Modeling and Analytics

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Measuring MBS curve risk with Implied Mortgage Rate Sensitivity ("IMS") approach

Backtesting model hedge ratios and "trader durations"

OAS models often produce questionable partial duration profiles, and thus reduce their usefulness in measuring and managing MBS curve risk. These are usually caused by idiosyncratic features in the embedded mortgage rate models. The Implied Mortgage Rate Sensitivity ("IMS") is a Credit Suisse proprietary methodology for mortgage rates modeling and for computing MBS partial durations. We show how it can be used to consistently model MBS curve risk across maturities and product types. Back test results are analyzed to account for additional risk factors of supply/demand shocks due to QE programs and high model risk for high premium coupons. Comparisons between model hedge ratios and "trader durations" show they are generally consistent once the shape of yield curve volatility and OAS directionality are taken into account.

Mathematical formula for the IMS method are listed in the appendix for our modeling peers who may wish to replicate it themselves.

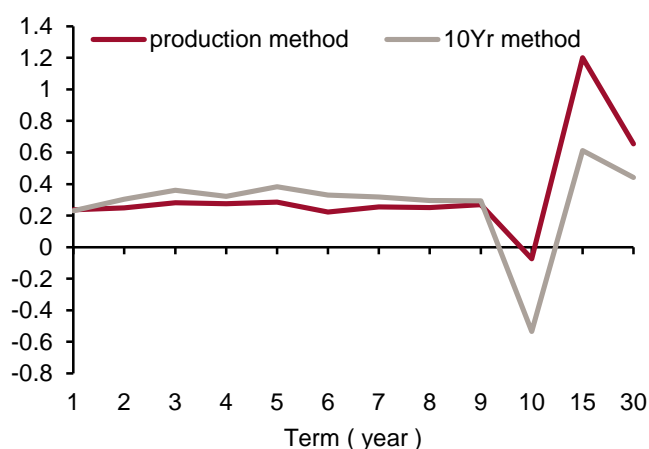# MBS partial durations from OAS models - impact of mortgage rate modeling choices

With the ongoing yield curve volatility amid uncertainties in monetary policy, investors have inquired about MBS curve risk and Locus model partial durations. We have developed a proprietary methodology at Credit Suisse, the "implied mortgage rate sensitivity" ("IMS") approach, to compute MBS durations and partial durations, and to project future mortgage rates in the OAS model. We share this methodology here and discuss its applications in MBS valuation and hedging.

In the Option-Adjusted-Spread (OAS) model framework, computing partial durations involves shocking the spot yield curve as well as shocking the spot mortgage rate simultaneously, to compute the sensitivities of model prices. Typically, the amount of mortgage rate shock associated with that particular yield curve shock is determined by the embedded mortgage rate model. The embedded mortgage rate model can be driven by discrete yield curve points or by the whole yield curve (or in certain hybrid forms, as in the Credit Suisse model). In this article, we use "mortgage rates" and "current coupon yield" ("cc") interchangeably, with the understanding that the mortgage rates are modeled through the cc.

Early implementation of the discrete yield points based cc model ("discrete cc model") often uses just a 10yr point, i.e., cc = spread + 10yr swap/treasury yield ("10yr cc model"). The Credit Suisse production model uses a nonlinear mix of 2/5/10 year swap yields ("2/5/10 yr cc model"). The advantages of this approach are simplicity and computational efficiency. The disadvantages are the arbitrariness of the modeling choices in both the specific maturities and the weights ("loadings") assigned to these maturities. The weight or "loading" is the sensitivity of cc to a change in yield for that specific maturity. For example, for a hypothetical mortgage rate model based on 2 and 10yr swap rates, cc = spread + 25% 2yr swap yield + 75% 10yr swap yield, the 25% and 75% are the weights or loadings for the 2yr and 10yr maturities.

Exhibit 1: Example of unreasonable kinks in partial duration profile, due to arbitrarily choosing certain discrete swap terms in the cc model

Partial durations profile for FNCL 4.5 as of 2/21/2014   Partial duration profile for FNCL 6 as of 2/21/2014
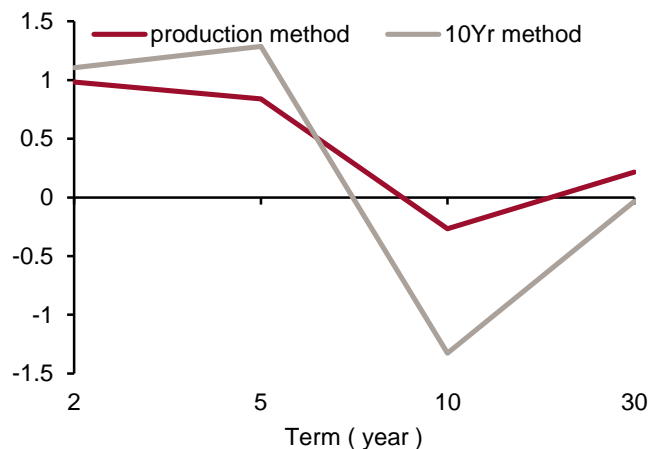
Source: Credit Suisse

Exhibit 1 shows the impact on the MBS partial duration profile due to the arbitrariness of these modeling choices, by comparing the TBA partials between the Credit Suisse production model (which uses a nonlinear combination of 2/5/10 year swap yields to drive future mortgage rates) and a simple "10yr cc model". The left diagram shows FNCL 4.5s partials in the 1/2/3/4/5/6/7/8/9/10/15/30 year maturity grids.[1] For the "10yr cc model", there are large differences between 9yr and 10yr partial durations. In fact, 9yr partial duration is positive, while 10yr partial duration is negative. Obviously these results are unreasonable, as one would expect similar partial durations between the neighboring 9yr and 10yr points. This is because the "10yr cc model" drives mortgage rates exclusively with the singular 10yr swap rates.

The right diagram of Exhibit 1 shows a similar issue for more sparse grids of 2/5/10/30 yr partials. The "10yr cc model" shows a large negative partial profile for the 10yr sector while 30yr partial is close to be zero. For the "2/5/10 yr cc model", the 10yr partial still shows a negative "kink" versus the positive 5yr and 30yr partials. These contrasts between 10yr and 30yr partials are due to the inclusion of the 10yr point and exclusion of the 30yr point in the mortgage rates models. (the 30yr point is not included in our mortgage rate model partly due to the high computation cost in projecting the 30yr swap rates in all future scenarios. We will discuss this issue in detail later.) Obviously, partial duration profiles (and, as a result, curve risk exposure measures) driven by these rather arbitrary modeling features do not inspire confidence.

