CONVEXITY AND EMPIRICAL OPTION COSTS OF MORTGAGE SECURITIES

DOUGLAS T. BREEDEN

The option to prepay is the main focus of researchers in mortgage securities, as it is extremely important for both hedging and valuation. The first-order effect of prepayments is to shorten the lives of mortgages, thereby reducing their effective durations and price elasticities with respect to interest rates.

While researchers at major brokerage houses differ significantly in forecasting the effective durations of various fixed-rate mortgage coupons, on average their forecasts for standard fixed-rate mortgages are closely related to subsequent empirical durations (see Breeden [1994]). Their forecasts of effective durations for interest-only strips by contrast vary hugely, and are highly inaccurate forecasts of subsequent price elasticities. The risks of interest-only strips are extremely difficult to forecast, despite the major talent and resources that investment banks have devoted to research on mortgage securities. Errors in these risk estimates may have contributed to the many well-publicized losses in derivative mortgage securities in 1992-1995.

This article examines the second-order effect of prepayments on mortgage risk, i.e., the cost of the "negative convexity" of mortgages (see Diller [1987]). This is the asymmetry in mortgage returns; losses are larger for rate increases than the gains are for corresponding decreases in rates, due to the borrowers' use of the prepayment option adverse to the mortgage investor's interests. For hedgers of interest rate risk (which includes most of the investment banks and major players in the market), the first-order duration risk is routinely hedged, which makes this second-order convexity risk really of the first order with regard to

DOUGLAS T. BREEDEN is chairman of the board of Smith Breeden Associates, and research professor of finance at the Fuqua School of Business at Duke University in Chapel Hill, North Carolina.

movements in hedged profits.

Mortgage derivatives such as interest-only strips (IOs) and principal-only strips (POs) may have positive or negative convexity and positive or negative skewness of returns, depending upon the level of interest rates. Thus, the option risk adjustment may reverse sign and reflect an option benefit, making the certainty equivalent yield greater than the yield of the base case. The option risk adjustment may also be very large and, indeed, overwhelm the duration risk adjustment.

For example, in 1993 some interest-only strips had estimated option benefits of positive convexity that were estimated to be worth as much as 1,000 basis points, which was a very large portion of their projected risk-adjusted spreads to Treasury. Also in 1993, other IO strips had option costs of *negative* convexity of 1,000 basis points, as estimated by one broker.

The expected patterns of option costs and option-adjusted durations for IO and PO strips are considerably more complex and interesting than for whole MBS, as is shown by work of Roll [1986] and Asay and Sears [1988]. For this reason, we focus on brokers' forecasts of option costs for IOs, as they illustrate the differences most vividly. We also empirically estimate the option costs using a dynamic hedging strategy and compare these estimates to brokers' forecasts. Following the analysis of IO convexity option costs is a similar analysis for conventional (whole) fixed-rate mortgage-backed securities.

Section I gives an overview of the cross-sectional diversity and time series behavior of brokers' forecasts of option costs, option-adjusted durations, and option-adjusted spreads for mortgage securities. Section II reviews the theory of pricing and expected patterns of risk for interest- and principal-only strips, as well as for whole mortgages. Section III presents the empirical data for IO price behavior and empirical durations and compares the data to the predictions of theory, as well as to the brokers' forecasts.

Section IV presents estimates for the scale and pattern of empirical option costs for IOs. The estimates are from a dynamic hedging strategy based upon brokers' forecasts of durations. These empirical option costs are then compared to the brokers' forecasts of option costs.

Section V briefly shows similar results for standard (whole, principal, and interest) FNMA mortgage-backed securities. Section VI concludes with a few remarks on the results and future work.

I. OVERVIEW OF MORTGAGE ENVIRONMENT AND BROKERS' FORECASTS

Exhibit 1 shows the roller coaster ride in FNMA 9% IO prices for 1991-1996. Prices dropped by over 50% from 1991 to 1993, as rates dropped sharply and prepayments surged. IO prices then doubled to near their original levels in 1994, as rates increased by 260 basis points. Prices fell again in 1995 by over 30%, and then rose in 1996 by 25% (through July), mirroring moves in interest rates.

Exhibit 2 shows corresponding movements in prices for principal-only strips, which also moved dramatically, but opposite to IO strip prices, as expected.

