Derivatives Strategy
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Research Note

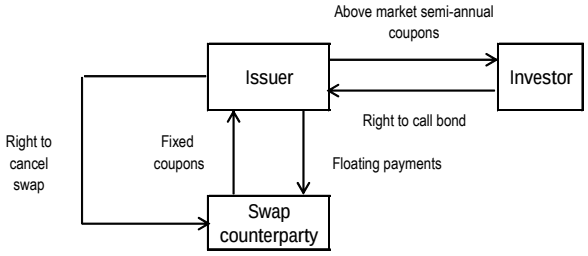
Bermudan Swaptions – A Relative Value Framework

- **Bermudan swaptions are very easy to describe, less easy to understand intuitively, and very hard to analyze—a relative value metric to answer the basic question of whether a Bermudan swaption is rich or cheap has been elusive**
- **A good relative value framework should not only provide a summary measure of richness/cheapness, but also provide an understanding of the sources of value, and be monetizable. In particular, any framework should specify exposures to correlations and implied vol curves in a hedge-able way**
- **In this paper, we develop such a framework. Our approach relies on the observation that Canary swaptions are the simplest structures that are complex enough to provide stable approximations to a Bermudan swaption. Since Canaries have exactly 2 exercise dates, they are specified by vanilla swaption implied volatilities and one implied correlation. This can be useful in the risk-management of Bermudan swaptions and in monetizing relative value**
- **A report based on the framework outlined in this paper may be found in the daily analytics packages on Morganmarkets**

Introduction[1]

Bermudan swaptions are relatively simple to describe, but can be quite difficult analyze from a relative value standpoint. Quite simply, a Bermudan receiver (payer) swaption is an option that gives the owner the right—but not the obligation—to receive (pay) fixed at a pre-determined rate (the strike) in a swap to a given final maturity, with the option being exercisable once at any one of a given set of dates prior to the final maturity of the swap. This is in contrast to European swaptions, which can only be exercised on a single exercise date. At the other extreme, an option that can be exercised at any point before the predetermined final maturity of the swap would be an American swaption.

Exhibit 1: Investor demand for the higher coupons that characterize callable bonds can spur issuance of such structures, which are often swapped to yield a lower synthetic funding rate for the issuer
A schematic illustrating the flows involved in issuing callable bonds and swapping to floating



The Bermudan as well as American swaptions markets are closely linked to the callable bond market. Investors frequently are willing to absorb reinvestment risk in search of higher current yield–i.e., they are willing to earn an above-market coupon for some minimum period of time that is less than their target investment horizon, in exchange for possibly being forced to accept lower reinvestment rates in the future. In other words, these investors are willing to own bonds with an embedded short call position, providing a higher coupon until the bond is called; should the bond be called, however, reinvestment rates will be lower by definition.

To accommodate this desire for higher current yield, issuers often find it attractive to issue callable bonds, even if they would prefer to have—say—floating rate liabilities without any call features. For instance, such an issuer might issue a Bermudan-style callable bond (typically callable on any coupon date) with a higher

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[1] The authors gratefully acknowledge the contributions of their colleagues Hui Fang and Feng Deng to this research.

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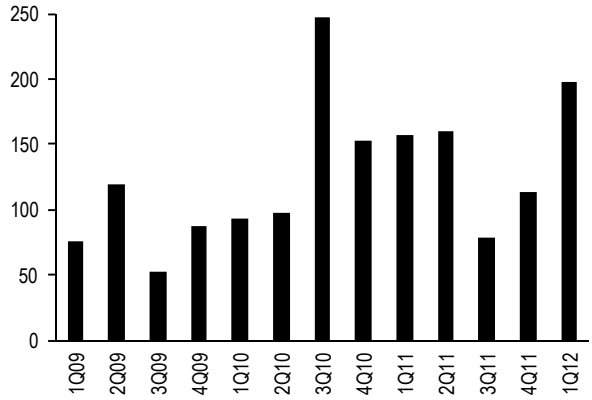
coupon, and then enter into a cancellable swap with a dealer. Effectively, the issuer would be selling the embedded call to the dealer and switching their liability into a synthetic floating rate note. Such a transaction is likely to occur when investor demand for callables is strong, allowing the issuer to synthetically obtain better funding costs through the callable market than might be possible directly. A schematic outlining this is shown in **Exhibit 1**.

One consequence of such transactions is that dealer desks are left warehousing long vol (often Bermudan) positions. Indeed, this is a key source of vol supply to swaption dealers; as seen in **Exhibit 2**, gross issuance of callables can be significant over time. Such issuance is also frequently in Bermudan or American form, given the greater yield enhancement possible by selling embedded calls with more than one exercise date. Thus, dealer desks tend to structurally warehouse long Bermudan swaptions positions, which are risk-managed using the more liquid European swaptions market.