While it seems one way to reduce the "kinks" in the partial duration profile is to use more maturity points on the yield curve to drive mortgage rates, modeling the weights/loadings across the term structure may entail additional complexities. For example, how do we determine weights for 2/5/10yr swap yields for mortgage rates in our production model and why do we choose to use a nonlinear form? A common estimation approach is multiple regression between historical data of mortgage rates/cc and swap yields of varying maturities. In practice, regression approaches produce such wide ranges of values for weights across maturities that the resulting curve risk exposures look arbitrary. The main difficulties for the multiple regression approach are multicollinearity (yields are highly correlated across maturities, making regression unstable) and model misspecification (forcing linear regressions on a set of nonlinear relationships).

Whole curve mortgage rate models ("whole curve cc model"), on the other hand, utilize the insight that the cc is the yield of a par mortgage pass-through bond. Hence, modeling mortgage rates in an OAS framework becomes a self-reference mathematical problem[2] The OAS model needs the embedded mortgage rate model to price MBS bonds, while the mortgage rate model needs to price a par pass-through bond to solve the yield as cc. While this method provides a consistent framework for the mortgage rate modeling, the mathematical complexity of this approach often obscures the benefits it brings to MBS valuation and risk management. For example, the backward induction method in this framework is computationally expensive, but the differences in model OAS are usually quite small, compared with a much simpler "10yr cc model". [3]

Based on the same insight, the Credit Suisse "implied mortgage rate sensitivity" ("IMS") methodology provides a practical and computationally economic approach for mortgage rates modeling and for MBS partial durations. We show a simple example below to illustrate the logic. The appendix lists the mathematical formula and some theoretical discussions for our modeling peers who may wish to implement similar method.

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[1] Partial durations are generally computed in the context of a "grid" of maturities. Yield curve shock is a triangle that peaks at one grid maturity, and diminishes at the two neighboring grid maturities.

[2] For example, "The term Structure of Mortgage Rates: Citigroup's MOATS Model", Bhattacharjee and Hayre, Journal of Fixed Income, March 2006

[3] For example, page 168-169, Andrew Davidson and Alexander Levin, "Mortgage Valuation Models, embedded options, risk, and uncertainty", 2014, Oxford University Press

How to "imply" mortgage rate sensitivity to yield curve shocks?

Using the February 21, 2014 pricing day as an example, Exhibit 2 shows a base swap curve, and a synthetic 30 year pass-through security, the "cc bond", at par price, with a coupon equal to the corresponding 30year current coupon yield of 3.3989% and a WAC set at coupon+55.61bps. This 55.61bps spread is derived from interpolation of our WAC assumptions for TBA 3s and 3.5s, which bracket the par cc bond. The "cc bond" is model priced at 25.6bps OAS.

We show two examples of how much cc change is "implied", given a 10bps increase in 5yr swap yield. The first example shocks the 5yr rate by 10bps in the 2/5/10/30 year "grid", which leads to a triangle curve shock centered on the 5yr point and between the 2yr point and 10yr point on the yield curve. In order to solve for the "implied" mortgage rate/cc change due to the curve shock, we construct a new "cc bond" with the new current coupon yield (to be solved for) as the bond coupon, and WAC at the same spread of 55.61bps to the new cc. The new cc yield, 3.4137%, is solved by requiring the new "cc bond" to be priced at par, under the same 25.6bps OAS. Hence the "implied" mortgage rate sensitivity is 1.48bps for the 10bps 5yr yield shock.

The second example also uses a 10bps increase in 5yr swap yield, but in a finer "grid" of 1/2/3/….8/9/10/11/15/30 year points. Hence, the curve shock is a triangle centered with 10bps at the 5yr point and between the 4yr and 6yr points. This is a far smaller curve shock than the previous 10bps 5yr swap yield shock in the 2/5/10/30 year "grid. As a result, the "implied" mortgage rate sensitivity is only 0.39bps for the 10bps 5yr yield shock.

Note that in a "discrete cc model", the mortgage rate shocks for the partial duration computation do not take into account of the shape of the curve shock. Take the example of a hypothetical mortgage rate model driven by linear combination of 2/5/10yr rates, and assume cc = spread + 25% 2yr swap yield + 25% 5yr swap yield + 50% 10yr swap yield. The mortgage rate sensitivities, used for partial duration computation, for our previous two examples (10bps 5yr swap yield shock on 2/5/10/30 year grid and on 1/2/3/…./9/10/11/15/30 year grid) will be 25% for both, despite the fact that the second curve shock is much smaller.

Exhibit 2: How to "imply" mortgage rate sensitivities to two examples of 10bps shocks to 5yr swap yield

February 21, 2014 pricing day

Base curve	1M	3M	6M	1YR	2YR	3YR	5YR	7YR	10YR	20YR	30YR
Yield	0.158	0.238	0.243	0.265	0.449	0.821	1.639	2.256	2.831	3.528	3.665

	Price	OAS	Coupon/Mortgage rate		WAC						
Base case "cc bond" under base curve	100	25.6	**3.3989**		3.9550						

10 bps shock (5yr point in 2/5/10/30 grid)

	1yr	2yr	3yr	4yr	5yr	6yr	7yr	8yr	9yr	10yr	15yr	30yr
Curve Shock	0	0	**3.3**	**6.7**	**10**	**8**	**6**	**4**	**2**	0	0	0

	Price	OAS	Coupon/Mortgage rate	WAC	**dCC**	
New "cc bond" under new curve, solving for coupon/WAC for the same oas at par price	100	25.6	**3.4137**	3.9699	**0.0148**	

10 bps shock (5yr point in 1/2/3/5/6/7/8/9/10/11/15/30 grid)

	1yr	2yr	3yr	4yr	5yr	6yr	7yr	8yr	9yr	10yr	15yr	30yr
Curve Shock	0	0	0	0	**10**	0	0	0	0	0	0	0

	Price	OAS	Coupon/Mortgage rate	WAC	**dCC**	
New "cc bond" under new curve, solving for coupon/WAC for the same oas at par price	100	25.6	**3.4028**	3.9590	**0.0039**	

Source: Credit Suisse

Apply the same method to all other maturities for 1/2/3/..../9/10/11/15/30 year points, Exhibit 3 shows a sample result of "implied" mortgage rate sensitivities ("IMS loadings") across the yield curve. These IMS loadings are then used to compute partial durations across all MBS securities.

