydown and loss absorption rules for each of the 80 subprime securitizations, it is extremely difficult to identify a "typical" tranche thickness (1-H-S). We use Stanton and Wallace's (2011) assumption for thickness: 1-H-S = 0.17.

When choosing appropriate inputs for the simple model, it is important to remember that most measures of prepayment, or CPR, include involuntary repayments that stem from recoveries on defaulted mortgages. In this point-estimate example, we use a 10% CPR, which is towards the upper end of a survey of analyst reports from major investment dealers at the time.[18] This assumption is thus conservative and above observed CPRs from 2009-10. (See Figure 6.) Assuming a lower CPR would imply an even lower fundamental ABX price.

In this paragraph we recalculate the point fundamental value estimate shown in Stanton and Wallace (2011). Apart from the 10% CPR assumption and the extension of model to 5 periods, the model inputs are as in Stanton and Wallace (2011), including the closing price of ABX.HE 2006-2 on June 30, 2009, 33.17%. At a 18% default rate and 50% recovery rate, the model suggests that the AAA index would be wiped out. How realistic were these inputs? As shown in Figure 6, 2006-2 CDR was running at 18% by mid-2008. Recovery rates (1-LGD) were around 50% for the 06-2 index in mid-2008 and declined further thereafter. It could

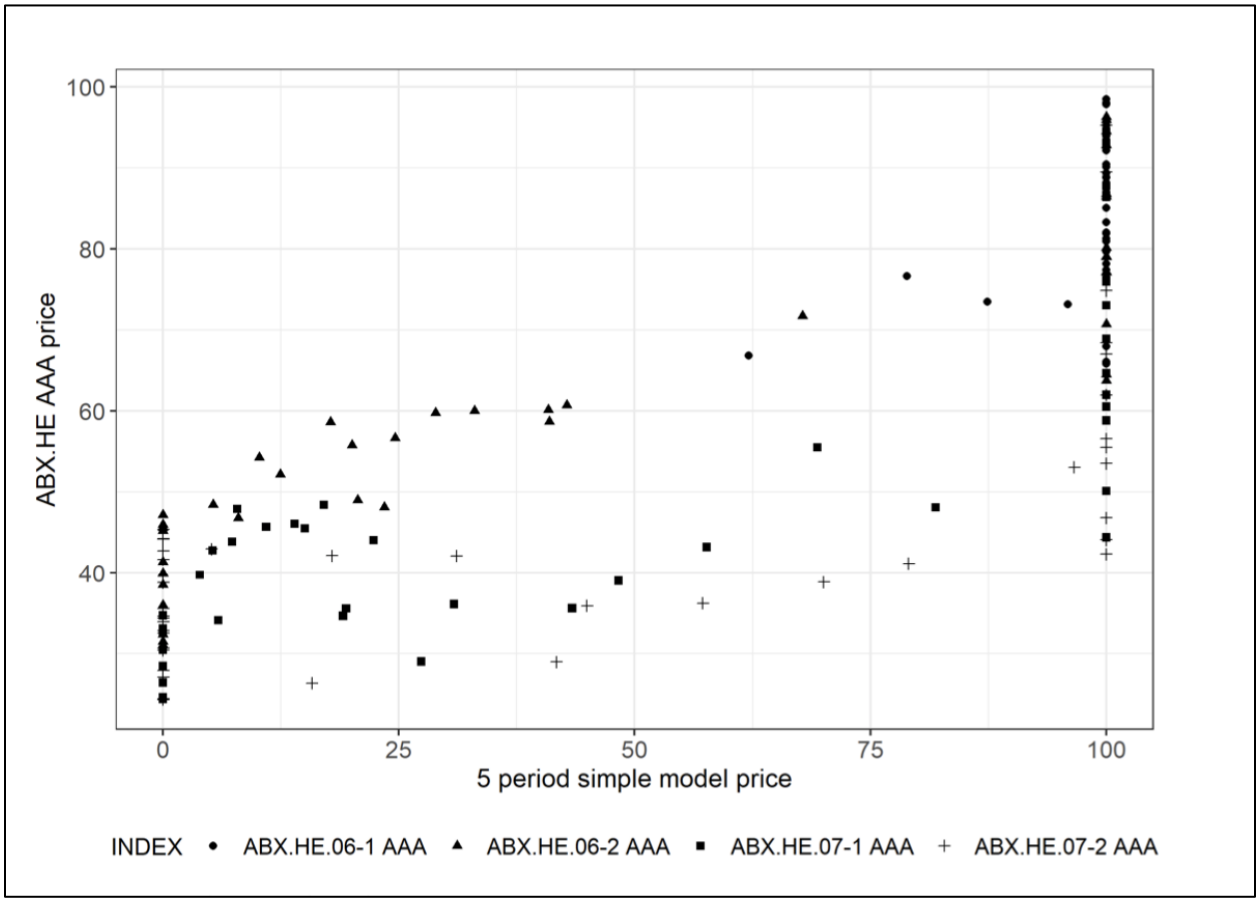
[17] Even though neither the pool default rate or the prepayment rate is "constant," CDR is accepted as industry standard for the annualized observed default rate, and CPR is accepted as the annualized observed (voluntary) prepayment rate.