This type of market structure makes it likely that Bermudan swaptions will offer a cheaper (albeit less liquid) source of interest rate optionality for investors needing structural hedges such as MBS portfolio hedgers. Indeed, the risk characteristics of Bermudan receiver swaptions (as opposed to European swaptions) are likely to be a better match for the risk characteristics of MBS, given that the embedded prepayment option is American in nature, and a properly structured Bermudan or American style swaption should represent a more stable hedge for MBS across a broader range of market environments. Despite these advantages, European swaptions remain by far the preferred hedging instrument. This is likely driven by three main factors. First, Bermudan swaptions are less liquid than their European-style counterparts. Second, Bermudan swaptions are more complex instruments and are simply less well understood. Third, and on a somewhat related note, a simple metric that quantifies the relative value in Bermudan swaptions versus European swaptions in a monetizable way has proven elusive. While investors can of course use a well-calibrated Bermudan pricing model to determine the fair price of an instrument and compare it to the market price, this is not a satisfactory way to assess mispricings in Bermudan swaptions. A good relative value framework for Bermudan

Exhibit 2: Issuance of swapped callables is a key source of vol supply

Quarterly vega supply from zero coupon callable issuance; $mn per 1 bp/day move in implied vol



swaptions should do more than merely deliver a rich/cheap number. It should:

- Be **decomposable** into its constituent parts. I.e., where does the mispricing come from? How much of the mispricing is idiosyncratic to the Bermudan swaptions market? How much reflects other market variables, such as mispriced implied vol curves or correlations?
- Be **monetizable**. Relative to European swaptions, Bermudans result in additional exposure to numerous other market variables, such as implied vol curves and implied correlations. Only a portion of the aggregate richness/cheapness of a Bermudan swaption is idiosyncratic to the instrument itself; some portion of it will derive from views on the mispricing of these market variables themselves. However, an investor might not wish to buy a “cheap” Bermudan swaption if most of its cheapness derives from a view on the implied vol curve, for instance, since vol curve views are more easily expressed via European swaptions. Thus, a proper relative value framework should allow an investor to determine the proper vol curve and correlation hedges, if those risks are deemed undesirable.

Finally, a useful metric of relative value should be demonstrably successful as a trading signal.

In previous research, we have attempted to make Bermudan swaptions easier to understand via

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European-swaption-based approximations (see *Introduction to Bermudan Swaptions and a Framework for Analysis*, J.P.Morgan Derivatives Strategy Research Note, 7/1/2003). In that paper, we built on some fairly simple observations to develop intuition regarding Bermudans. Specifically, we noted that each Bermudan swaption (say, a 1Yx10Y receiver struck at 3%, exercisable semiannually after the first exercise date) may be thought of as spanning a basket of European swaptions (including the 1Yx10Y, the 1Y6Mx9Y6M, the 2Yx9Y, and so on, with all these European swaptions also being receivers struck at 3%). Depending on the current optimal exercise date of the Bermudan swaption, it would most closely resemble one of these European swaptions. It is also straightforward that the Bermudan swaption's premium must be at least as much as the highest premium of all the swaptions in this basket. Moreover, the European swaption in the basket with the highest premium may be thought of as the locally best European approximation to the more complex Bermudan swaption. Inspired by the analogy with the Treasury futures market, we call this European swaption as the CTD (even though the term "cheapest" is of course incorrect in this context). And much like the CTD into a Treasury futures contract can change as market conditions change, so too can the CTD for a Bermudan swaption. For instance, in a sharp rally, a 1Yx10Y Bermudan receiver swaption's CTD would likely become the 1Yx10Y European swaption as the Bermudan becomes highly exercisable at the earliest possible date. In contrast, as rates rise and near-term exercise becomes less rewarding, the CTD would shift towards longer expiries, perhaps the 5Yx6Y.

This analogy with futures baskets allows an investor to develop some intuition regarding Bermudans. However, it doesn't easily translate into a relative value metric, because the European swaption CTD is generally not stable enough to use the "basis" between the Bermudan swaption and its CTD as a relative value metric. We also considered a slightly modified approach to developing a relative value metric in our earlier research, based upon the basis between a Bermudan swaption and a "replicating portfolio" of spanned European swaptions from its basket. While more stable than a single CTD based approach, replicating portfolios proved not to be stable enough to translate into a meaningful relative value metric.

This, then, is the objective of this research note—to develop a simple relative value metric for Bermudan swaptions, and test its effectiveness in a trading strategy using Bermudan swaptions versus European swaptions. To do this, we build on the basic ideas explored in our earlier research, but extend them in a slightly different direction. Specifically, rather than attempting to replicate Bermudans with a portfolio of European swaptions, we instead seek to find a "Canary" or a 2-exercise swaption that best approximates a given Bermudan. Put simply, if our earlier research was based on finding each Bermudan swaption's European CTD, this paper explores the usefulness of considering each Bermudan swaption's Canary CTD. We demonstrate that a Bermudan swaption's Canary CTD is stable enough for it to serve as an approximation of the Bermudan itself; in addition, it is also simple enough to analyze, given that Canary pricing is determined by vanilla swaption implied volatilities and one implied correlation. In the rest of this paper, we develop a monetizable metric of relative value that builds on this observation.

Bermudan swaptions as a basket of Canary swaptions

A Canary swaption is simply a Bermudan with exactly two possible exercise dates; in other words, it is the simplest possible Bermudan-style option that is not "too simple" (i.e., a European swaption). Albert Einstein famously said that everything must be made "as simple as possible, but not simpler". In our context, it turns out that approximating Bermudans with European swaptions is too simple to be useful; Canary-based approximations, on the other hand, strike the right balance between simplicity and usefulness.

