University of Illinois, Urbana-Champaign *Professor Tim Johnson*
FIN 513 - Spring 2018 *tcj@illinois.edu*

Lecture Note 9.3: Financial Engineering and the Subprime Crisis

Introduction:

The global financial crisis of 2007-2009 was partially caused by a failure of financial engineering.

During this period the largest financial institutions suffered losses that they thought were nearly impossible in a specific class of assets linked to the performance of subprime mortgages. Their models led them to believe these securities were a good deal because they were rated AAA and paid interest that was a few basis points greater than usual AAA paper.

In fact, there was an enormous amount of risk in these assets, which they missed.

Let us try to understand why.

Outline:

I. Subprime MBS

II. Re-securitization

III. Risk Analysis

IV. Summary

I. Subprime MBS.

- Last week we thought about modeling guaranteed claims to pools of
  residential mortgages, RMBS.

- Today the story starts with similar claims, but with the underlying pool being of particularly **bad** credit quality.
  - ▶ As we discussed, the government agencies (FNMA, GNMA, FHA, FHMC) only guarantee mortgages pools whose borrowers met some minimum credit guidelines. *Subprime* mortgages, by contrast, were ones taken out by people who did not qualitfy.

- While the defining feature of subprime loans is the borrowers' credit score, the loans would also often have special contractual features tailored to someone with low income.
  - ▶ Typically their interest rate would be set artificially low for the first two years, and then re-set to a high rate for the rest of their life.

  - ▶ Or the monthly payments might *not* include any principal amortization, so that the payoff profile looked more like a corporate bond ("balloon" mortgages.)

- With big pools, however, the low credit quality can be largely isolated to lower tranches of multi-tiered structures.
  - ▶ Even low quality borrowers had a historical life-time cumulative default rate of only around 5%-7%.

- ▶ With a 60% recovery rate upon default, total losses would then be unlikely to exceed 2% - 4% of total pool value.
- ▶ On this basis, a pool could typically attain a AAA rating on the top 80% or so of the principal.
  - ∗ Between 2002 and 2007 the total principal amount of subprime RMBS tranches that were rated AAA (or Aaa by Moody's) was $3.2 trillion.

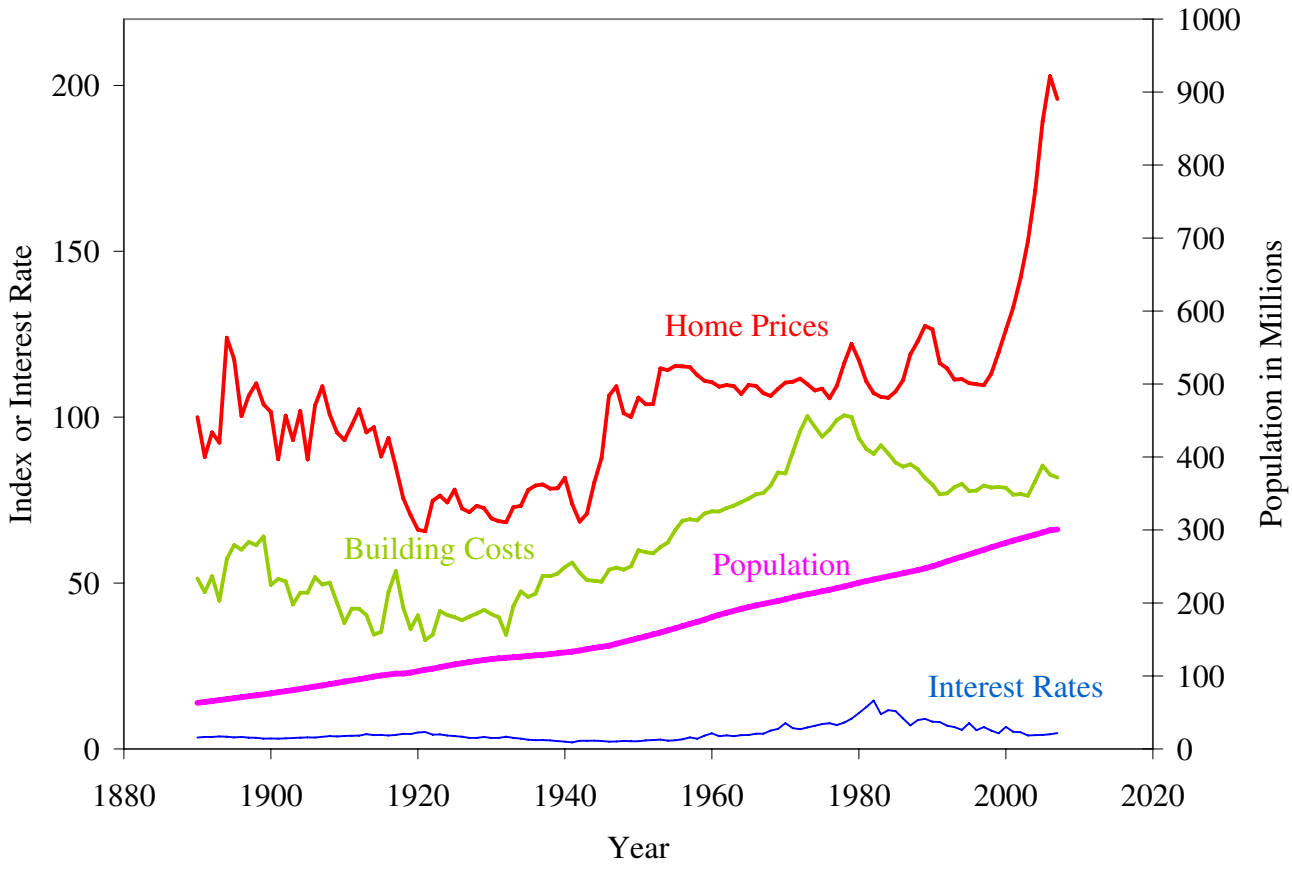
- The loan pool agreements might also have additional contractual features to mitigate credit quality problems, such as the right to put loans back to the originator if they failed within the first 60 days.