[18] By April 2008, Credit Suisse, for example, was using 5% and 10% CPR (calling the 10% input the "higher" CPR, with 5% as the base case) as alternative futures for analysing the ABX index and its components (Credit Suisse 2008) when voluntary CPRs were running between 14.1% (ABX 2006-2) and 7.0% (ABX 2007-1). Indeed, as per ABX Remit reports, CPR was running at a one-year moving average of 4.1% as at June 1, 2009. However, it had declined from a high of 8.3% a year earlier to 2.4% for the month ended May 31, 2009.

be argued that a five-period distress model is too aggressive, yet a three-period model does not significantly alter the results. Three stressful years would result in a loss of more than 50% in the ABX 2006-2 index. Comparing 0% and 48% model values to the market price on Jun 30, 2008, of 33.17% reveals that market prices could, to some extent, be approximated by a very simple pricing model. Simple models are unlikely to be able to show that the market was completely detached from reality even at the depths of the GFC.

Figure 7 below reinforces the preliminary finding that ABX prices could be explained by fundamentals. Here, we compare the ABX price on the simple five-period model-implied price. We use S, R and CDRs contained in the ABX remit data releases for January 2008 to October 2010. Note that fundamental data lagged somewhat due to the time taken between actions within the mortgage pools and the reporting in the remit data that is sourced from deal trustee reports. Simple eyeballing of the data suggests that the prices bore a relationship to this very crude proxy of fundamentals. The right-hand-side data shows, however, that model price can be par even when market price is low. Three influences account for this, Firstly, when the market price is high and fundamental impairments are not expected, the prices should vary according to liquidity and risk preferences. The second issue is that the simple model's specification results in a highly volatile price. If the CDR for the month is temporarily lower than recent periods, the price will be abnormally high. Thirdly, once losses hit the pools, CDRs will be less responsible for price decreases. This indeed occurred in the ABX markets. CDRs fell as losses rose after October 2010. Losses are shown still accruing to the bonds even though CDRs have fallen from their 2009-11 highs. Most often, however, when market prices were well below par, significant losses were expected in this simple model. In fact, the regression relationship is positive and significant at the 99.9% level, with an R^2 of 68%.

Figure 7: Actual versus five-period model predicted ABX prices, January 2008 – October 2010



Sources: IHS Markit, Bloomberg.

Figure 7 indicates that even a very simple model properly applied and populated with realistic data can identify potential rationality in ABX pricing. In fact, given the price volatility observed in 2008-10, the simple model is reasonably accurate. This conclusion is reinforced by the fact that the model does not incorporate forward-looking estimates, such as expectations of house-price appreciation, or even data on 30-90-day delinquencies (some of which would be assumed to transition into default). It should be obvious, however, that other evolving characteristics of the mortgage pools besides observed realized default, loss, and repayment rates could have an impact on the pricing of the ABX bonds.

5. Regressions and Results

In section four we showed that contemporary point observations of slightly lagged mortgage data can explain some pricing of ABX during the crisis, even though the fit of this model is far from perfect. In this section we refine our analysis and show that the credit performance of

assets underlying the indices were significant drivers of ABX prices, while not dismissing the role played by broader macroeconomic factors.

In previous literature that econometrically examines the drivers of ABX prices, regressions typically assume a linear relationship between fundamentals and senior index tranches (e.g. Stanton and Wallace, 2011). This approach has shortcomings, as senior tranches only start absorbing losses significantly after losses (driven by delinquencies) have started to accumulate to junior and mezzanine tranches. Losses affecting junior tranches reduce the credit support (which can be thought of as "loss-absorbing buffers") of senior tranches, which should be reflected in their pricing. But it is only after credit support is expected to be eroded that the mapping of losses to ABX prices should be expected to be strong. By accounting for this feature by using a simple interaction term in a standard pooled panel regression specification, we show below that fundamentals did play a role in the pricing of ABX indices. This contrasts with findings by Fender and Scheicher (2009) as well as those by Stanton and Wallace (2011), who argue that subprime AAA RMBS CDS indexes reacted primarily to systemic risk and developments in broader financial markets, while underlying fundamentals had a small role to play.

To incorporate nonlinearities discussed above, we interact the level of credit support for each vintage with the change in delinquencies. This parsimoniously captures a key feature of CDS pricing: the prices should become more sensitive to credit deterioration as the loss-absorbing buffer (credit support) deteriorates. Our baseline regression specification is as follows:

$$\Delta ABX_{t,i} = \alpha + \beta_1 \Delta ABX_{t-1,i} + \beta_2 \Delta Delinq60plus_{t,i} * \left(100 - Credit\ support_{t,i}\right) + \boldsymbol{\gamma_1'} \boldsymbol{X_t^{controls}} + \epsilon_{t,i}$$

The variables here are as discussed in section 3. Recall that in this specification, $\Delta ABX_{t,i}$ is the log change in price of the AAA ABX.HE index *i* in month *t*, where *i* represents the vintage (06-1, 06-2, etc.). $\boldsymbol{X_t^{controls}}$ includes market and macroeconomic controls, as specified above in section 3.