We introduce the following notation for Canary swaptions: by a 1Y(4Y)×10y Canary we mean a 1Y×10Y European with an additional exercise possibility 4 years from now, with the final maturity of the underlying swap being 11 years from now, regardless of when the option is exercised. Similar to the description of Bermudans in terms of their European basket, Bermudans can also be thought of as baskets of Canary swaptions with a single exercise. For example, a 1Y×5Y Bermudan, with annual exercise dates (for the sake of simplicity in illustration) after the first exercise date at the 1y point, can be thought of as spanning a basket of 5 Europeans with exercises 1 year

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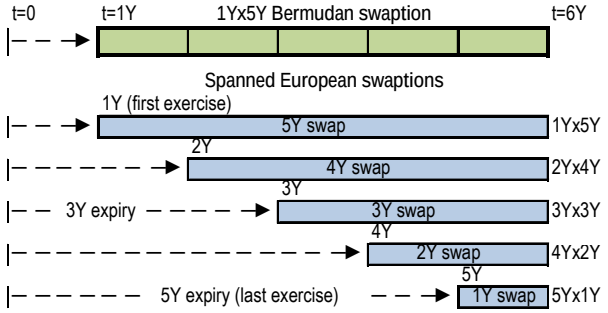
Exhibit 3: A Bermudan swaption may be thought of as spanning numerous European swaptions, corresponding to each of the various possible exercise dates

Graphic representation of a 1Yx5Y Bermudan swaption with annual exercise points, and its spanned European swaptions.



from now (to enter into a 5 year swap), 2 years from now (to enter into a 4 year swap) and so on (see illustration in **Exhibit 3**).

It is straightforward to generalize this idea, and to think of a Bermudan swaption as spanning a set of Canary swaptions. Specifically, the same Bermudan mentioned earlier can also be thought of as spanning a basket of 10 Canary swaptions (one for each possible pair of allowable exercise dates). These possibilities are enumerated for the above example of a 1x5 Bermudan with annual exercise in **Exhibit 4**.

For each Canary swaption spanned by a Bermudan, we can also define the Bermudan/Canary or BC basis as the premium of the Bermudan minus the Canary's premium. The highest-premium Canary in the basket (that is, the "CTD" in our terminology), therefore, has the smallest basis in the basket.

The real value in analyzing Bermudans by using their Canary baskets stems from the greater stability of the Canary CTD. As seen in **Exhibit 5,** the Canary CTD's BC basis is not only narrower (in comparison to the BE basis of the European CTD), but also much more stable across different rate regimes. In addition, Canaries also mirror the risk characteristics of a Bermudan swaption more closely than European swaptions. In order to match the risk profile of a Bermudan swaption using Europeans alone, typically two-to-three or more are needed, and the replicating portfolio is typically only stable under a narrow range of market moves. For example, a 1Y×5Y Bermudan receiver might combine the risk characteristics of a 1Y×5Y European receiver in a rally and a 2.5Y×3.5Y European in a selloff

Exhibit 4: It is straightforward to generalize this idea and to think of Bermudans as spanning a set of Canary swaptions

Graphic representation of a 1Yx5Y Bermudan with annual exercise points, and its 10 spanned Canary swaptions

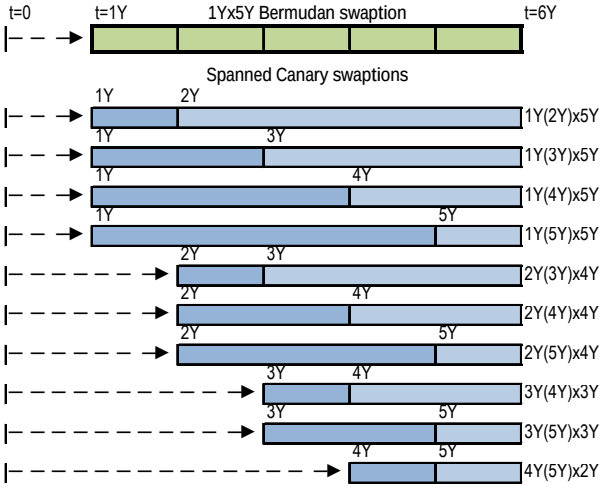
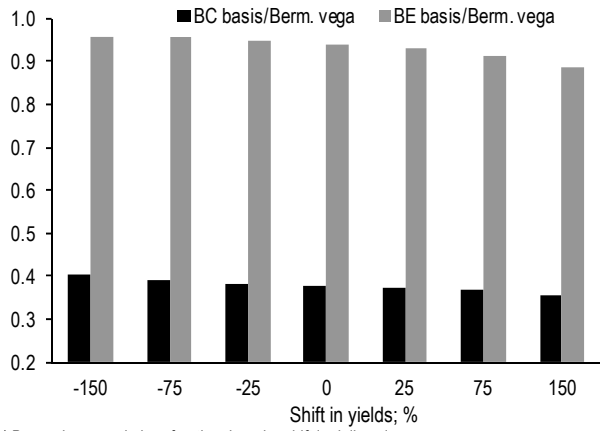


Exhibit 5: The BC basis is consistently narrower than the BE basis under different yield scenarios