- We discussed last week the feasibility of modeling the default and prepayment profiles of ABS pools as functions of macroeconomic statistics.
  - ▶ The structure of the subprime loans was such that nearly all the prepayments and defaults would happen within the first few years.
  - ▶ Essentially the borrowers would be able to pay them off *only if they could sell the house for a profit.* In almost all cases, their income would not allow them to make the payments after the initial rates expired.
  - ▶ In effect, then the pool cashflows were almost like binary call options written on, h_{t+2}, the level of house prices in two years.

- ▶ Or, the cumulative default and prepayment functions would be very steeply sloped functions of this variable.

- Of course, it would be impossible to discover the exact relationship statistically, since there was no history of loan contracts of this form.
  - ▶ However, the basic functional form can be inferred based on just reading the loan contracts and understanding the economic logic behind subprime lending.

- For modelling the underlying state variable, h, there is historical data.



- (This picture is from Robert Shiller's web site.)

- Recent historical experience (prior to 2007) might have suggested a strong upward trend, and thus little likelihood of a drop in prices.
- Of course one should never estimate the expected rate of return on an asset (like a house) based on extrapolating near-term past performance.
- The long term history suggest something like a random walk model with substantial volatility.

- Clearly tranched subprime MBSs are complex and potentially risky securities.
  - It is certainly true that mistakes were made in modelling the default likelihoods of subprime borrowers.
  - *Yet these are NOT the securities that caused the crisis.*