Prices of both IO and PO strips are closely related to mortgage prepayments, which are closely related to interest rates. Exhibit 3 shows the movements in the prepayment rate on the conventional mortgage coupon (with over $1 billion outstanding) with the highest prepayment rate, which is usually a coupon rate 100 to 300 basis points over the current par mortgage rate.

In this chart, four unprecedented surges in prepayment rates are seen in 1992-1993, as they rise from 30% in 1991 to a peak of 70% annualized paydowns in late 1993. Then follows a huge plunge in prepayments in 1994 to a 15% maximum, responding to a 260-basis point increase in mortgage rates.

In 1995 and 1996, prepayment rates mirrored

EXHIBIT 1 ■ FNMA 9% Interest-Only Prices: 1991-1996

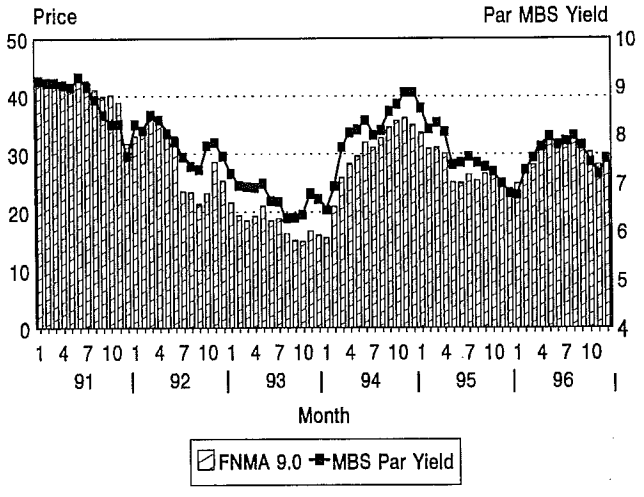


EXHIBIT 2 ■ FNMA 9% Principal-Only Prices: 1991-1996

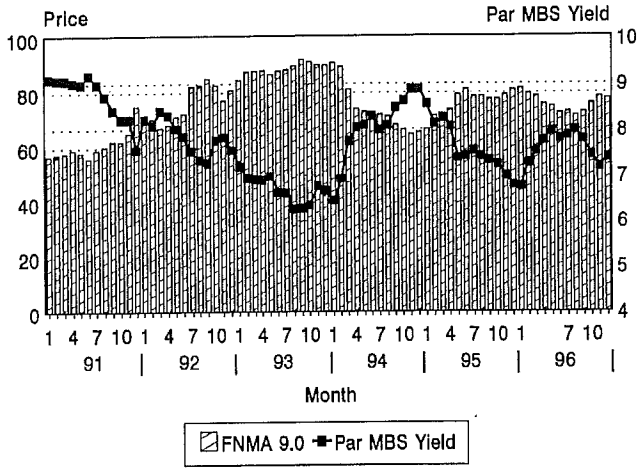
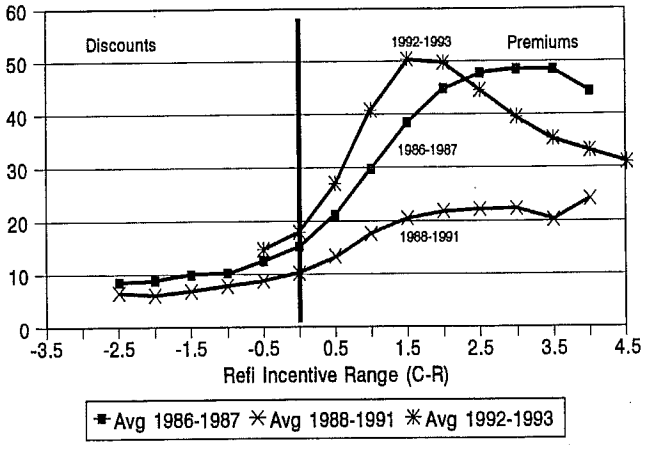


EXHIBIT 4 ■ Empirical Data for FHLMC and FNMA ■ Prepayments Sorted by Refinancing Incentive (C – R)



mortgage rate movements, increasing sharply in 1995 and early 1996 to 40% annualized prepayments, before falling back to a 25% pace in mid-1996.