1Yx5Y ATM receiver Bermudan/Canary basis and Bermudan/European basis for the CTD divided by the Bermudan vega* for various parallel shifts of the yield curve**; %



* Bermudan vega in bp of notional per bp shift in daily vol.
** COB 5/22/2012

(**Exhibits 6 & 7**). Over the same scenarios, a single Canary swaption (the CTD, in fact) provides a better match than any of the individual Europeans. Intuitively, this result is not surprising. Under most circumstances the Bermudan may either be exercised early on or somewhere near the midpoint of the exercise period. Exercising much closer to the final

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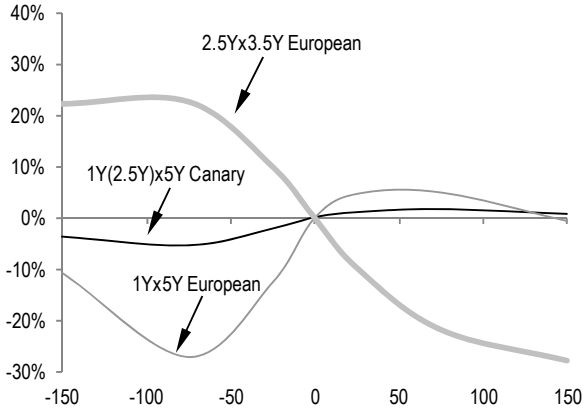
Exhibit 6: The Canary CTD mimics its parent's risk characteristics better than individual European counterparts, as seen in the deviation profiles for delta …

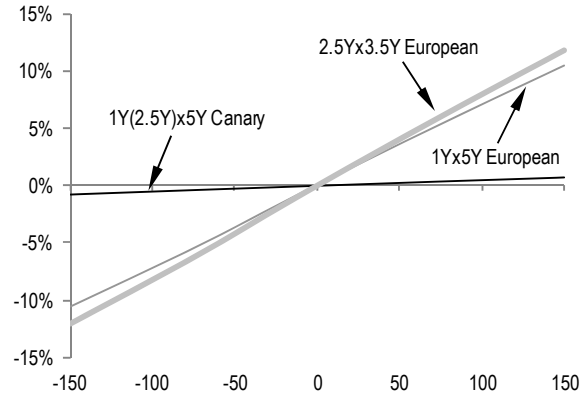
Deviation of the delta profile of selected European and Canary swaptions from the 1Yx5Y Bermudan delta profile plotted against shifts of the yield curve; %



The delta profile is obtained as a % of the original delta (that is, for no change in the yield curve). Each curve is obtained by subtracting the European or Canary delta profile from the Bermudan delta profile. The 1Y(2.5Y)x5Y Canary and the 1Yx5Y European are the CTDs. COB 5/22/2012

Exhibit 7: … and vega

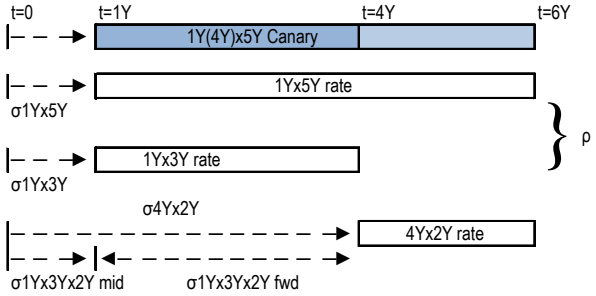
Deviation of the vega profile of selected European and Canary swaptions from the 1Yx5Y Bermudan vega profile plotted against shifts of the yield curve; %



The vega profile is obtained as a % of the original vega (that is, for no change in the yield curve). Each curve is obtained by subtracting the European or Canary vega profile from the Bermudan vega profile. The 1Y(2.5Y)x5Y Canary and the 1Yx5Y European are the CTDs. COB 5/22/2012

Exhibit 8: Pricing a 1Y(4Y)×5y Canary swaption

Symbolic representation of a 1y (4y) × 5y Canary swaption and the minimal components needed to price it



maturity of the option tends not to be advantageous due to the lower annuity factors of the residual swap.

Thus, a Bermudan swaption's Canary CTD is in fact likely to be a very good approximation to the Bermudan swaption. But why is this useful? After all, the more exercise dates one is willing to allow in the approximating structure, the better one can approximate the characteristics of a Bermudan swaption.

The answer lies in the greater tractability of Canaries. Since—as discussed above—Canaries do indeed serve as reasonable approximations to the more complex Bermudan structures, the problem of developing a relative value metric for the more complex Bermudans can be simplified to that of developing relative value views on its Canary CTD. Also, Canary swaption premia are determined by vanilla swaption pricing inputs plus one implied correlation input, meaning that relative value metrics based on Canary approximations can be estimated from (and monetized through) the vanilla swaptions and correlation markets.