II. Re-securitization.

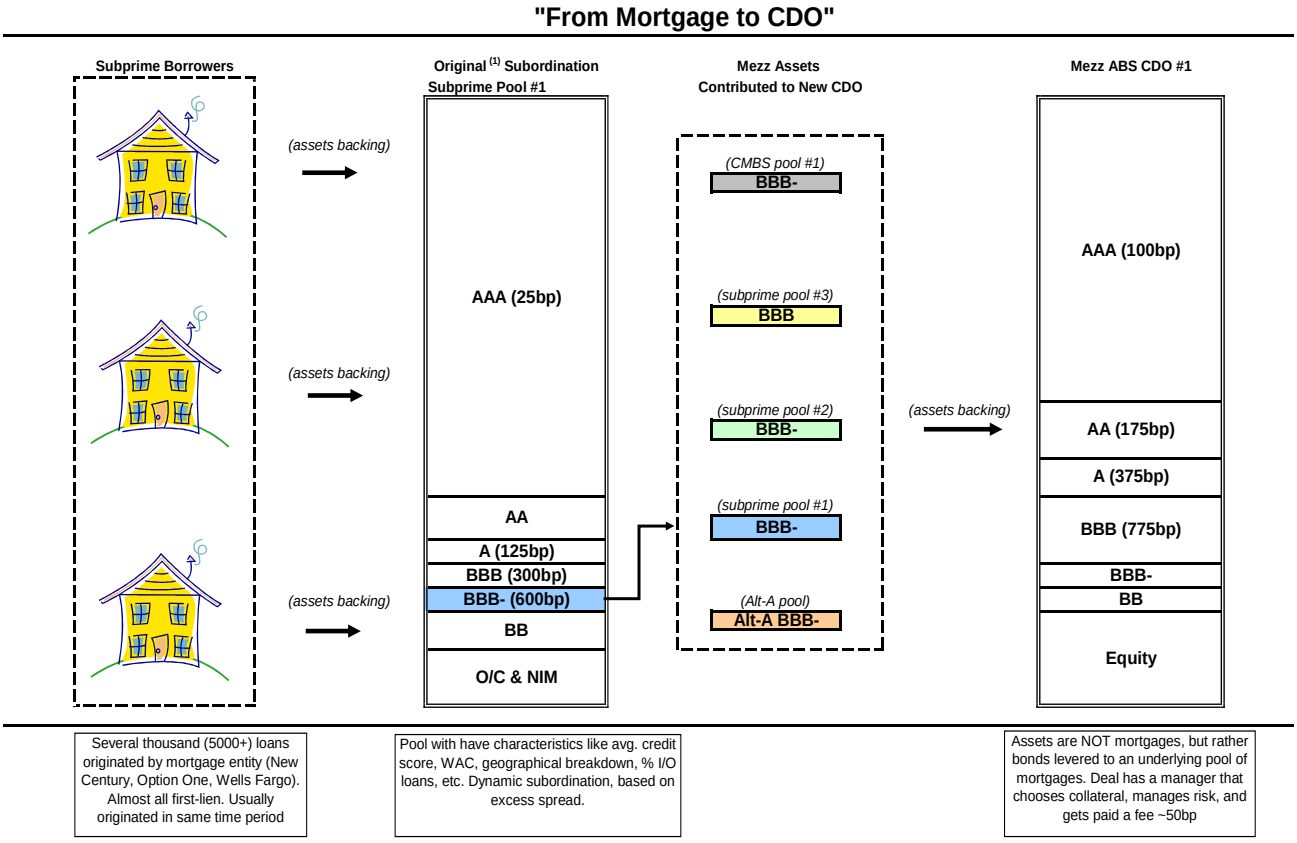
- Creating tranched subprime MBSs was a huge business. But most of the profit from this was in selling the AAA tranches. There was not much demand for the lower and intermediate ones.

- At some point somebody realized that these securities could themselves be packaged into another tranched pool to create more AAA paper: re-securitization was born.

- After all, each one of these intermediate tranches from the original pools (I'll call them *level-one* tranches) is itself a corporate bond.
  - ▶ So it is not much more complex to create a new CDO out of them than it is to do so with ordinary corporate bonds.

- Such *level-two* tranched bonds were generically called ABS-CDOs.
  - ▶ Likewise the industry created CDOs out of level-one tranches of other CDOs. These are called CDO-squareds.

- A typical ABS-CDO might own 20-50 BBB tranches each of $10-20 million in value, from different subprime RMBS.
  - ▶ Depending on how the rating agencies analyzed the structure, it might be able to have 50-70% of its liabilities (the top tranches) rated AAA.



- (Picture from Morgan Stanley.)
- This business quickly created a lot of demand for BBB level-one tranches. They themselves became rather illiquid as they were bought up to go into ABS-CDOs.
  - Meanwhile, there was still a lot of demand for AAA ABS-CDO tranches.
  - Note the spread in the picture between the level-one and level-two AAA yields.
- The industry had already figured out – in the case of ordinary CDOs – how to overcome supply constraints: *synthetics*.

- So it's no surprise that they figured out how to play this trick again.

- There were two primary innovations here.

- First, since the level-one tranches were ordinary corporate bonds, you will not be surprised to hear that there were credit default swaps traded on them.
  - These single-name ABS-CDSs were a little different from ordinary CDSs because the tranches themselves could not technically default.

  - Instead, the protection seller had to pay the buyer the fractional write-down amount whenever the level-one tranche had its principal reduced due to defaults in the underlying mortgage pool.

- Given markets for these ABS-CDSs, one could then create a (funded) synthetic ABS-CDO by buying risk-free bonds and selling protection on a bunch of level-one BBB tranches.
  - Then, as with ordinary (corporate bond) CDOs, the buyer of the new tranches are effectively sellers of the CDS.

  - This mechanism could effectively create unlimited amounts of AAA paper to be sold to conservative fixed-income funds.

    * ...as long as someone could be found who would go long the CDS on the level-one subprime tranches. (See M. Lewis *The Big Short* (2010).)

- The second synthetic development, also in analogy with ordinary CDOs, was the creation of an index of single-name ABS-CDSs.