Exhibit 3: "Implied" mortgage rate sensitivities "IMS loadings" across a grid of yield points

February 21, 2014 pricing day

Term	1YR	2YR	3YR	4YR	5YR	6YR	7YR	8YR	9YR	10YR	15YR	30YR
dcc/dr	0.0065	0.0182	0.0292	0.0337	0.0395	0.0382	0.0371	0.0361	0.0471	0.1293	0.2269	0.1209

Source: Credit Suisse

We believe the IMS methodology provides a consistent framework for the mortgage rates sensitivities for partial duration curve shocks. This leads to consistent and intuitive partial duration profiles, and, as an extension, sensible curve risk measures. Exhibit 4 shows the comparison between the IMS partials and partials based on standard methodology, which we show in Exhibit 1. The IMS partials profiles are free of these issues identified in previous sections.

Exhibit 4: Sensible and intuitive partials profile from the IMS method

Partials profile for FNCL 4.5 as of 2/21/2014
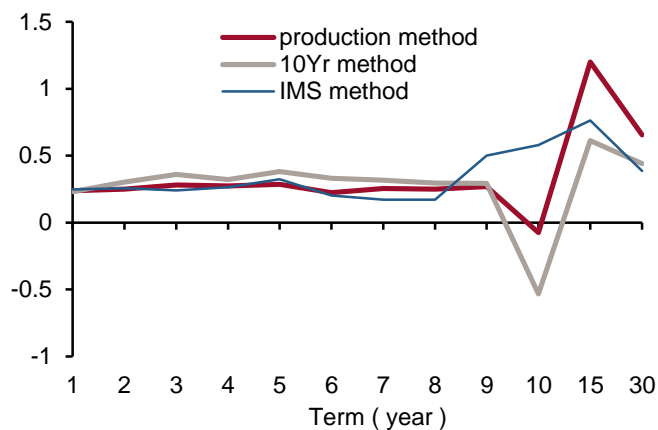
Partials profile for FNCL 6 as of 2/21/2014
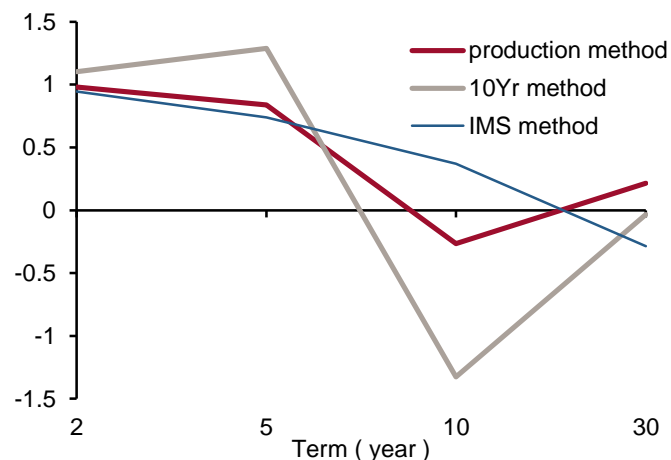
Source: Credit Suisse

IMS captures nonlinear behaviors of mortgage rates

Profiles of the IMS loadings (sensitivities of mortgage rates to yield curve shocks) reveal the nonlinear relationship between mortgage rates and swap rates, hence, the shortcomings of linear mortgage rates models.

Exhibit 5 compares the IMS loadings for a 2/5/10/30 year grid for a steep and a flat yield curve from 2014 and 2007. The loadings have much higher weightings for the front end of the yield curve in a flat curve environment. This behavior is consistent with the mortgage call options having a higher chance of earlier exercise given a flatter curve and lower forward rates. A linear mortgage rates model produces constant loadings, and will not shift loadings to the front end of yield curve as the curve flattens. As a result, it will overprice the call option values, create artificial OAS tightening (positive OAS correlation with yield curve slope), and its partial duration profile will be erroneously over-concentrated in the front.

Other factors responsible for the nonlinear relationships between mortgage rates and swap yields include

- Yield level: higher yields/discount factors tend to shift the mortgage rates loading to the front end of the curve, because the higher discount factors reduce the present value of the back end cashflow in the mortgage pass-through.

Exhibit 5: Flat yield curve tends to push the IMS loadings to the front of the yield curve

Left panel: Swap curves as of 2/21/2014(steep) and 2/21/2007 (flat)
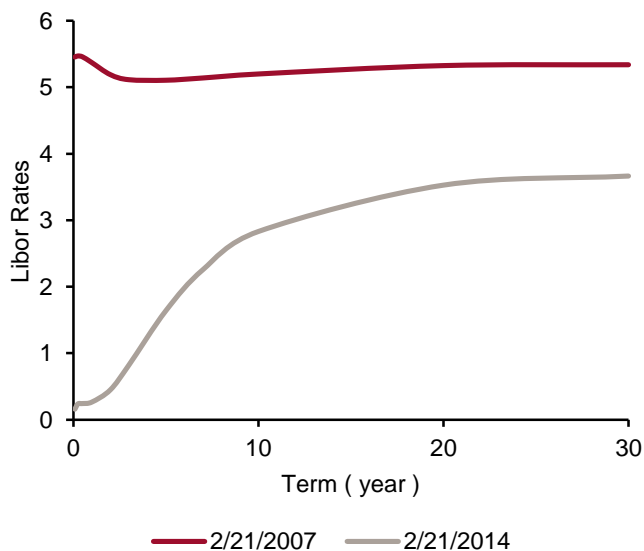
IMS loadings (sensitivities of mortgage rate to swap rates shocks) for 2/5/10/30 year points on swap curve
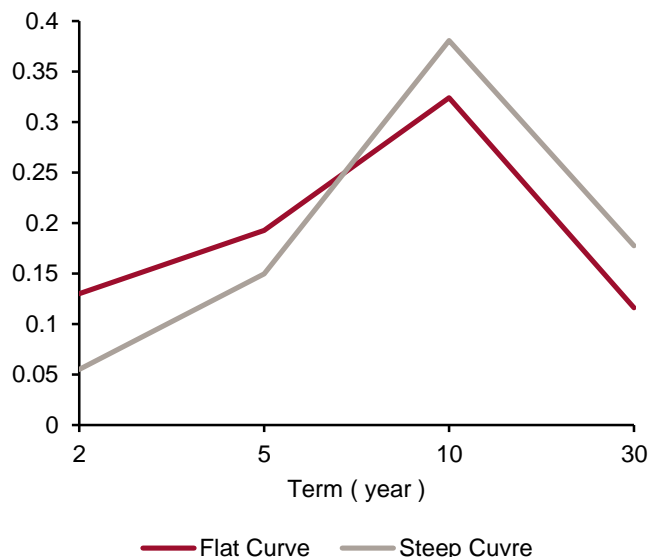
Source: Credit Suisse