Table 4 shows our main results. In all specifications, we find that credit performance of the ABX.HE indices is associated with price changes. Both the change in delinquencies and the interaction between credit support and delinquencies are highly significant. The fact that the credit performance used in this specification employs no forward-looking information whatsoever reinforces our argument that ABX prices were not detached from fundamentals. We show in the supplementary materials that the results in Table 4 hold when we restrict the period studied to July 2007 through December 2010.

Table 4: Regression results

	(1)	(2)	(3)	(4)	(5)	(6)
ΔABX_t-1	-0.224***	-0.191**	-0.189**	-0.196**	-0.188**	-0.193**
	(0.073)	(0.095)	(0.096)	(0.094)	(0.094)	(0.096)
(100-Credit support_t) x Δdelinq_60+_t	-0.033***	-0.019***		-0.050**		
	(0.005)	(0.006)		(0.021)		
Δdelinq_60day+_t			-1.115***	2.125		
			(0.401)	(1.341)		
(100-Credit support_t) x Δdelinq_90+_t					-0.025***	
					(0.006)	
(100-Credit support_t) x ΔCDR_t						-0.012*
						(0.007)
ΔHPI_t		1.271*	1.348**	1.331*	1.076	1.527**
		(0.708)	(0.713)	(0.715)	(0.720)	(0.690)
Δemployment_t		1.914	2.121	1.879	1.582	2.771
		(3.709)	(3.731)	(3.698)	(3.597)	(3.598)
ΔVIX_t		0.019	0.02	0.024	0.015	0.052
		(0.130)	(0.131)	(0.130)	(0.130)	(0.128)
Δterm_premia_t		2.239	2.145	2.049	2.744*	0.877
		(1.604)	(1.642)	(1.627)	(1.627)	(1.565)
ΔLIBOR-OIS_t		0.021	0.021	0.021	0.022	0.019
		(0.040)	(0.041)	(0.039)	(0.040)	(0.040)
ΔS&Pfinancials_t		0.378***	0.384***	0.380***	0.370***	0.414***
		(0.111)	(0.111)	(0.112)	(0.110)	(0.109)
Constant	0.112	0.199	0.194	0.151	0.278	-0.009
	(0.416)	(0.434)	(0.431)	(0.433)	(0.425)	(0.425)
R^2	0.106	0.287	0.283	0.29	0.296	0.28
Observations	310	310	310	310	310	310

*Notes: Block bootstrap standard errors in parentheses, with a block window of three months. Results are highly similar with Newey-West standard errors. ***, ** and * denote p- values below 0.01, 0.05 and 0.1, respectively. Sources: Bloomberg, IHS Markit, Eikon.*

Column 2 in Table 4 shows our key results: delinquencies, interacted with the remaining credit support, were strongly associated with ABX prices. However, over the sample period, even the change in 60+ day delinquencies alone is a significant factor in explaining the ABX prices, thus reinforcing our case that fundamentals mattered. Finally, columns 5 and 6 show that significantly more lagging variables of credit quality—over 90-day delinquencies and the constant default rate—were also significant factors in explaining ABX pricing. Because we use simple and backward-looking indicators of credit quality, our results are likely to understate the role of fundamentals.

We cannot, however, dismiss the role of macrofinancial drivers of ABX prices. In particular, the S&P financials index returns, along with national house-price changes, were significantly associated with ABX price changes. Indeed, analyst reports that we discuss below often cite house-price changes, or incorporate these into ABX loss projections. We would also expect

there to be a strong link between the S&P financials index and ABX.HE indices, given the importance of RMBS in driving financial sector losses.

We know from the theory that pricing is based on expectations, and not simply on observations of historical data. Table 5 reveals that the simple pricing model outlined in section 4 helps predict ABX prices. Here, we compare the ABX price with the simple five-period model component depicting the implied reduction in ABX principal: $((\sum_t D(1-R)(1-Y)^t) - S)/(1-H-S)$.[19] We are intentionally conservative in our assumptions here, because there is a plethora of potential models or forward-looking variables that, ex post, could be used to justify asset prices. Our model only uses backward-looking data to estimate future defaults. Faster moving indicators of upcoming defaults, such as macroeconomic variables, enter the regressions separately, and even 60+ day delinquencies, which contain more forward-looking information than other pricing model inputs, only enter the regression in column 3.