- Just like a single-name CDS, an index CDS requires the protection seller to pay the default losses on each of the individual names to the protectin buyer.
  - The **ABX-HE-BBB**, for example, was an index (a new one created every six months) whose components were 20 BBB tranches of large subprime MBS deals.
  - A synthetic ABS-CDO could then be created by selling protection on the basket.

- In fact, these synthetic tranches are pure derivatives to the extent that the underlying ABS-CDSs are liquid and tradeable (and free of counterparty risk).

- Huge volumes of subprime-mezzanine-tranche-referenced ABS-CDOs – both synthetic and cash – were created.

- *These were the assets that caused the crisis.*

- Moreover, the originating banks were not just doing this to fulfill customer demand.
  - They kept a lot of the resulting (level-two) tranches on their books and in hedge-funds that they controlled.

- Some of this was merely inventory held during the process of creation and selling.
- But a vast amount was retained because the issuers believed it represented a good investment. In particular, they liked the top tranches: they thought they were creating cheap AAA securities.
- AAA-rated bonds are especially priveleged with respect to bank capital requirements: under Basel regulations, they are treated as essentially riskless.

• Why did banks think they were safe?

III. Risk-Assessment

- Consider a typical 5-year ABS-CDO made up of 50 equal positions in BBB tranches of subprime RMBS.
  - The BBB rating implies that the 5-year "default probability" of each tranche was expected to be about 2.5%.
    - I used quotation marks to remind you that the tranche itself is not defaulting, but is instead experiencing principal write-downs. So the 2.5% is the probability that those write downs exceed the lower attachment point.
  - Also these tranches were typically quite thin. For example they might have attachment and detachment points of 12% and 15% of the underlying subprime pool's principal.
  - This means that, conditional on any write-downs occurring, the tranche is likely to lose a large fraction – perhaps 50% or more – of its principal.

- So what does our ABS-CDO look like if we view it through the lense of the "market standard model" for ordinary CDOs?
  - I do not know for sure that any banks specifically did model them this way.
  - But I do know that that is how S&P modeled them for purposes of assigning ratings to their (level-two) tranches.
    - **Reference:** *CDO Evaluator Version 3.0*, by K. Gilkes, N. Jobst, and B. Watson, `S&P Publications`, 19-Dec-2005.

- I also know that banks believed that *other people believed* the rating agency models.
  - Any time the agencies proposed even minor changes to their methods the banks fought them fiercely.

- It is easy enough to make up some plausible numbers and see how that model would assess the risk of the level-two tranches.

- If we assume that the BBB-tranches had constant and equal default intensity of .025/5 per year and a recovery rate of 50%, then the only thing left to decide is the copula correlation between their default times.

Correlation Assumptions for CDO Evaluator Assets

Rated Securities

Sovereign vs. Sovereign

Within region	0.2
Between regions	0.0

Obligor vs. Obligor

	Between sectors				Within sector				
	Corp	ABS	Muni	SME	Corp	ABS	Muni	CDO	SME
Within country	0.05	0.10	0.00	0.04	0.15	0.30	0.30	0.15	0.10
Within region****	0.05	0.10	—	0.04	*0.00 **0.15 ***0.15	0.20	0.30	—	0.10
Between regions****	0.00	0.00	—	0.04	*0.00 **0.00 ***0.15	0.00	0.00	—	0.10

*Local

**Regional

***Global

****If any correlation is without local, regional, or global classifications, then correlation applies to asset pairs regardless of classifications.

- S&P states that they used correlations estimated from actual historical default correlations from entities of the same asset class.

- However, since there was essentially no history of subprime MBSs (and essentially no defaults within the limited history that there was), they ended up using similar assumptions as for corporate securities in the same industry: between 10 and 30%.

- If you put $\rho = 0.20$ into the normal Gaussian copula, and use the other numbers given above, you find that a level-two tranche with an attachment point of about 14% yields a 5-year default probability of about 0.001% which is approximately the threshhold for a AAA rating.
  - In other words, the S&P model would view the pooling-tranching machine as transforming around 86% of lower grade assets into high-grade.
  - And that is indeed how the AAA tranches came into being.

- This was a big mistake.