– Volatility skew and prepayment propensity: the MBS/swap yield spreads are mainly attributed to the call options embedded in mortgages. The call option valuation is driven by volatility assumptions and refinance propensity. This leads to complex nonlinear behavior in mortgage rates loadings with regard to rates change. For example, in a lognormal interest rate model, where rates volatilities increase with rates, one would expect mortgage/swap spread (which is proportional to option cost) to increase with rates if OAS stays constant for the current coupon bond. As a result, mortgage rates would increase more than one-to-one with regard to swap rates, i.e. the mortgage/swap beta, produced from the IMS method, may be bigger than one in a lognormal model. As we discussed in a previous report published on 20 September 2012 (*Modeling and Analytics: Neither normal, nor lognormal when it comes to volatility skew*), volatility skew changes with rates level. Hence, mortgage/swap beta should also change with rates level.

Prepayment model choices also affect the profile of the IMS loadings. Many models use present-value-saved as driver to define the refinance S-curve. Due to the effect of discounting, this means a 3.5% mortgage with 50bps Refi incentive has more refinance propensity than a 5.5% mortgage with the same 50bps Refi incentive. If volatility assumptions are the same, the option cost and current coupon/swap spread will be higher for a 3.5% current coupon mortgage than a 5.5% current coupon mortgage. This would suggest a less-than-one and decreasing mortgage/swap beta, based on the IMS method. On the other hand, as we discussed in the previous section, the volatility skew increases as rates rally, which tends to increase the mortgage/swap beta. Combined, this leads to complex behavior for mortgage/swap beta as a function of rates level.

Credit Suisse mortgage rates model

As discussed previously, the mortgage rates model in the OAS model framework is a self-reference mathematical problem. The IMS loadings (the mortgage rate sensitivities to curve shocks) are based on the OAS model valuation, which has a mortgage rate model embedded in itself. The embedded mortgage rate model produce its own mortgage rate sensitivities to curve shocks. These two sets of mortgage rate sensitivities are often far from being consistent.

Based on this intuition, the Credit Suisse mortgage rates model solves for a particular set of model parameters that allows these two sets of loadings/mortgage rate sensitivities to be consistent with each other. (The mathematical representations for this method are listed in the appendix.) While the methodology is based on whole curve/IMS approach, the forward projections of mortgage rates use a nonlinear combination of only 2/5/10 yr swap rates, hence we have termed the Credit Suisse mortgage rate model as a "hybrid" in previous sections. Using only 2/5/10 year rates to project mortgage rates in the stochastic simulation does not reduce valuation accuracy compared with using the entire curve, because yield curves in the stochastic simulations are usually "well behaved"/smooth and can be well represented by just 2/5/10 year points. The partial duration shocks, on the other hand, can be arbitrary, so we apply the IMS methodology. This "hybrid" combination allows the right balance between computation efficiency and valuation accuracy, in our view.

While the Credit Suisse mortgage rate model/IMS method is constructed from the OAS valuation approach, we can test its ability to forecast mortgage rates as well. For example, we use the previous day/period's OAS/spread and current day/period's yield curve to forecast the current day's mortgage rate. We show that forecasting error from our method is much smaller than that of a linear regression between mortgage rates and yield curve points. (Exhibit 41 on page 39 of the *Credit Suisse Agency Model Overview* dated August 2010). This is remarkable, in our view, since the linear regression is an in-sample fit that aims to minimize the "forecasting" error, while our IMS approach is valuation based and does not use historical current coupon yield data directly, but it produces a much smaller forecasting error. This provides some validation to the IMS methodology and Credit Suisse mortgage rate model.

Measure MBS curve risk under the IMS methodology

Exhibit 6: Yield curve risk measures are generally unbiased in CS models: low correlations between curve changes and model OAS changes for FNCL 3.5s

(Left panel) 1st and 2nd Principal Components (PCA) for swap yields between Nov. 2010 and Nov. 2014; (Right panel) Regression analysis between PCAs and FNCL 3.5s OAS
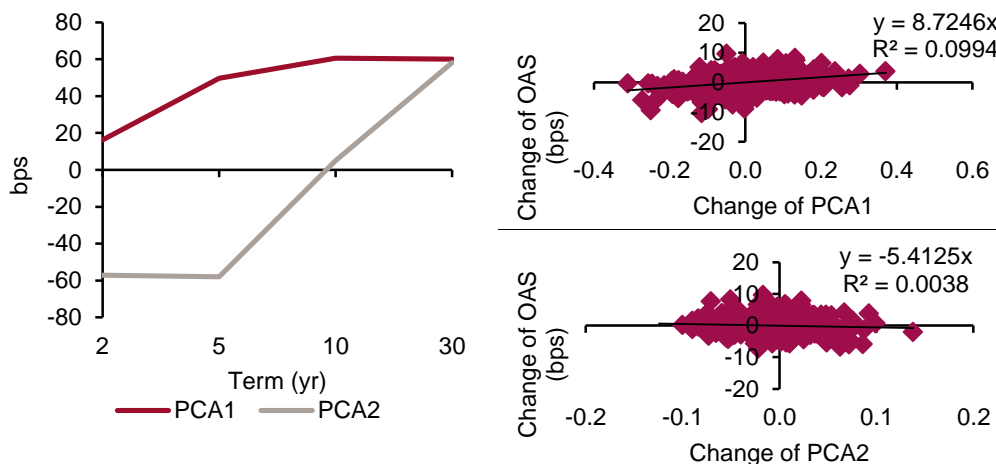
Source: Credit Suisse

While the Credit Suisse IMS methodology provides a consistent framework to measure yield curve risk across MBS products and yield maturities, market prices are often affected by factors outside of the OAS model framework. Exhibit 6 is an example of empirical analysis separating these risk factors.

The left panel shows the 1st and 2nd principal components (PCA) of swap curve daily movement between the Novembers of 2010 and 2014. Pre-2009, PCA1 tends to mimic a parallel curve shift. In recent years, however, the front end volatilities have been greatly reduced, as a result, the 2yr and 5yr levels are only about 27% and 82% of the 10yr level in the PCA1. The swaption implied volatility surfaces have a similar shape as well. The PCA2 represents a yield curve twist. The PCA1/PCA2 account for 89% and 9% of total variance of yield curve variability during this period.