Table 5: Regression results with simple model

	(1)	(2)	(3)
ΔABX_t-1	-0.180***	-0.189**	-0.191**
	(0.074)	(0.095)	(0.094)
Δmodelled_loss_t	-10.481***	-4.917*	-4.855*
	(2.539)	(2.799)	(2.790)
(100-Credit support_t) x Δdelinq_60+_t			-0.019***
			(0.006)
ΔHPI_t		1.726**	1.018
		(0.687)	(0.713)
Δemployment_t		2.274	1.049
		(3.491)	(3.535)
ΔVIX_t		0.059	0.03
		(0.127)	(0.128)
Δterm_premia_t		0.889	2.164
		(1.564)	(1.571)
ΔLIBOR-OIS_t		0.017	0.02
		(0.040)	(0.041)
ΔS&Pfinancials_t		0.425***	0.379***
		(0.108)	(0.107)
Constant	-0.300		0.261
	(0.418)		(0.417)
R^2	0.067	0.277	0.294
Observations	310	310	310

*Notes: The valuation denotes the model-implied loss, on which we do not bound between 0 and 1. Block bootstrap standard errors in parentheses, with a block window of three months. Results are highly similar with Newey-West standard errors. ***, ** and * denote p-values below 0.01, 0.05 and 0.1, respectively.*
Sources: Bloomberg, IHS Markit, Eikon.

[19] This model-implied reduction in principal might be greater than 1, which can be interpreted analogously to shadow prices, as the likelihood and severity of actual losses: the greater the implied loss in principal, the more severe actual write-downs are expected to be.

To examine nonlinearities in ABX pricing through a different lens, we estimate quantile regressions to study how our explanatory variables relate to pricing at different quantiles of ABX.HE index returns. Our results, shown in Table 6, provide further support of our key arguments above. In months with the largest ABX price declines (10th and 20th percentiles), prices were associated with the deterioration in credit quality. This is supported by the significant interaction term with delinquencies and credit support. This result remains the same if we only include delinquencies. Additionally, price changes were significantly larger after credit support had eroded. This is evidenced by the declining coefficient for credit support as we move to lower quantiles of ABX price changes, which is in line with intuition about the importance of "loss-absorbing buffers" in non-agency RMBS pricing.

Of course, quantile regression results based on a modest sample size should be interpreted with caution. It is worth noting, however, that including the intercept term in the regressions absorbs a significant portion of the variance in ABX prices in this sample, thus possibly biasing the results against the hypothesis that fundamentals mattered for ABX pricing. If we remove the intercept, the coefficients for delinquencies become more significant.

Table 6: Quantile regression results with ABX index price changes as the dependent variable

	Quantile								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ΔABX_t-1	-0.183	-0.186**	-0.201	-0.13	-0.143	-0.220**	-0.239***	-0.291***	-0.242**
	(0.082)	(0.093)	(0.152)	(0.170)	(0.121)	(0.081)	(0.062)	(0.063)	(0.095)
(100-Credit support_t) x Δdelinq_60+_t	-0.033**	-0.026***	-0.014	-0.005	-0.011	-0.009**	-0.003	-0.008*	-0.014*
	(0.015)	(0.013)	(0.012)	(0.010)	(0.007)	(0.006)	(0.005)	(0.006)	(0.008)
(100-Credit support_t)	-0.095***	-0.060***	-0.040*	-0.004	0.004	0.021	0.034**	0.041**	0.045
	(0.025)	(0.025)	(0.025)	(0.020)	(0.016)	(0.016)	(0.017)	(0.021)	(0.036)
ΔHPI_t	1.455	1.64	1.051	1.135	0.649	0.834	0.983	0.824	0.697
	(0.933)	(1.064)	(1.146)	(1.086)	(0.900)	(0.765)	(0.723)	(0.882)	(1.145)
Δemployment_t	11.786***	9.767*	10.554**	4.419	-4.336	-8.139*	-10.355***	-10.647**	-17.919***
	(4.958)	(4.727)	(5.777)	(6.621)	(5.728)	(4.391)	(3.482)	(3.785)	(4.986)
ΔVIX_t	-0.131	-0.114	0.012	-0.134	-0.045	0.082	0.217**	0.332***	0.433**
	(0.161)	(0.141)	(0.163)	(0.200)	(0.195)	(0.154)	(0.128)	(0.115)	(0.161)
Δterm_premia_t	3.207**	0.756	1.476	-0.818	0.087	1.779*	-0.075	1.183	1.074
	(2.318)	(2.054)	(2.271)	(2.193)	(1.881)	(1.610)	(1.439)	(1.624)	(1.781)
ΔLIBOR-OIS_t	0.016	0.0002	0.003	0.036	0.011	-0.027	-0.014	-0.023	-0.024
	(0.085)	(0.092)	(0.094)	(0.082)	(0.058)	(0.043)	(0.033)	(0.031)	(0.035)
ΔS&Pfinancials_t	0.268	0.321***	0.313***	0.346**	0.366**	0.463***	0.551***	0.564***	0.806***
	(0.107)	(0.112)	(0.139)	(0.195)	(0.203)	(0.156)	(0.115)	(0.115)	(0.163)
Constant	-1.492	-1.78	-1.051	-0.788	0.619	0.68	0.98	2.061	4.809**
	(1.768)	(1.570)	(1.485)	(1.266)	(1.044)	(1.082)	(1.235)	(1.551)	(2.729)

*Notes: The lowest quantile (0.1) denotes the lowest (most negative) decile of returns of the ABX index, whereas the highest quantile (0.9) denotes the highest return decile. Block bootstrap standard errors in parentheses, with a block window of three months. Results are highly similar with Newey-West standard errors. ***, ** and * denote p-values below 0.01, 0.05 and 0.1, respectively.*
Sources: Bloomberg, IHS Markit, Eikon.