- Think about those BBB level-one tranches.
  - Each one is based on a pool of perhaps 1000 subprime mortgages.
  - Each one is highly diversified and thus represents mostly systematic risk related to house prices.
  - Each pool thus looks stochastically *exactly the same.*

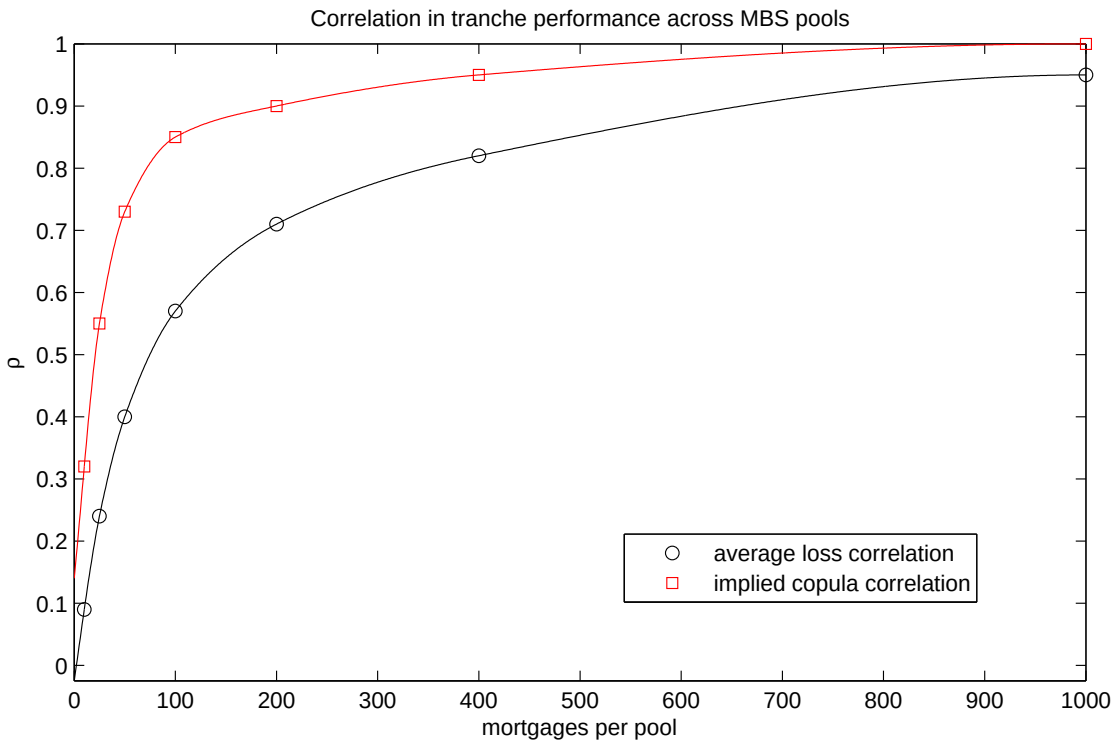
- Moreover, think about the event that a BBB tranche actually experiences losses.
  - If it has only a 2.5% chance of occurring then, *conditional on that event happening*, it is extremely *unlikely* to be due to idiosyncratic defaults.
  - Thus, it is likely to be due to a cause that affects all pools.
  - The level-one tranching thus exaggerates the – already high – correlation across pools.

- For these reasons, the level-two copula correlation should be effectively 1.00.

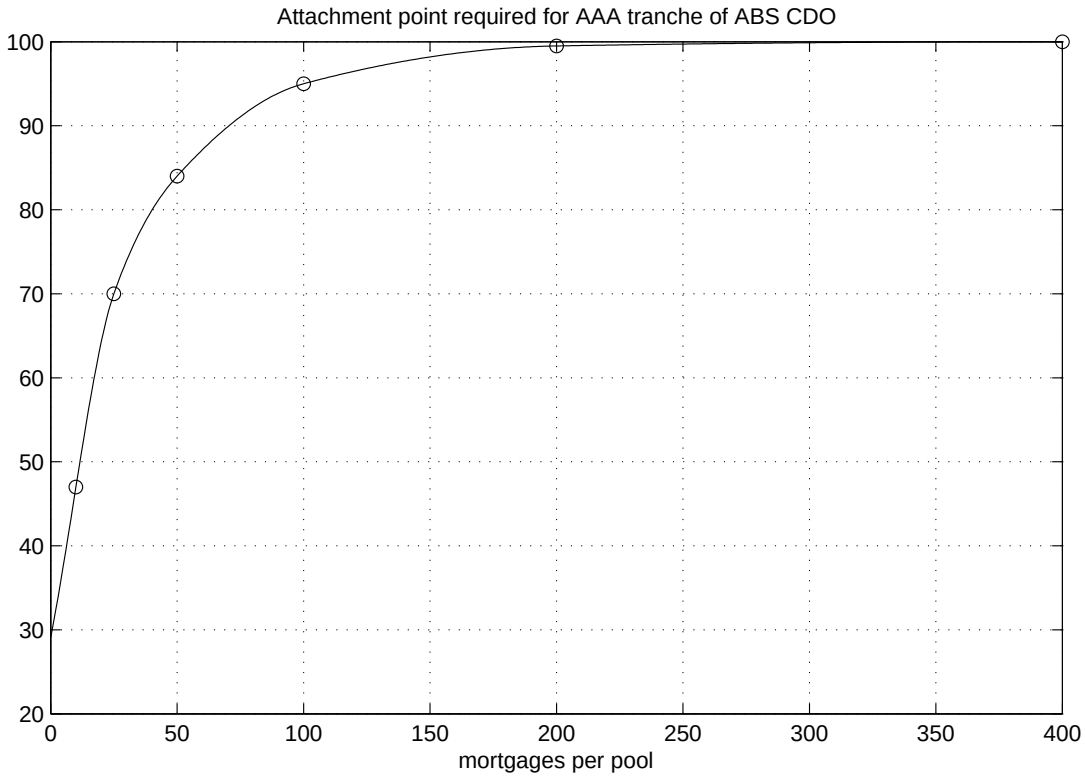
- Let me illustrate this by doing another computation with the Gaussian copula model.