The right panel shows the correlation between FNCL 3.5s OAS and the PCA1/PCA2. If model OAS are not correlated with yield curve movement, then model price changes, under the constant OAS assumption, driven by changes in yield curve and volatility inputs, are unbiased estimators of market price changes. Hence, model hedge ratios are effective if correlations are low between OAS and yield curve changes. (The typical OAS model also has a price change attribution component from current coupon yield. This is typically small in our model. While we model the secular trend of MBS/swap basis, for example, QE related mortgage basis changes, our view is that the MBS/swap basis is heavily traded and mean-reverting, so we discount the high frequency part of the basis volatility. This leads to weaker current coupon durations compared with a typical OAS model that carries forward the pricing day's MBS/swap basis forever. See the 11 December 2012 *Modeling and Analytics: New CS6.7 Model Release* for detail. The appendix has some discussions on whether this approach is consistent with non-arbitrage pricing framework.)

Exhibit 6 shows, for FNCL 3.5s, PCA2 is uncorrelated with OAS, while PCA1 has some weak correlation, with regression R-square at 9.9% and a regression beta at 8.7. "Beta = 8.7" means that for 1 unit of PCA1 curve movement (about 60bps at the 10yr point), OAS moves 8.7bps in the same direction. This implies that over this four year period of 2010-2014 the empirical durations, on average, are slightly longer than model durations. And based on the slopped shape of PCA1, most of the longer durations are attributed to the backend of the yield curve (the empirical partial durations are longer in the backend of the yield curve).

Exhibit 7 shows similar performance patterns across 30yr and 15yr coupon stacks. The R-square and beta for the 15yr stacks are much smaller than the 30yr, implying more effective model hedge ratio performance in the 15yr sector.

Exhibit 7: Weak correlations and positive beta between OAS and PCA1 imply on average slightly longer durations for the coupon stack vs. model durations

OAS correlation with PCA1 and PCA2 across 30yr and 15yr coupon stack; Nov. 2010 – Nov. 2014; the regression beta is in the unit of bps OAS per PCA1/PCA2 movement

	PCA1 vs. OAS		PCA2 vs. OAS	
	Regression R-square	Regression beta	Regression R-square	Regression beta
FNCL 3s	0.10	9.7	0.02	-12.5
FNCL 3.5s	0.10	8.7	0.00	-5.4
FNCL 4s	0.07	7.3	0.00	3.3
FNCL 4.5s	0.05	6.3	0.01	8.6
FNCl 3s	0.03	4.7	0.00	0.39
FNCl 3.5s	0.01	2.1	0.01	9.5

Source: Credit Suisse

However, this "average" view over 4 years might be misleading, as model bias could be concentrated in certain historical periods and in certain price ranges. We apply the same analysis to the 60 days rolling regression between model OAS and PCA1 to exam the model hedge ratio performance patterns across the period of 2011-2014. Since low R-square values may indicate spurious correlation where beta values have little significance, we use the regression beta "weighted" by R-square values as indicator.

Exhibit 8: Three periods of model hedge ratio "failures": QE related high OAS directionalities in Aug-Sep 2011 and July-Aug 2013, and high model risk (high premium and prepayment volatility) around July 2012

60 days rolling regression between OAS and PCA1, Product of regression beta and R-square for FNCL 3.5s and 4s for 2011-2014 (unit: bps/PCA1)
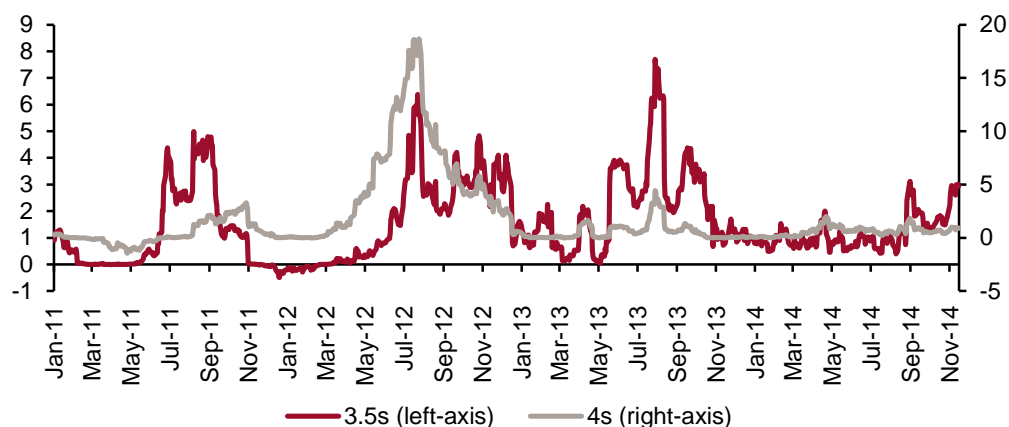
Source: Credit Suisse

Exhibit 8 shows the value of this indicator for FNCL 3.5s and 4s across 2011-2014. Three periods of model hedge ratio "failures" (with regard to predicting market price changes) stand out, while model hedge ratios are generally realistic curve risk measures outside of these three periods.

- The periods of Aug-Sep 2011 and July-Aug 2013 saw high volatilities in both rates and MBS basis due to market perceptions of the Federal Reserve's QE asset purchase programs. Both treasuries and MBS were affected in similar fashion in the asset purchase programs, which led to high positive correlations between rates and MBS basis. Exhibit 8 shows this pattern mostly affected 3.5s (the then production coupon which was the main target of Fed purchases), and less for the 4s.

- July 2012 saw rates reaching historical lows, and 3.5s and 4s were at $106-107 high premium territories. Prepayment performances were highly volatile over this period. Furthermore, there is little historical data for prepayment analysis to rely on when the MBS universe reached this high premium level, and model risk is high given uncertainties about borrowers' and servicers' behaviors. Credit Suisse's model appeared to significantly under-hedge market price movements for 3.5s and 4s during this period. One possible driver for this discrepancy could be our model's forward mortgage credit availability assumption. The model assumes mortgage underwriting recovery in 5 years (average prepayment propensity increases by 60% from then current levels, when the "macro credit variable" increases from 0.5 to 0.8) (see pages 3-4 of the 21 January 2014 *Modeling and Analytics: New agency model CS6.9 released to Locus.*) This might be biased to the optimistic side versus the market view, hence model durations might be too short for high premium coupons.