6. Market Predictions

Recall that our econometric models use only contemporary, yet backward-looking, portfolio performance characteristics to measure the role of fundamentals in ABX pricing. In reality, market participants also relied on forward-looking models.[20] We have evidence that dealers often thought the fundamentals would get much worse than they actually did in 2010 through to the present. Generally, in finance scholarship, expectations are difficult if not impossible to measure, but in this case we have evidence from analyst publications that show that realistic parameters could be identified that would indicate that pricing for indices was reasonably efficient during the GFC. Rational (at the time) but defensive forward-looking CPRs, CDRs, and RRs can easily be identified in most ABX pricing during the crisis.[21] Some analysts were clearly closer to the mark than others. In March 2008, JPMorgan (2008) thought that a market-implied 31.3% collateral loss for late 2006 origination was likely too conservative. Deutsche Bank (2008a) was more on the mark with an estimate of 38%, almost spot on the final loss expected by Moody's in 2018. Voluntary CPRs were expected to be around 10% for the foreseeable future, while loss severity was expected to maintain lofty heights 60-80% for the same late-2006 originations. Though the firm thought market prices were too low, JPMorgan's models showed AAA ABX prices significantly below par for 07-2 (69.95% of par), 07-1 (71.62% of par) and 06-2 (90.41% of par), 17 to 20 points higher than the market. As 2008 went on, however, JP Morgan dropped their theoretical values in their bearish scenario by approximately 10 points for all AAAs other than 06-1, and by 15-20 points in early 2009. In early 2010, Barclays Capital thought that market prices of 88 (06-1), 57 (06-2), 46 (07-1), and 44 (07-2) would yield 5% to 8% IRRs using their baseline portfolio performance assumptions. Using migration models, Barclays Capital (2009) in early 2009 expected 85% of 2007 originations to default, as approximately 4.5 percentage points of always current borrowers rolled to delinquent every month during 2008. Barclays Capital (2010) saw potential returns to 2007 vintage subprime bonds in early 2010 to be between 0% and 1% on a yield-to-maturity basis in their stressed scenario. With current LTVs significantly above 100% in subprime mortgage pools, defaults would continue high and prepayments would fall.

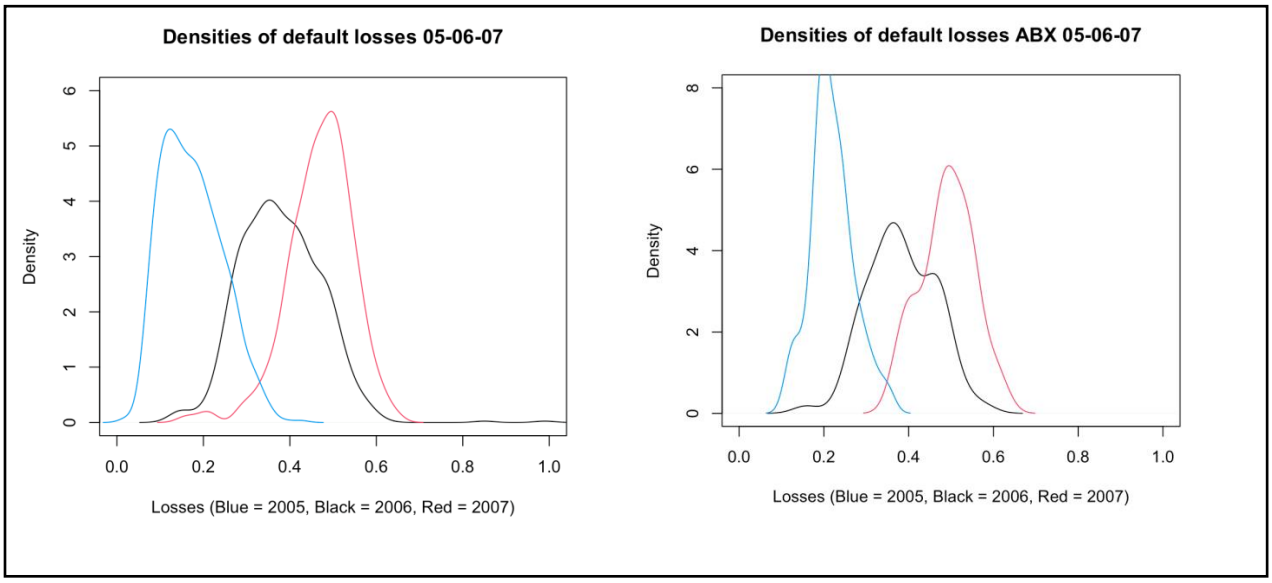
Scholars have argued that ABX price declines revealed that there were risks in the subprime market, but not where those risks lay (Gorton 2009). Indiscriminate selling should put equal pressure on outwardly similar assets. However, the ABX AAA tranches behaved differently depending on their fundamentals. It is also evident from the market prices that there was

[20] For example, already in August 2007, Credit Suisse (2007a) presented loss projections on ABX indices based on roll rate models and econometric models, both of which used unemployment and house-price projections as additional inputs.