- Let us apply that model *to the original subprime mortgages*.
- We can use the model to see what happens when we pool them into separate level-one securities, and then evaluate the true correlations between their default experience via simulation.
- Specifically, imagine that each individual mortgage has a default intensity of $\lambda = 0.02$, a recovery rate of 50%. And suppose that their joint default distribution is governed by a Gaussian copula with common correlation $\rho = 0.10$.
  - These are reasonable numbers for generating the BBB tranche characteristics we used above.
  - Applying the copula calculation to a level-one tranche of 1000 of these loans with $L = 12\%$ and $U = 15\%$ gives a 5-year default probability of about 2.5% and an expected loss of about 1.6%, i.e. it looks like a BBB tranche.
- But now what happens if we have 50000 loans and form them into 50 pools of 1000 each?
  - Answer: The average correlation in default losses between any two BBB tranches is over 90%.
- If we now wanted to apply the NGC model again TO THESE 50 POOLS, we would need to convert that correlation in default losses to an implied copula correlation.
  - Recall that the copula parameter controls the correlation in default *times*.

- I did this exercise so as to match the cross-pool distribution of tranche defaults in the loan-level simulation for different assumptions about the number of loans in the individual pools.



- If we used the correlations in this graph for our second-stage application of the copula model to compute expected losses for the (level-two) ABS-CDO tranches, we would find that MUCH HIGHER attachment points would be required to achieve a AAA rating.
  - ▶ Here's that computation:



- Clearly this shows that making AAA tranches at the second level is impossible!
  - By the way, I am not saying that this example is an especially good model of individual mortgage defaults.
  - I just used the NGC to illustrate that even its assumptions imply nearly perfect correlation of cross-tranche outcomes.
  - The type of pool level model I described earlier – with default intensities driven by specific risk factors – would give a more realistic dependency structure.
    - But it wouldn't change the message.

- In a nutshell, pooling and tranching only works when it involves diversifying away risks within the pool.
  - If the underlying BBB assets have perfectly correlated pay-offs, then any structure created out of them will still just be BBB.