Exhibit 9 shows similar behavior for 15yr TBA stack. Note FNCI 3.5s had both positive and negative directionality periods during the high premium period of July 2012 to Feb. 2013.

Exhibit 9: Similar performance patterns for the 15yr sector

60 days rolling regression between OAS and PCA1, Product of regression beta and R-square for FNCI 3s and 3.5s for 2011-2014 (unit: bps/PCA1)
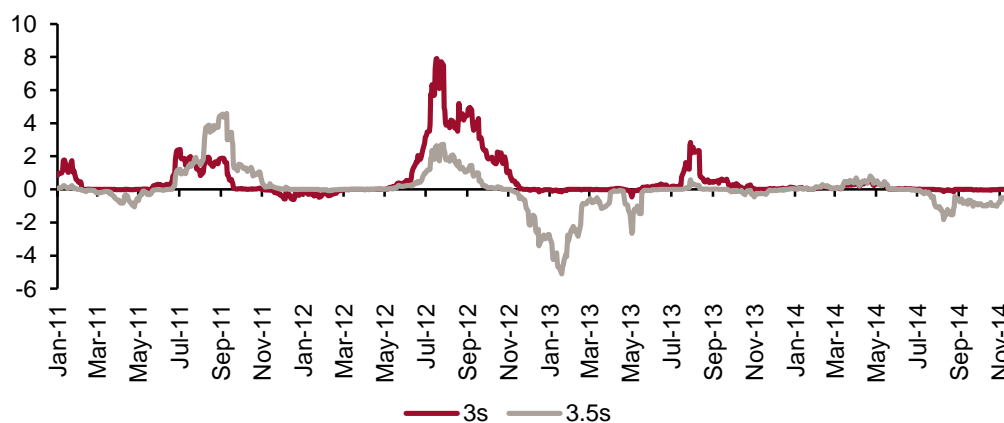
Source: Credit Suisse

Understanding the sources of model discrepancy from market price performance is important if we need to extend model adjustments to other MBS products that do not have liquid price information, and thus cannot afford this kind of empirical analysis. In this context, we discuss a common market practice of comparing model durations to "trader durations" as part of model validation process.

Exhibit 10: FNCL 4s: compare "trader durations", model durations and an ex-post duration target: model durations seem to be biased longer?

The ex-post duration target regresses between TBA prices and 10yr swap rates for future 20 days. The "goodness" of "trader durations" and model durations are measured by their distances to this duration target

Source: Credit Suisse

TBA "trader duration" is a form of market view of future hedge ratios between TBA and 10 year swap/treasuries. Exhibit 10 shows the comparison between "trader durations", model durations and an ex-post duration target for FNCL 4s. The ex-post duration target regresses between TBA prices and 10yr swap rates for future 20 days, hence this is the "best" hedge ratio/duration measure if one has perfect information for the future. Hence, the "goodness" of either "trader durations" or model durations is measured by their distances to this ex-post duration target.

Overall, the "trader durations" track the ex-post duration target well, revealing the high skills of the market in anticipating price actions. Model durations, on the other hand, tend to be generally longer than "trader durations" and the ex-post duration measures, except around July-August 2012. Does this mean that the model is doing well for July-August 2012, and may need to be adjusted for the rest of the time periods?

Exhibit 11:FNCL 4s: model durations, once adjusted for the shape of PCA1, track the ex-post duration target well

The ex-post duration target regresses between TBA prices and 10yr swap rates for future 20 days. The "goodness" of "trader durations" and model durations is measured by their distances to this duration target
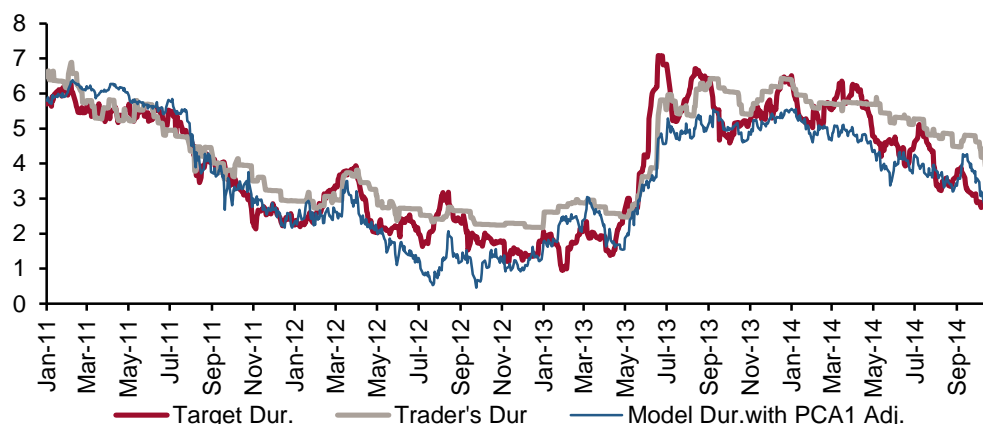
Source: Credit Suisse

On the contrary, we would argue quite the opposite, that the model provides good hedge ratios for market prices for much of the periods, except July-August 2012, and July-August 2013. Note that model durations are computed with the assumption of parallel yield curve shift, while, as discussed previously, yield curve movements in recent years are distinctively slopped with much diminished volatilities for the front end. Hence, once adjusted for the shape of PCA1, the model duration measure tracks well the "trader durations" and the ex-post duration target, except for July-August 2012 and July-August 2013 when OAS directionality was very strong, as discussed in previous sections. Note that, for recent periods, the PCA1 adjusted durations for 4s are about 1yr shorter than standard model durations, and this measure generally outperformed the "trader durations" for much of 2014.