As an example, consider a 1Y(4Y)×5Y Canary receiver. At the 1-year horizon, this option will be exercised if and only if the exercise value (the forward value of the 5-year swap with fixed coupon equal to the strike) is greater than residual option value (the value of a 3Y×2Y receiver swaption at that point in time). Thus, the value of the right to defer exercise at the 1Y point depends on the then spot 3Y×2Y swaption volatility, which we approximate by the *forward* volatility, in addition to the 1Y×5Y spot swaption volatility. Moreover, as illustrated in the grey box below, 1-year forward 3Y×2Y implied volatility is itself determined by 3 vanilla swaption implied vols and a correlation: in this example, one would require 1Y×3Y, 1Y×5Y and 4Y×2Y swaption implieds, as well as an implied correlation input that represents the 1-year correlation between the 1Y×3Y and 1Y×5Y forward swap yields (see the schematic in **Exhibit 8**). This means that we may derive a fair price for the

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Introduction to forward volatility

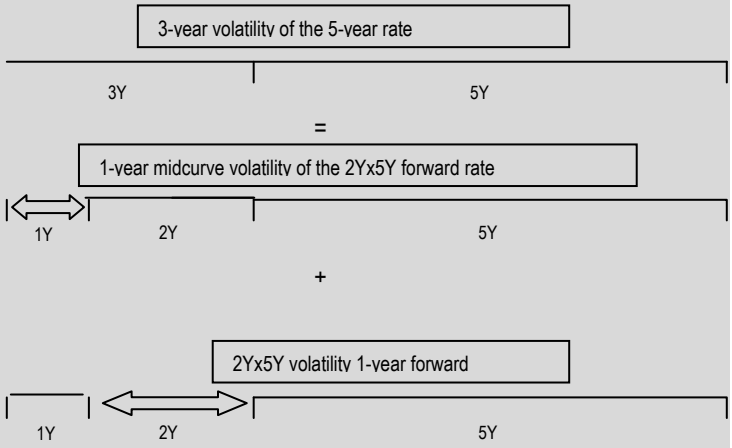
Forward volatility exposure in the USD swaptions market is typically created via forward option agreements. This generally involves an agreement that enables one counterparty to buy an ATM straddle at a future point in time, at a price (i.e., the forward premium) agreed to on the trade date. For instance, a 1Yx2Yx5Y forward option agreement would allow a client to purchase a 2Yx5Y then-at-the-money straddle 1-year from trade date, at the pre-determined price. Note that the strike on the 2Yx5Y would be set at the completion of the 1-year forward term; indeed, it is this characteristic that makes it a forward volatility instrument, since the absence of strike results in no delta or gamma exposure for the first 1-year period in this example. This can be a desirable characteristic indeed; for instance, this allows an investor to create vega exposure without having to manage delta or gamma exposures. Alternatively, an investor looking to put on vol positions with desirable implied vol slide characteristics can simply buy or sell a forward option agreement, with no subsequent dynamic position management as would be necessitated if the investor were to trade swaption calendar spreads.

The pricing of any given forward option structure is determined by 3 different swaption implied volatilities, and one correlation input. The discussion below clarifies this in the context of the example mentioned above. Consider a 3Yx5Y plain vanilla swaption; its implied volatility may be thought of as a weighted average of the volatility of the underlying forward yield over the 1st year of the option (which we can call the midcurve volatility, since the underlying forward rolls down from being 3-years forward to only 2-years forward as opposed to spot), and the volatility of the same underlying yield over the last 2 years of the options life (over which period the underlying yield rolls from being 2-years forward to spot).

More precisely, we can write:

$$1*\sigma^2_{M,1\times2\times5} + 2*\sigma^2_{F,1\times2\times5} = 3*\sigma^2_{E,3\times5}$$

where $\sigma^2_{M,1\times2\times5}$ denotes the implied volatility of a midcurve that expires in 1 year, but with the same underlying swap as the 3Yx5Y - ie., upon expiry, the midcurve swaption, if exercised, would result in a 2Yx5Y forward swap position. $\sigma^2_{F,1\times2\times5}$ denotes 1-year forward volatility on the 2Yx5Y volatility while $\sigma^2_{E,3\times5}$ refers to the 3Yx5Y European swaption volatility.



If a sufficiently deep and liquid market existed in midcurve options, nothing further would be necessary. However, in practice, dealers will likely need to synthetically create exposure to midcurve volatility, via more liquid plain vanilla swaption instruments. This is done by viewing forward swap rates as linear combinations of spot swap rates. For instance, if we suppose that:

$$\Delta s_{2\times5} = b1*\Delta s_2 + b2*\Delta s_{7,}$$

Then, we may approximately infer the 1Yx2Yx5Y midcurve volatility from 1Yx2Y and 1Yx7Y volatilities, as well as the 1-year average correlation between 2- and 7-year swaps, via the following equation:

$$\sigma^2_{M,1\times2\times5} = b1^2\sigma^2_{E,1\times2} + b2^2\sigma^2_{E,1\times7} - 2\rho*b1*b2*\sigma_{E,1\times7}\sigma_{E,1\times2},$$

where ρ is the 1-year correlation between 2-year and 7-year swap yields

Combining our expression for midcurve volatility with our earlier expression, we may write:

$$\sigma^2_{F,1\times2\times5} = \frac{1}{2}(3*\sigma^2_{E,3\times5} - (b1^2\sigma^2_{E,1\times2} + b2^2\sigma^2_{E,1\times7} - 2\rho*b1*b2*\sigma_{E,1\times7}\sigma_{E,1\times2})$$

Thus, the pricing of a 1Yx2Yx5Y forward vol contract, for instance, is determined by the implied volatilities of the 3Yx5Y, 1Yx2Y and 1Yx7Y swaptions, as well as the 1year implied correlation between 2- and 7-year swap yield changes. Equivalently, the risk exposure in a long 1Yx2Yx5Y forward option agreement position typically decomposes into:

- a long position in 3Yx5Y swaptions
- a long position in 1Yx2Y swaptions,
- a short position in 1Yx7Y swaptions, and
- long exposure to the 1-year correlation between 2- and 7-year swaps.