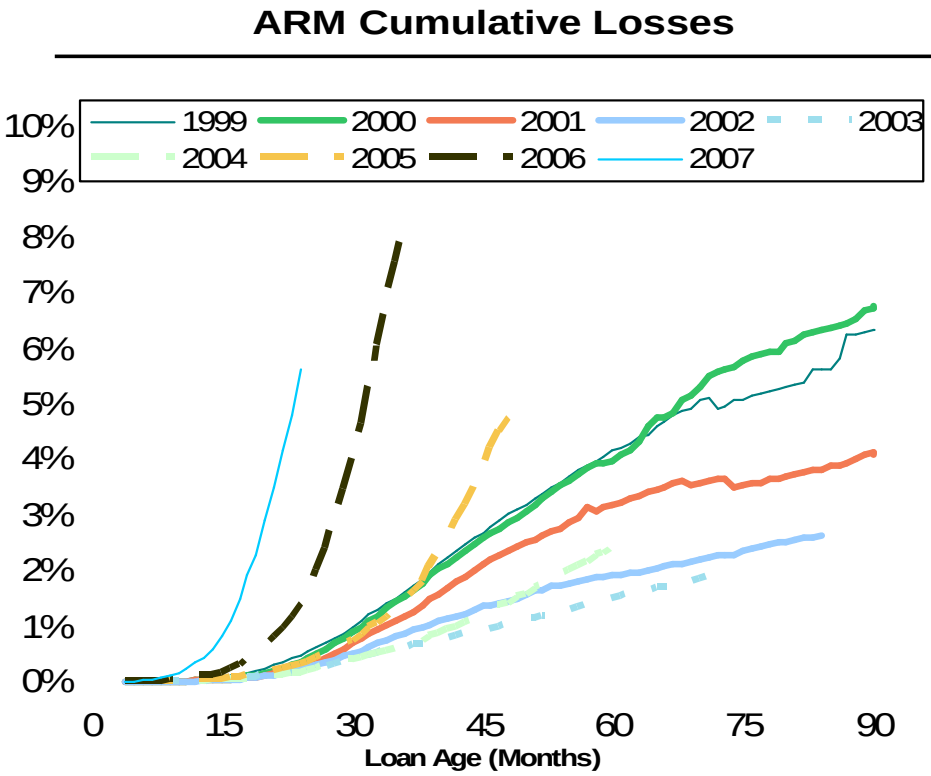
- With properly modelled correlation, then, the whole machinery of securitization should have stopped at level-one and the ABS-CDOS would never have been created.
  - Without AAA ratings, banks would have had to reserve too much regulatory capital against their holding and they would lose their appetite.

- Having said that, we cannot blame the entire financial crisis on one single correlation number.

- After all, even if the ABS-CDO AAA tranches were recognized to be of BBB quality, that's still fairly safe – hardly "toxic waste".

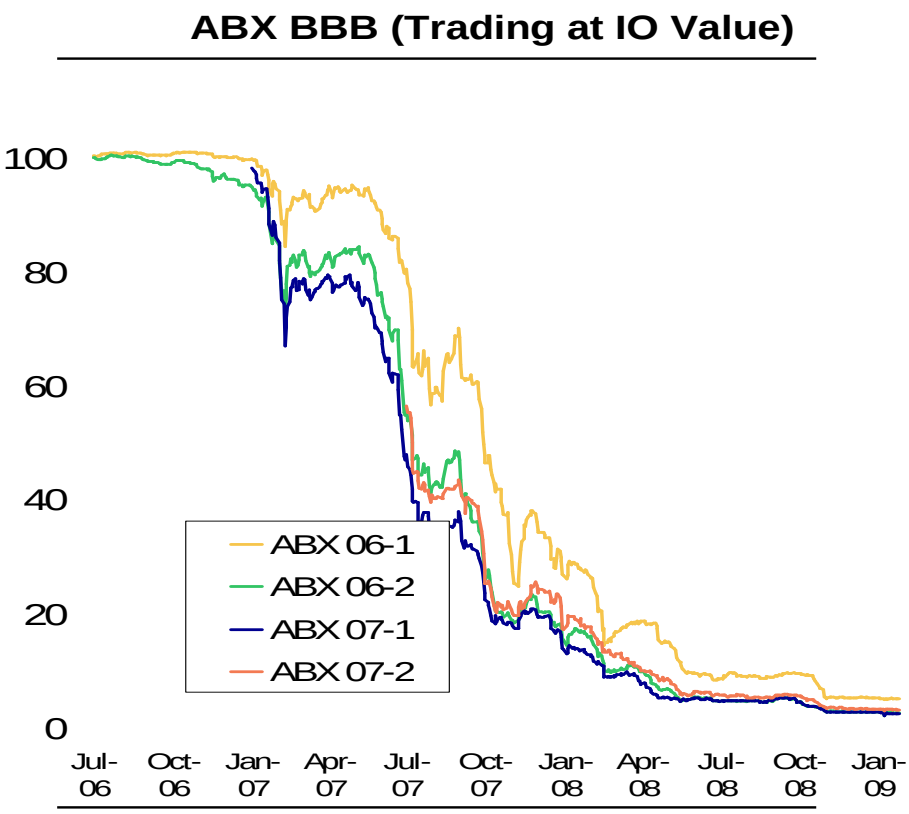
- A further problem is that those mezz tranches of the original subprime pools should never have been BBB rated in the first place. This is a huge estimation error.

- It is true that, in 2005, the 5-year losses on subprime pools had only been around 5% cumulatively, which (with 50% recovery) implies a one year default intensity of about 0.02.