[21] Barclays Capital (2010) annual outlook projected overall subprime lifetime loss expectation as a % of *original* balance to be 53% (based on 10% drop in Case-Shiller national HPA).

differentiation between the different ratings categories within and between the vintages. BBB tranche indices indicated a complete and almost immediate write-down of all bonds for securitizations originated in late 2006 and early 2007, but prices were somewhat higher for BBBs for the earlier vintages, where subordination was much higher due to earlier prepayments. That ABX 2006-1 AAA had almost fully recovered in price by 2011 predicted that most of the Class A bonds in this index would repay full notional, which in fact is what has occurred (Table 7). On the other hand, the lower pricing of 2007-1 and 2007-2 predicted serious impairment of the AAA tranches in those deals. This also has come to pass, though losses are not likely to be as high as those predicted during the crisis. Price discrimination between vintages therefore reveals that market participants understood that higher LTVs, lower subordination, and lower creditworthiness would cause declining performance between the four semi-annual origination periods (Figure 8 and Table 8).

Figure 8: Pool loss densities, 2005-07 vintage effects, Moody's universe (97% of market) and ABX 80



Sources: Moody's, Bloomberg.

Table 7: Current impairments of the 80 ABX AAA tranches

Unallocated loss to ABX AAA tranches by vintage					
	ABX 2007-2	ABX 2007-1	ABX 2006-2	ABX 2006-1	Totals
Tranches with loss	14	16	4	1	35
Total tranches	20	20	20	20	80
Percent with loss	70.0%	80.0%	20.0%	5.0%	43.8%

Notes: As of October 2020. Unallocated loss implies eventual default. 19 of the 20 ABX 2006-1 bonds have repaid full principal. None of the 2007-2 bonds have repaid in full.
Source: Bloomberg.

As of March 2018, ABX AAA prices were mostly still predicting losses. While 06-1 has experienced many repayments, it was still trading with almost no distress at around 97% of par. ABX 07-2 on the other hand, with no full repayments and average remaining balance of 91% of original issuance, was trading at the highly distressed level of 61.9%. The investors and traders involved in the ABX market during the crisis appear quite rational without the benefit of hindsight.

ABX might be a poor benchmark if the indices were not representative of the universe of bonds being marked against it (Fender and Scheicher 2009). Here, though, that was not the case. During the crisis, subprime CDOs were being marked against the ABX (UBS 2008), but this was actually overly-conservative, as the CDOs failed faster and more frequently than the subprime AAAs in ABX. Mezzanine ABS CDOs held junior subprime tranches that quickly declined to near zero value, wiping out all including the senior tranches.

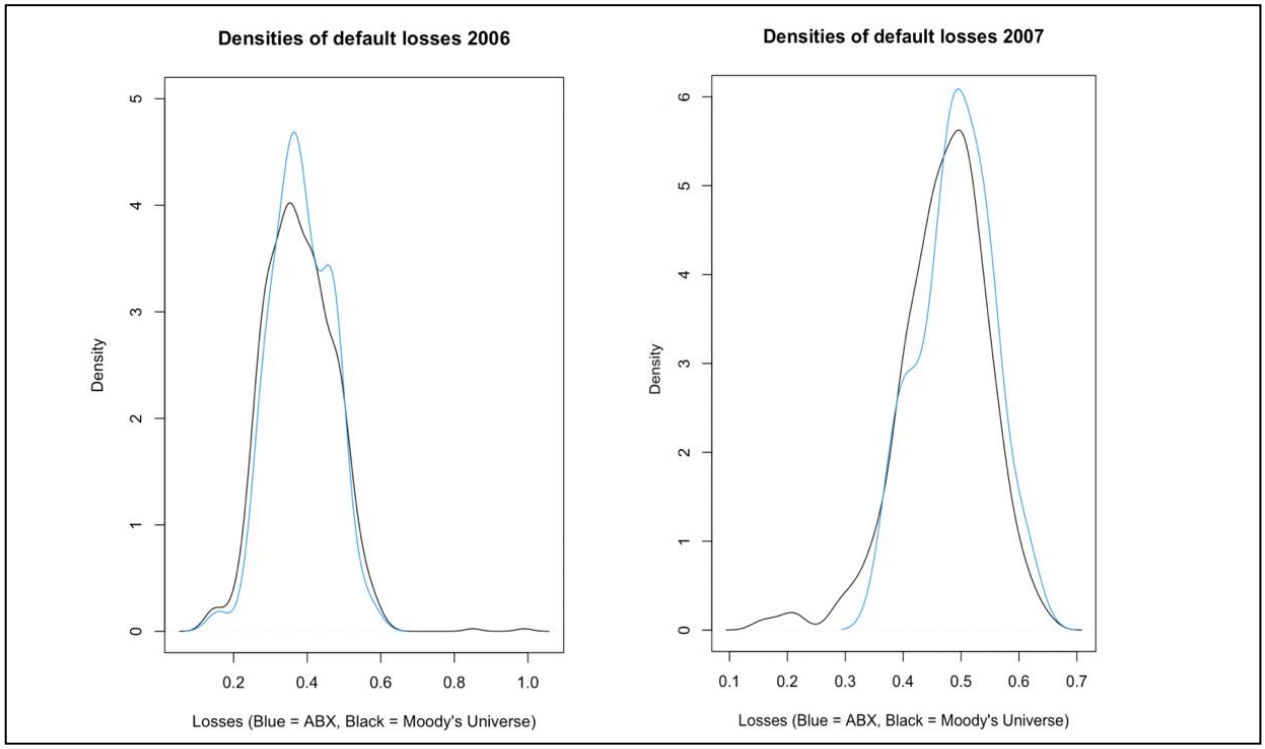
More importantly, losses to the ABX index portfolios and the universe have been rather highly correlated. Saleuddin (2021) examines Moody's (2018) estimates for lifetime pool losses for approximately 97% of all subprime issuance and finds that they are significantly similar to the 80 ABX pools with small standard deviations. (See Figure 9 for the distribution comparison, and Table 8.) ABX indices cannot be said to be unrepresentative of the wider market.