Exhibit 12:FNCL 4s: adjust the model durations further with ex-post OAS directionality

The ex-post duration target regresses between TBA prices and 10yr swap rates for future 20 days. The "goodness" of "trader durations" and model durations is measured by their distances to this duration target

Legend:
- Target Dur.
- Trader's Dur
- Model Dur. with PCA1&OAS directionality Adj.
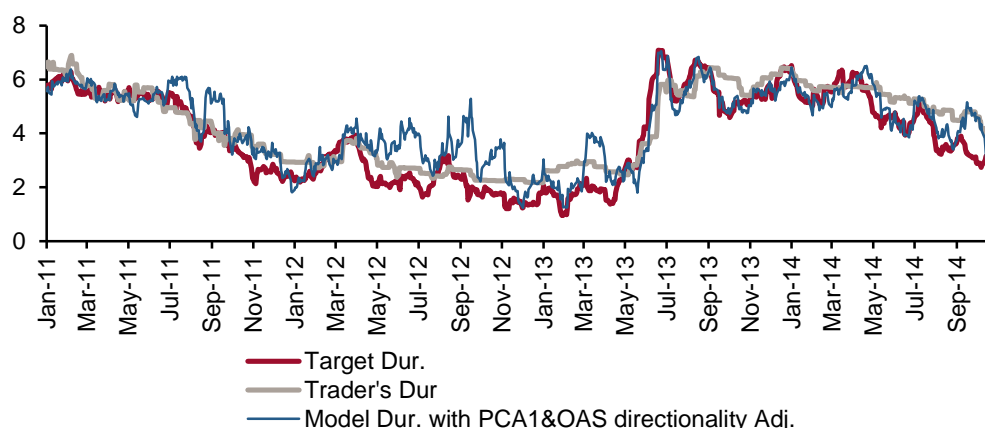
Source: Credit Suisse

If we adjust the PCA1 model durations further, with an ex-post correlation between 4s OAS and 10yr swap rates for future 20 days (applying the differentiation chain rule by combining yield curve duration and OAS spread duration), the resulting model durations track the ex-post duration target well.

Obviously, it might be difficult to forecast the future correlations between OAS and yield curve. Given the information content of the "trader durations", one can back out the implied future correlations between OAS and yield curve from the differences between the "trader durations" and the PCA1 adjusted model durations, and apply this information consistently across maturities and other related MBS products.

Exhibit 13: FNCI 3.5s: PCA1 adjusted model duration generally outperforms "trader durations" except in the period of Nov. 2012-March 2013 due to high and negative OAS directionality

The ex-post duration target regresses between TBA prices and 10yr swap rates for future 20 days. The "goodness" of "trader durations" and model durations is measured by their distances to this duration target
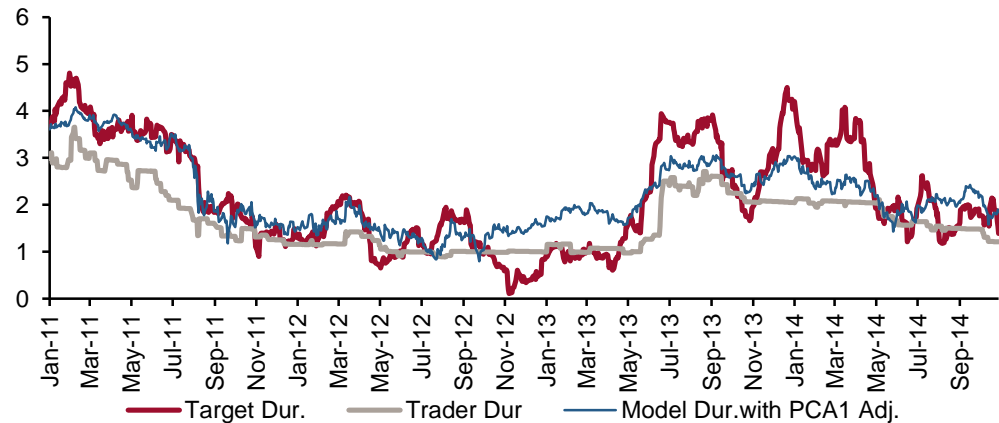
Source: Credit Suisse

Exhibit 13 shows similar performance patterns for 15yr 3.5s. Note that the PCA1 adjusted model duration generally outperforms "trader durations" except in the period between November 2012 to March 2013 due to high and negative OAS directionality. For recent periods, the PCA1 adjusted durations are about 1yr shorter than the standard (parallel) durations.

In summary, we believe the IMS methodology provides a consistent framework to model MBS curve risk across yield maturities and MBS products, and an additional overlay of empirical analysis is needed for periods of high market price volatilities due to supply/demand shocks and high model risk issues.

Appendix: Formulations for IMS methodology and Credit Suisse mortgage rates model; additional discussions

Formulations for IMS partials

We list two methods of implementing the IMS methodology here[4]
  1) Recognize the current coupon yield is often computed by interpolating the coupons of the two TBA prices bracketing par

$$cc = cp_1 + \frac{cp_2 - cp_1}{p_2 - p_1}(100 - p_1) = g(p_2, p_1)$$

P are the prices of the two TBA prices. Based on OAS pricing model:

$$p = f(OAS, r_i, cc, \dots)$$

Apply differentiation and chain rules:

$$\frac{dcc}{dr_i} = \frac{\partial g}{\partial p_1}\frac{dp_1}{dr_i} + \frac{\partial g}{\partial p_2}\frac{dp_2}{dr_i}$$
$$\frac{dp_{1,2}}{dr_i} = \frac{\partial f_{1,2}}{\partial r_i} + \frac{\partial f_{1,2}}{\partial cc}\frac{dcc}{dr_i}$$

Apply substitution to obtain IMS loadings (sensitivities of mortgage rates to swap curve shocks)

$$\frac{dcc}{dr_i} = \frac{\partial g}{\partial p_1}\left(\frac{\partial f_1}{\partial r_i} + \frac{\partial f_1}{\partial cc}\frac{dcc}{dr_i}\right) + \frac{\partial g}{\partial p_2}\left(\frac{\partial f_2}{\partial r_i} + \frac{\partial f_2}{\partial cc}\frac{dcc}{dr_i}\right)$$
$$\frac{dcc}{dr_i} = \frac{\frac{\partial g}{\partial p_1}\frac{\partial f_1}{\partial r_i} + \frac{\partial g}{\partial p_2}\frac{\partial f_2}{\partial r_i}}{1 - \frac{\partial g}{\partial p_1}\frac{\partial f_1}{\partial cc} - \frac{\partial g}{\partial p_2}\frac{\partial f_2}{\partial cc}}$$

  2) Follow the insight that current coupon mortgage rate is the yield of a par pass-through bond

$$100 = f(OAS, r_i, M, coupon, WAC, \dots)$$

Where
$$coupon = cc, WAC = cc + \Delta$$

Apply differentiation to swap curve shocks

$$\frac{\partial f}{\partial r_i} + \frac{\partial f}{\partial M}\frac{dcc}{dr_i} + \frac{\partial f}{\partial coupon\&WAC}\frac{dcc}{dr_i} = 0$$

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[4] The formulation is for illustration purpose. Implementation needs to take into account of TBA settlement convention as well as the existing mortgage rates sensitivities to interest rate curve in the model.