Exhibit 4 shows some of the differences in the prepayment response curves of the 1992-1993 epoch, vis-à-vis the 1986-1987 and 1988-1991 epochs. Technological change, program rules changes, consumer learning, and a pronounced media effect have led to great non-stationarities in the mortgage prepayment function. This is what makes the valuation and forecasting of risk problems so difficult for mortgage researchers.

The workhorse model for researchers in mortgages has been estimation of "option-adjusted spreads" (OAS) to Treasury or to LIBOR and selection of securities for purchase that have wide OAS. Although in recent years there have been criticisms of OAS models, as well as some improvements in focusing on projected total returns, OAS models continue to prevail.

A typical OAS analysis starts with a prepayment model to simulate the mortgage's cash flows under a wide variety of interest rate paths. From these cash flows, an internal rate of return is estimated, which is then risk-adjusted based upon the interest rate sensitivity (effective duration or price elasticity) and upon the prepayment option risk (negative or positive convexity).

Exhibit 5 shows the quarterly time series of the

EXHIBIT 3 ■ Mortgage Prepayments: 1991-1996

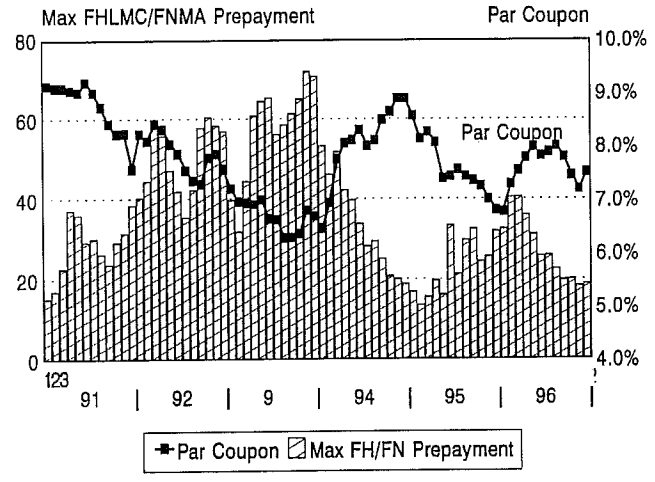


EXHIBIT 5 ■ Median Broker Forecasts Interest-Only Strips: Option-Adjusted Spreads ■ End of Quarter: December 1990-June 1996

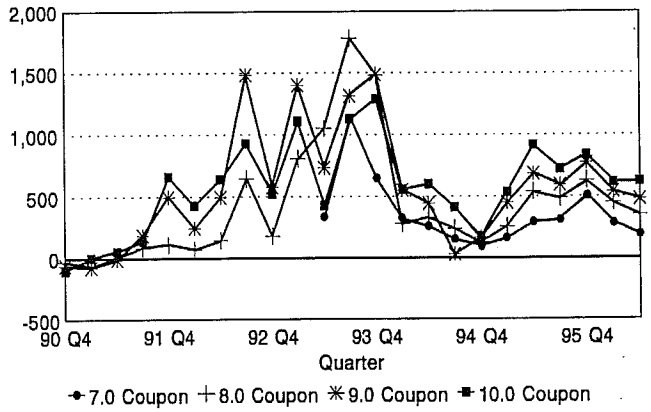
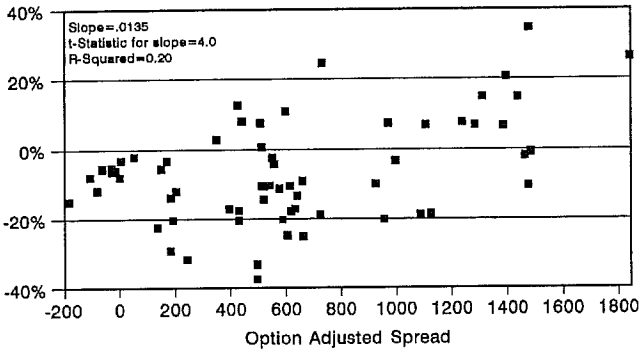


EXHIBIT 6 ■ Median Broker Forecasts ■ Interest-Only Strips: Broker OAS versus Hedged Returns



median broker's forecasts of option-adjusted spreads for IO strips with coupons of 7% to 10%. In late 1990, OAS were negative. Then as prices of IOs fell sharply from 1991 to 1993, OAS surged to as much as 1,500 basis points (over Treasury rates).