Source: Moody's

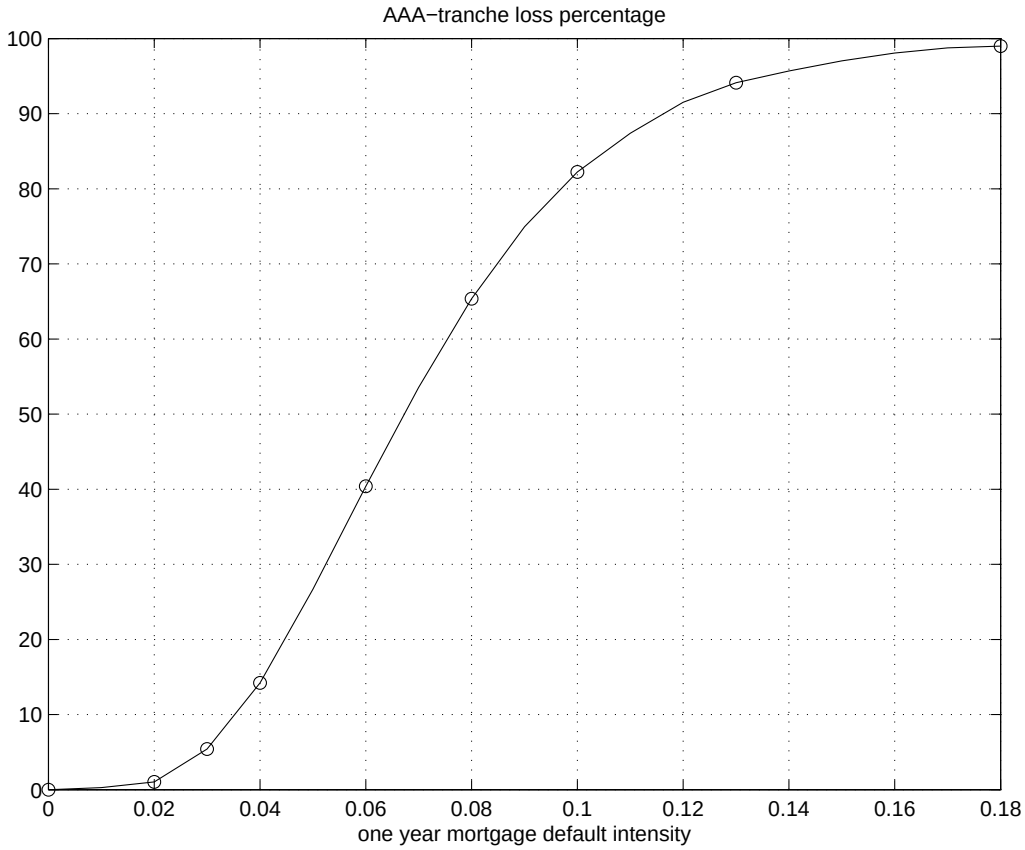
- That is about all the history anyone had, since subprime mortgages were a recent invention.
- But that was in a period of very rapid house-price appreciation. No one needed to default on their mortgage if they could just sell their house at a profit.
- It is difficult to see why the market did not grasp that house prices might fall – or even just stop rising – and forecast the effect this would have on subprime defaults.



Note: Through Feb 16, 2009
Source: Mark-It

- When we first looked at ordinary CDOs we recognized that the delta of a tranche with respect to an individual name's credit rating (or its λ) was *also an increasing function of correlation*.
- In this regard, a secondary effect of the correlation mistake in ABS-CDOs was to mislead the people who held high rated tranches about their degree of exposure to the credit quality of the BBB pools, and thus to the underlying housing market.

- Here is how my example AAA tranche above is affected by the assumed mortgage-level default intensity λ.



- As of 2010, the experienced 5-year pool losses for subprime mortgages reached around 40%. At 50% recovery, that translates to one-year default intensity of about 0.16.
  - ▶ Now <u>that</u> produces some toxic waste.

IV. Summary

- Creating asset-backed products via pooling and tranching is an important tool in finance.

- However it applies a complex operator to the underlying risks. And, the operator effectively breaks down when applied twice *to the same risks*.

- I have described failures in modelling the risks of ABS-CDOs. I have not even talked about going from risks to prices. The market also failed to appreciate the systematic nature of the risks, and to price the low-risk events accordingly.

- The failures we have described were not confined to the rating agencies.
  - ▶ Passive buy-side funds who blindly believed them were just as much to blame.

- Nor were they a case of investment banks dishonestly misrepresenting risks to fool dumb customers.
  - ▶ Much of the losses were borne by the largest and supposedly most sophisticated players – who originated the products in question.

- These were honest mistakes of financial engineering which we must learn not to repeat.