Canary using vanilla swaption implied volatilities and implied correlations.

Moreover, the recent growth and development of a correlation market, thanks to rising activity in bivariate options such as YCSOs as well as increased trading

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Exhibit 9: An illustration of the sources of value in a sample Bermudan receiver swaption

An illustration of the components driving the richness/cheapness of a 6M×30Y Bermudan receiver swaption, based upon its Canary CTD*

Premiums from a Bermudan model		
6Mx30Y Berm receiver	1409.5	bp
3Y6M(14Y)x30Y Canary	1176.6	bp
Vega	32.5	bp of notl per 0.1 bp/day
Alternate fair values for Canary based on:		
Implied correlation	1191.8	bp
Mispricing of Canary (& Berm)		
In price terms	-15.3	bp of notional
In vol units	-0.05	bp/day
plus		
Mispricing in correlation markets		
Canary price using implied correlation	1191.8	bp
Canary price using realized correlation	1192.0	bp
Correlation driven mispricing of Berm		
In price units	-0.11	bp of notional
In vol units	0.00	bp/day
plus		
Mispricing of 3.5x27/14x16.5 vol curve		
Canary price using realized correlation	1192.0	bp
Canary price under tweaked vol curve	1202.3	bp
Vol curve driven mispricing of Berm		
In price terms	-10.3	bp of notional
In vol units	-0.03	bp/day
equals		
Total mispricing	-0.08	bp/day

* Premia quoted in bp of notional. Data as of COB 5/14/2012

activity in forward and midcurve volatility, means that relative value metrics for Bermudan swaptions that are based on the idea of approximating Bermudans via Canaries, can likely be monetized by buying or selling Bermudan swaptions versus offsetting positions in vanilla volatility and correlation. These ideas are explored further in the next section.

A relative value measure

We may now develop a relative value metric. In doing so, we note that there are three possible sources of value. First, any cheapness/richness in a Bermudan swaption would likely extend into its Canary CTD, meaning that the "Bermudan market price" of its canary CTD (which can be inferred from a suitably

Exhibit 10: Indicative mispricings for various Bermudan receiver structures

Components* of our relative value metric for Bermudan receiver swaptions and the total richness/cheapness in various sectors expressed in price terms (bp of notional) and Bermudan implied volatility terms (bp/day)

Sector	Bermudan swaption mispricing*		Correlation mispricing**		Total	
	Price	Vol	Price	Vol	Price	Vol
6Mx5Y	-5.7	-0.16	-0.7	-0.02	-6.4	-0.18
6Mx10Y	-10.2	-0.11	-2.8	-0.03	-13.0	-0.15
6Mx2Y	-1.5	-0.14	0.4	0.03	-1.2	-0.11
6Mx3Y	-1.5	-0.08	-0.1	-0.01	-1.6	-0.09
1Yx10Y	-2.6	-0.03	-3.4	-0.04	-6.1	-0.06
1Yx5Y	-0.7	-0.02	-1.2	-0.03	-1.9	-0.05
6Mx30Y	-13.3	-0.04	-0.1	0.00	-13.4	-0.04
1Yx30Y	-6.1	-0.02	-0.2	0.00	-6.4	-0.02
2Yx30Y	7.0	0.02	-0.6	0.00	6.3	0.02
2Yx10Y	8.2	0.07	-2.6	-0.02	5.6	0.05
3Yx30Y	21.5	0.06	-1.2	0.00	20.3	0.06
5Yx30Y	25.5	0.07	-1.8	0.00	23.7	0.06
3Yx5Y	7.3	0.13	-3.5	-0.06	3.7	0.06
3Yx10Y	13.2	0.11	-3.3	-0.03	10.0	0.08
5Yx7Y	16.5	0.17	-2.9	-0.03	13.6	0.14
5Yx10Y	23.2	0.16	-3.2	-0.02	20.0	0.14

* The price of the Canary CTD from a Bermudan swaption pricing model, minus its fair value estimated from vanilla swaption inputs and implied correlations from the YCSO market. Esimate based on Bermudan pricing model, may not represent tradable prices. As of COB 5/29/2012.
** Canary CTD premium using 6M realized correlation minus premium using implied correlation.

calibrated Bermudan swaption pricing model) may differ from the price of the same Canary that can independently be calculated from vanilla implied volatilities and implied correlations from the YCSO market. Second, using an empirical framework, we may conclude that implied correlations in the YCSO market are themselves rich or cheap, based on comparisons to realized correlations over time. Third, since Bermudans are often traded as BE switches with respect to the European swaption corresponding to the first exercise date, the implied vol curve could be another source of value (more on this later). Again using an empirical framework, we may take a view on the volatility curve corresponding to a given canary (i.e., the implied volatility differential between the longer and short expiries for the Canary). By repricing the Canary using the estimated fair level for the vol curve, we may back out the contribution of any potential vol curve mispricing to the richness/cheapness of the Bermudan swaption being