Table 8: Tests for adverse selection

	Obs	Mean Loss	Std dev	MAD/std dev	t-test p-value	Kolmogorov-Smirnov Test
ABX 2007-2	41	49.09%	6.26%	0.79	0.054	D = 0.16284
Moody's Universe 2007	371	47.02%	7.64%	0.76		p-value = 0.2815
ABX 2006-2 and 2007-1	73	38.30%	7.88%	0.81	0.682	D = 0.0913
Moody's Universe 2006	752	37.90%	9.36%	0.80		p-value = 0.6358
Between universe vintages					0.000	D = 0.4565
						p-value = .0000

Notes: The t-test and K-S test p-value indicate that the Moody's estimated loss percentage for ABX pools and Moody's universe cannot be said to be of different mean and of different distribution for each of the 2007 and 2006 originations. Therefore, it does appear that the ABX 391 current losses per bond are unlikely to be unrepresentative of the universe. The t-test and the K-S test do also suggest that there is a vintage effect between 2006 and 2007.
Sources: Moody's (2008), Bloomberg, Saleuddin (2021).

Figure 9: Moody's universe vs ABX lifetime expected portfolio losses



Source: Moody's (2008),

7. Conclusions

Deterioration in subprime fundamentals initiated the GFC. The "run on repo" and other leveraged vehicles then forced the sale of these and other financial assets to repay collateralized short-term lenders and their investors, such as money market funds. During the depths of the crisis it appeared, at least in hindsight, that liquidity concerns overwhelmed fundamental values, perhaps due to the limits of arbitrage. Many scholars and practitioners conclude that the "fire sale" pricing of the ABX indices, in particular, was irrational. Such "irrational" pricing forced holders of RMBS to mark down their investments, causing artificially low equity levels for banks and severe under-collateralization for others such as the insurance giant, AIG (Blankfein 2010). The assumption that ABX prices were irrational and the observation that such prices were used to estimate impairment to RMBS investments led to claims that mark to market exacerbated the GFC. The logical conclusion for some is that fair value accounting should be ignored during crises.

It is not uncommon, and perhaps expected, that we should see *ex post* that there is more downside pressure in the short run in crisis than in the long run, and the common equity indices performed similarly. ABX prices did recover, but only after (1) the largest injection of USD liquidity in history; (2) government and industry programs to improve mortgage affordability; and (3) U.S. Treasury (taxpayer-funded) support programmes for distressed assets. This is neither proof of the irrationality postulate, nor evidence that prices were driven primarily by liquidity effects and fears. That is, it is only in hindsight that irrationality appears quite easy to identify. It does not imply that experienced traders during 2008-09 were ignoring fundamentals.