Exhibit 6 shows that the brokers' forecasts of OAS were very useful in predicting the subsequent quarter's hedged excess returns on IOs. The relatively low OAS (at least in hindsight) that brokers forecasted for IOs in 1990 and 1991 were followed by very negative hedged returns in 1992 and 1993. In contrast, the very high OAS that brokers forecasted in 1992 and 1993 were followed by outstanding hedged performance of IOs in 1994 and 1995.

Unfortunately, while the OAS valuation results are very good on IOs for the brokers' researchers, the duration estimation and hedge precision results are not so comforting. (These results are opposite from those for whole fixed-rate mortgages, which have good duration estimation, but poor OAS correlation with hedged returns, as Breeden [1994] shows.)

Exhibit 7A shows the various investment bankers' published forecasts of option-adjusted durations at (or near) the ends of years from 1991 to 1995 and at mid-year 1996. For portfolio managers, the spread in risk estimates is not comforting. In many cases, one broker's estimate of an IO's duration will be a multiple of another broker's forecast, and occasionally they even are of the opposite sign (1991, 1993).

We can see the difficulty that brokers had in forecasting IO durations by examining Exhibit 7B, which shows the option-adjusted durations forecasted by one broker for 8%, 9%, and 10.5% IOs. Major revisions to the model are apparent in both April 1993 and December 1993, as forecasts of durations of 8% IOs flipped from negative fifteen years to positive three years and back to negative twelve years, without corresponding interest rate movements.

This illustrates what traders call "model whipsaw" as researchers almost everywhere frequently changed their models as the unprecedented prepayment waves came in. Also, it should be noted that some brokers have other estimates that they publish for the best recommended hedges, which may be based more on empirical durations than on option-adjusted durations from computer models.

Exhibit 8 shows that brokers' estimates of the durations of IOs were significantly smaller in absolute value than were the empirical durations measured. Brokers' duration estimates averaged about negative fifteen years, while empirical durations averaged negative twenty-five to negative thirty years in the 1992-1994 period — a substantial difference. As Exhibit 9 shows, however, brokers' option-adjusted duration forecasts were useful predictors of realized durations (but statistically biased toward zero), as there is a significant correlation of the sizes of the forecasts with the sizes of realized durations.

In this article, the focus is on the "option cost" that is subtracted in risk-adjusting the mortgage's projected return for its negative convexity, which is due to the borrower's prepayment option. Even if an OAS approach is not used, all pricing models in mortgages must reflect these option features and, implicitly if not explicitly, adjust for the value of the negative convexity or negative skewness in normal mortgage returns. This article addresses whether or not the scale and pattern (both cross-sectional and time series) of option cost estimates make theoretical sense and are validated by the empirical data.

Empirical estimates of option costs ("whipsaw costs") for MBS using a dynamic hedging strategy are presented in Breeden [1991] for 1982-1990, using monthly data. The much more volatile dynamic option hedging costs for stripped securities are not examined. Also, the series of actual brokers' forecasts of durations is not used in those earlier estimates of dynamic option hedging costs, as they are here.

Exhibit 10 shows brokers' forecasts of option costs and OAS for IO strips at year-end 1991-1995 and mid-year 1996. Positive numbers indicate option costs (due to negative convexity), and negative numbers indicate option benefits (due to positive convexity).

EXHIBIT 7A ■ Broker Forecasts ■ Interest-Only Strip Option-Adjusted Durations

	December 31, 1991 (Par Yield = 7.55)					December 31, 1994 (Par Yield = 8.88)				
	#1 Goldman	#2 Prudential	#3 J.P. Morgan	#5 BS	#6 DLJ	#1 Goldman	#3 J.P. Morgan	#4 Salomon	#5 BS	#6 DLJ
6.5						1.3			(1.5)	1.9
7.0						(0.4)	(1.9)		(2.7)	0.8
7.5						(1.7)	(3.8)		(4.3)	(0.8)
8.0	(6.4)	(3.7)	(6.1)			(2.6)	(6.1)		(6.0)	(3.1)
8.5	(9.5)	(8.6)	8.9			(2.9)	(7.7)			(2.7)
9.0	(16.8)	(16.8)	12.1			(4.2)	(8.9)		(6.7)	(6.3)
9.5	(22.0)	(16.9)	12.8			(4.9)	(10.0)		(5.6)	(9.9)
10.0	(24.0)	(12.1)	12.1			(4.5)	(11.8)		(5.8)	(15.4)
10.5		(5.7)	(9.6)				(12.9)		(8.2)	