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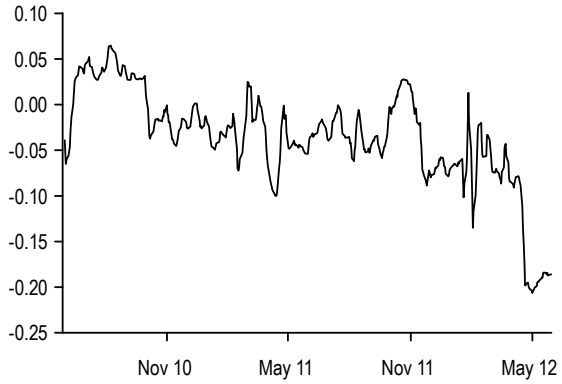
analyzed. Last, we may total up the mispricing from all three sources, and divide by the vega of the Bermudan swaption to compute the richness or cheapness of the Bermudan swaption, expressed in basis points per day. This is illustrated in detail for the case of the 6M×30Y Bermudan receiver swaption in **Exhibit 9**.

In practice, we prefer to use the sum of the first two contributing factors as our metric for the Bermudan swaption's mispricing, ignoring the impact of any mispricing in the implied vol curve. We included this contributing factor in Exhibit 9 to showcase all the sources of value in a Bermudan swaption. However, while correlation risk can be viewed as an intrinsic part of Bermudan swaptions, views on the implied volatility curve are more easily expressed via vanilla European swaptions, making it less useful to include it in a summary measure of mispricing for Bermudan swaptions. Therefore, going forward, any references to the richness/cheapness of Bermudan swaptions can be understood to mean the sum of the first two components—the current indicative mispricing for several benchmark Bermudan swaption structures is illustrated in **Exhibit 10**, along with a breakdown. A time series of the R/C values for a sample Bermudan receiver swaption is also shown in **Exhibit 11**; similar charts for a wide range of structures can be found in the *J.P.Morgan Bermudan Receiver Swaption Relative Value Report*, which can be found in daily analytics packages and available via http://mm.jpmorgan.com.

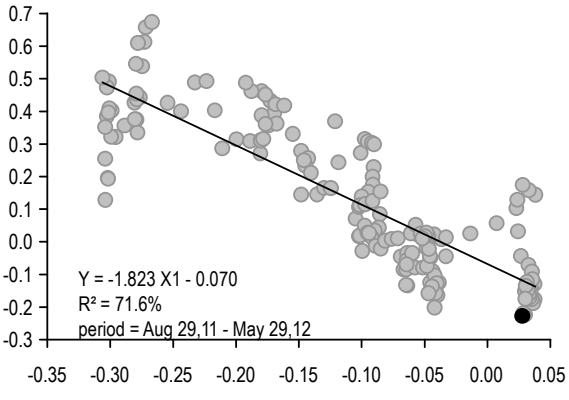
Having developed a metric for the richness/cheapness of Bermudan swaptions, the last remaining question is: does it work in practice as a trading signal? To assess the usefulness of our metric in this regard, we examined rolling 3-month total returns from a reasonably practical strategy—buying a Bermudan receiver swaption versus selling its European CTD. Both swaptions were assumed to be delta-hedged daily with their underlying forward swaps in order to isolate the vol effects. As seen in **Exhibit 12**, and as one would expect, returns from this strategy (expressed in implied vol units) are inversely correlated to the richness of Bermudans. In particular, when Bermudan swaptions are sufficiently cheap (say, cheaper by 0.3bp/day or more), our results suggest that the value in Bermudans can be monetized via a relatively simple strategy of buying Bermudan swaptions versus selling its European CTD on a delta-hedged basis.

Exhibit 11: 6M×5Y Bermudan receiver swaptions are currently the cheapest they have been in recent years
Total mispricing* in the 6Mx5Y Bermudan receiver swaption; bp/day



* Negative values indicate cheapness of Bermudan swaptions. As of COB 5/29/2012. Estimate from Bermudan pricing model, may not represent tradable values.

Exhibit 12: Returns on delta and vega hedged Bermudan longs appear inversely correlated to its richness estimated by our relative value metric
Rolling 3M total returns from buying 5Yx30Y Bermudan receiver swaptions versus selling its European CTD swaption*, regressed against ex-ante mispricing**; bp/day



* Both the Bermudan swaption and its European CTD swaption are assumed to be delta hedged daily using the underlying forward swap. Options are re-struck at the end of each month.
** As estimated by our relative value framework, as of the start of the rolling 3-month period

Conclusions

In any market, one of the most basic questions that investors ask is whether a particular financial instrument is rich or cheap. With regards to the Bermudan swaptions market, this question has been easier asked than answered. Moreover, it is equally important that any framework that attempts to quantify relative value be monetizable.