Findings of irrationality should only be accepted once a full analysis of micro and macro issues has been thoroughly investigated. Certainly, ABX pricing, along with all other asset classes, were affected by liquidity and funding concerns during the GFC. However, it does appear that subprime mortgages and their derivatives were trading based on fundamentals, even in early 2009, when ABX hit its absolute lows. This study shows that pricing was reasonably rational, in contrast to the results of Stanton and Wallace (2011) and others. Though liquidity fears almost certainly had an influence on the pricing of ABX, as for all other financial assets (Longstaff 2010), the depressed prices of 2008-09 were not removed from the reality of worsening fundamentals. Our headline message—that prices reflected both fundamentals and potential liquidity concerns—is thus consistent with empirical observations from even more opaque asset classes such as asset backed commercial paper (Covitz, Liang and Suarez 2013). For ABX, changes in default rates (CDR), loss severity (LGD), and voluntary repayment (CPR) are correlated with changes in the market prices during the crisis. As backward-looking fundamentals changed, prices changed. Additionally, prices of different tranches and vintages of ABX at any point of the crisis (in cross section)

were correlated with observable fundamentals, providing evidence against any suggestion of indiscriminate selling. ABX prices have also remained below original historical cost, indicating that fundamental value was most definitely impaired in all indices. Investors and traders were not wrong that impairments were unavoidable and imminent for many subprime AAA bonds, even if they were wrong—again, in hindsight—as to the severity of those losses.

Blaming ABX for deepening the crisis may be akin to blaming the meteorologist for the weather. The TV weather forecast is not always correct, and sometimes is horribly wrong, but it is not generally irrational, and we ignore forecasts at our peril. The ABX, like other reasonably liquid markets, may reveal fundamental weakness before less liquid instruments do.[22] ABX, CDX, and CMBX pricing did not allow dealers and other mark-to-market investors any place to hide. Prices began to fall well before the general market realized there was a problem.

We certainly acknowledge that marking illiquid assets to market during stress episodes is not optimal due to the procyclicality of such an approach. However, a lack of transparency of financial institutions' balance sheets can itself be a source of procyclicality during periods of uncertainty, which could adversely impact their funding.[23] Was 35% the right price for 2007-1 AAA? Was it 55%? Was anything a better predictor of impairments than ABX? Looking at ABX in the rear-view mirror, the most irrational price of ABX 2007-1 in mid-2007 was par (100%)! Almost every AAA bond in ABX 2007-1 and 2 is likely to suffer a loss.

Marking to ABX might have been too conservative in some cases, leading one to question how anyone can make an *ex ante* determination of irrationality. Firms that used ABX to mark multisector (mezzanine) CDO of ABS to market were underestimating future losses, as the asset class was generally worthless by 2009 (UBS 2008). Not marking AA or A tranches to market would have hidden the likelihood that almost 100% of such tranches would be completely written down in only a few years hence. When do we decide when the price is "right" and when it is "wrong"?

Many subprime investor strategies relied on an assumption of instantaneous liquidity. The GFC problem was not market-price deterioration as such but the reliance on the collateral calls that were unaffordable when marked to market, as well as overly aggressive capital charges (as low as zero in many cases). Rather than focus on fair value as a culprit, it might be better to improve the resilience of the financial system in the Admati and Hellwig (2014) vein of revising prices for accounting and capital purposes only after a prolonged decline in

[22] While shorting a subprime bond is quite difficult, shorting the ABX as a hedge was quite possible for much of 2007, and even deep into the crisis, allowing risk managers to hedge their positions, saving their firms, particularly Goldman Sachs and Deutsche Bank, from the otherwise catastrophic losses (Lewis 2011).
[23] "Sunlight is said to be the best disinfectant" (Justice Brandeis 1914).

market value, while requiring substantially more capital to cushion any such blow, especially when investments are leveraged. If institutions cannot survive the marking of their portfolios to liquid markets, then they should not be holding such investments.

From a regulatory standpoint, it is surely better to build financial-sector resilience through appropriate solvency and liquidity requirements (where appropriate and justified) to ensure that institutions can withstand adverse market conditions than by effectively relying on regulatory forbearance by pretending that prices of reasonably liquid assets differ from those observed on the market. Major central banks can then access transaction-level data in several derivatives classes to judge whether illiquidity is a valid concern. Taking the risk of liquidity holes out of the picture may allow prices to be more reflective of fundamentals. We would therefore agree with Ellul et al. (2015) that "critically, it is important not to consider the accounting treatment in isolation, but rather how the different treatments interact with capital regulations … to influence financial institutions' trading incentives."

ABX price declines were at least partially fundamentally driven during the GFC, and this has implications for Government intervention programs, which often aim to temper fire sales while allowing taxpayers to profit by capturing the liquidity premium. The fact that ABX prices incorporated fundamentals and were less sensitive to liquidity measures than previously thought suggests that government and central bank programs that sought to inject liquidity into risky credit markets in 2008 and 2020 subjected the taxpayer to some risk that the price declines would not reverse once liquidity concerns have faded. If in 2020, high yield prices, for example, were responding to financial distress rather the distress of the holders (due to runs on repo, for example), then liquidity or purchase backstops may be ill-advised. Purchase price becomes important in determining the risk, and the fact that U.S. government liquidity programs in 2008 and 2020 were profitable does not imply that the asset class as a whole was affected only by liquidity concerns and therefore was otherwise irrational. That is, while purchasers of subprime RMBS who bought at the depths of the GFC have made money, buyers at anywhere near par have lost, regardless of accounting treatment.

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