Solving for IMS loadings (sensitivities of mortgage rates to swap curve shocks)

$$\frac{dcc}{dr_i} = -\frac{\frac{\partial f}{\partial r_i}}{\frac{\partial f}{\partial M} + \frac{\partial f}{\partial coupon\&WAC}}$$

Using either method to obtain the IMS loadings $\frac{dcc}{dr_i}$, then MBS partial durations can be consistently computed across all product types and across all maturities and shock types.

$$\frac{dp}{dr_i} = \frac{\partial p}{\partial r_i} + \frac{\partial p}{\partial M}\frac{dcc}{dr_i}$$

Formulations for Credit Suisse mortgage rate model

Follow the insight that current coupon mortgage rate is the yield of a par pass-through bond. Use 2/5/0 year swap to represent the swap curve. Also note that the OAS model includes the mortgage rate/current coupon model.

$$p = 100 = f(OAS, r_2, r_5, r_{10}, cc_{model})$$

Follow the same derivation of the IMS loadings, and require these loadings to be consistent with the mortgage rate sensitivities from the current coupon model $\frac{dcc_{model}}{dr_i}$

$$\frac{dcc}{dr_i} = -\frac{\frac{\partial f}{\partial r_i}}{\frac{\partial f}{\partial M} + \frac{\partial f}{\partial coupon\&WAC}} = \frac{dcc_{model}}{dr_i}$$

This is a fixed point problem for functions.[5] One can parameterize the functions based on insight of the nonlinear mortgage rate properties discussed in previous sections. Solving for these parameters typically requires only 2-3 iterations.

Validity of IMS methodology and assumptions

The dearth of traded TBA prices across future settlement dates makes it a little difficult to model mortgage rates in the non-arbitrage framework. The IMS methodology assumes that OAS of current coupon bonds are uncorrelated with yield curves. As discussed in previous sections, empirical data generally support this assumption.

Note that the typical "OAS directionality" issue does not contradict this assumption. "OAS directionality" refers to the observation that OAS of a predetermined TBA/pass-through security tends to widen with a rates rally. In the IMS methodology, the "cc bonds" changes with the yield curve.

In addition, the trend of "cc bond" OAS or MBS/swap basis can be modeled in the same framework by adding a time dependent component to the "constant OAS" mortgage rates process. Many OAS models assume the pricing day's MBS/swap basis/spread stay

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[5] For example, "On the existence of the endogenous mortgage rate process", Yevgeny Goncharov, Mathematical Finance, Volume 22, Issue 3, pp. 475-487, July 2012

perpetually, which leads to significant current coupon durations for MBS. Our view is that the MBS/swap basis is heavily traded, so we discount the high frequency part of the basis volatility with strong mean reversion. This leads to weaker current coupon durations. At the same time, we do model the trend of MBS basis, for example, the recent mortgage basis tightening and widening caused by various QE related issues. The combination of modeling the basis trend and suppressing the high frequency part of the basis volatility is validated by the empirical behavior of MBS/swap basis going through the various QE programs.

The IMS methodology can be further expanded by adding additional factors of MBS/swap basis that are correlated with swap curves. This can potentially help model the OAS directionality issue discussed in previous sections.

One valid criticism is the inconsistency of the price attribution process using the IMS partials. Follow the formulations from the previous section on the mortgage rate model, the regular partial durations are computed with the mortgage rates sensitivities $\frac{dcc_{model}}{dr_i}$ from the embedded mortgage rates model, while the IMS partial durations use, instead, the valuation implied sensitivities $\frac{dcc}{dr_i}$. Since the OAS are computed using the former set of sensitivities $\frac{dcc_{model}}{dr_i}$, using IMS partials for the price change attribution process seems to be inconsistent. (In the case of 2/5/10 year partial durations in Credit Suisse's model, the two sets of sensitivities are consistent as discussed in previous sections, thus this issue is muted.)

It is useful to note that the OAS model itself is fundamentally inconsistent, when these two sets of sensitivities are inconsistent. If using a computationally expensive "whole curve constant OAS" mortgage rate model is the ultimate "consistent" model, then the main deficiency of using a simple mortgage rate model (for example, a 10yr rate based mortgage rate model) may be the resulting questionable partial duration profile, while the OAS valuation is reasonably close. [6] Overlaying IMS partial durations would correct much of the partial duration profile, and improve the curve risk measure across maturities and MBS products at a modest computational cost. The effectiveness of the IMS correction of the partial duration profile (even when the underlying mortgage rate model is overly simplistic) is due to the quick convergence property of using iterations in this self-reference problem.

In reality, the price change attribution "leakage" (price changes that cannot be attributed to market variables such as yield curve and volatility changes) due to using the IMS partials is generally small, and is of similar magnitude as other "leakages" caused by other types of modeling imperfections, for example:

- Weekly primary mortgage rates update: while our primary/secondary mortgage rate spread model aims to forecast the primary rates both for short term and long term, it inevitably has errors when the primary rates are "marked-to-data" weekly, thus creating price attribution leakage.

- Monthly HPI update and quarterly forecast update: while our HPA models aim to forecast national/state/MSA level HPA/HPIs, model forecasting errors and our quarterly updating forecasts process will create price attribution leakage.

- Monthly factor update: prepayment and default model forecasts are never perfect, hence monthly pool factor updates also generate price attribution leakage.

- Monthly loan/pool level attributes change: the model uses loan/pool attributes (for example, loan size, WAC, FICO, etc.) to project prepayment and default. And, to some extent, the model also tries to project drifts of these attributes over time due to loan level inhomogeneity in the pools/securities. The inconsistences between projected attributes drifts and actual attributes changes lead to price attribution leakage.

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[6] For example, see discussion on pages 168-173 Davidson & Levin, "Mortgage Valuation Models" Oxford University Press 2014

Similar to models in each example (primary/secondary spread model, HPA models, etc.), the IMS methodology, while subject to small price attribution leakage, serves a useful purpose of improving valuation and hedging.

The analysis of OAS directionality is shown as a residual curve risk after applying IMS methodology. This analysis provides insight to the development of a "Market Implied Model" (or so-called prepayment model risk adjusted model). We identified two types of OAS directionality, the supply/demand driven (for example, the QE induced high OAS directionality for par coupons) versus model risk driven for premium coupons. Different "implied model tuning" approaches might be needed to model these two types of issues.

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