In this paper, we have addressed this basic question for Bermudan swaptions. Our approach draws on the

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observation that Canary swaptions—options with precisely two exercise dates—are rich enough to provide a stable approximation of Bermudans while also being simple enough to analyze. Moreover, while Bermudan swaptions have always been understood to include risk exposure to implied volatility levels, the implied volatility curve, as well as correlations, these exposures have always been rather amorphous and difficult to break down. Which vol curves are the ones that matter, and to what extent? Which correlations are most relevant to a given Bermudan swaption's pricing? What are the sensitivities? These are all important questions to answer in order to truly understand the risks in a Bermudan swaption position. The beauty of using approximating Canaries is that all of these questions are answerable—since the Canary CTD is a decent approximation of the more complex Bermudan swaption, the implied volatility curves and implied correlations that are relevant to the Canary's pricing are also the relevant market variables that the Bermudan is most exposed to. Quantifying the sensitivities is also rather straightforward once one has determined the best Canary approximation.

Our approach also leads to a rich/cheap value metric that is monetizable, via a relatively straightforward trading strategy involving the Bermudan swaption versus its European swaption CTD. A daily Bermudan Receiver Swaption Relative Value Report, based on the framework discussed in this paper, is attached here and will be included in J.P.Morgan's daily analytics packages.

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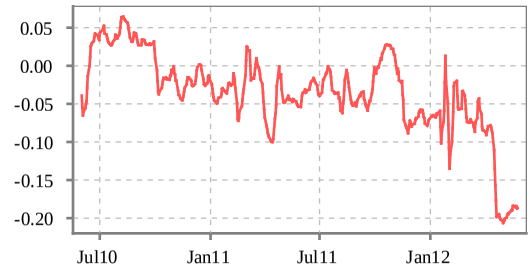
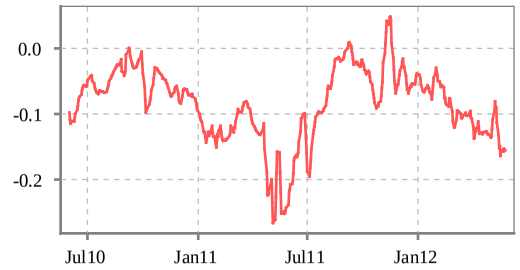
Bermudan Receiver Swaption Relative Value

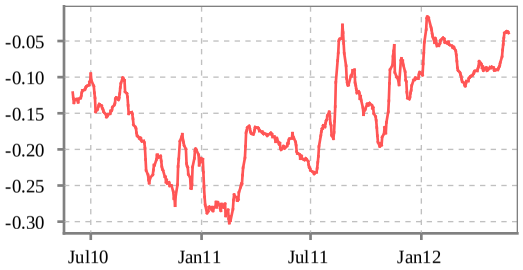
6Mx5Y



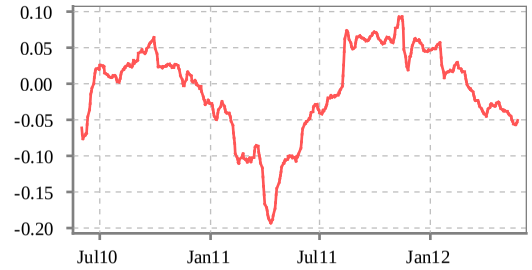
6Mx10Y



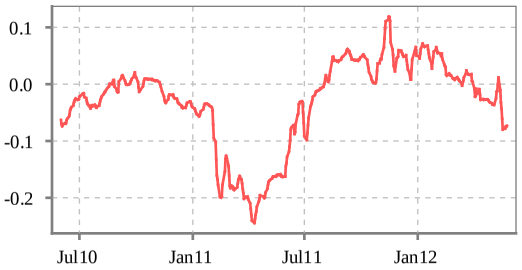
6Mx30Y



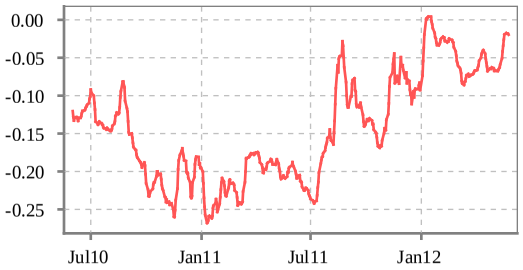
1Yx5Y



1Yx10Y



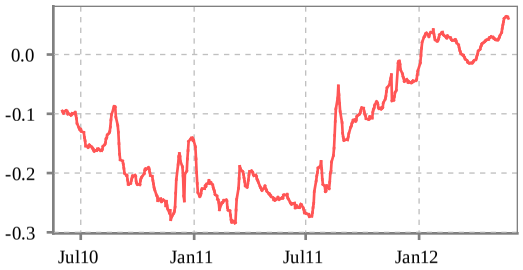
1Yx30Y



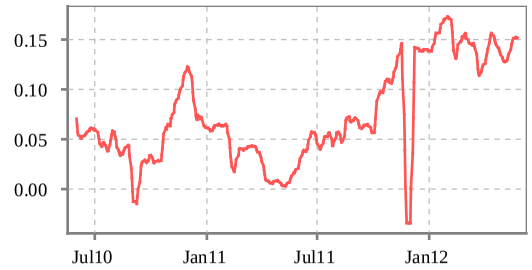
3Yx5Y

3Yx10Y

3Yx30Y



5Yx5Y



5Yx10Y

5Yx30Y

Mispricing on bermudan receiver swaptions defined as sum of the Canary CTD mispricing and the market correlation mispricing. In bermudan volatility terms; bp/day. See "Bermudan Swaptions - A relative value framework" for details.

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