	December 31, 1992 (Par Yield = 7.55)					December 31, 1995 (Par Yield = 6.79)				
	#1 Goldman	#2 Prudential	#3 J.P. Morgan	#5 BS	#6 DLJ	#1 Goldman	#3 J.P. Morgan	#4 Salomon	#5 BS	#6 DLJ
6.5						(6.1)		(17.2)	(16.1)	(5.0)
7.0						(14.9)		(28.1)	(22.0)	(12.2)
7.5						(25.0)		(40.5)	(28.9)	(21.5)
8.0	(4.0)	(8.1)	(9.0)			(33.9)		(37.7)	(34.5)	(40.8)
8.5	(7.4)	(12.4)	(15.0)	(7.3)		(23.4)		(22.3)	(25.1)	(61.2)
9.0	(17.3)	(14.7)	(18.0)	(7.6)		(19.4)		(17.9)	(13.7)	(12.6)
9.5	(22.8)	(12.5)	(17.0)	(8.8)		(14.5)		(15.4)	(9.0)	(10.9)
10.0	(28.3)	(8.6)	(12.0)	(9.0)		(10.7)		(13.2)	(7.4)	(11.8)
10.5		(5.9)	(8.0)	(12.4)				(12.6)	(8.5)	

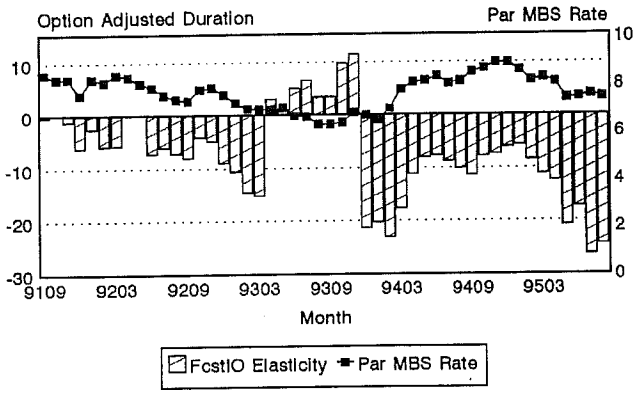
	December 31, 1993 (Par Yield = 6.67)					June 30, 1996 (Par Yield = 7.80)				
	#1 Goldman	#2 Prudential	#3 J.P. Morgan	#5 BS	#6 DLJ	#1 Goldman	#3 J.P. Morgan	#4 Salomon	#5 BS	#6 DLJ
6.5					(13.3)	1.3			(1.5)	1.9
7.0	(22.4)	(17.0)	8.5		(16.5)	(0.4)		(1.9)	(2.7)	0.8
7.5	(34.6)	(27.8)	9.8		(26.8)	(1.7)		(3.8)	(4.3)	(0.8)
8.0	(41.6)	(32.4)	11.5		(31.3)	(2.6)		(6.1)	(6.0)	(3.1)
8.5	(11.3)	(17.4)	3.8		(26.7)	(2.9)		(7.7)		(2.7)
9.0	(5.8)	(14.1)	(5.1)	(12.4)	(24.2)	(4.2)		(8.9)	(6.7)	(6.3)
9.5	(5.6)	(11.0)	(5.1)	(12.5)	(24.7)	(4.9)		(10.0)	(5.6)	(9.9)
10.0	(4.1)	(6.1)	(0.6)	(12.1)	(24.5)	(4.5)		(11.8)	(5.8)	(15.4)
10.5			4.7	(14.8)				(12.9)	(8.2)	

There are several interesting points to be seen in this table. First, the general scale of the option cost is quite large in absolute value, and is of the same order of magnitude as the OAS. Second, brokers differ significantly in their forecasts of IO option costs. For example, as of December 31, 1991, Goldman Sachs forecasted option costs of −169 and −1,153 for 8% and 10% IOs, respectively, while J.P. Morgan forecasted +766 and −366 basis points of cost for those same coupons. They don't even agree whether these IOs have positive or negative convexities!

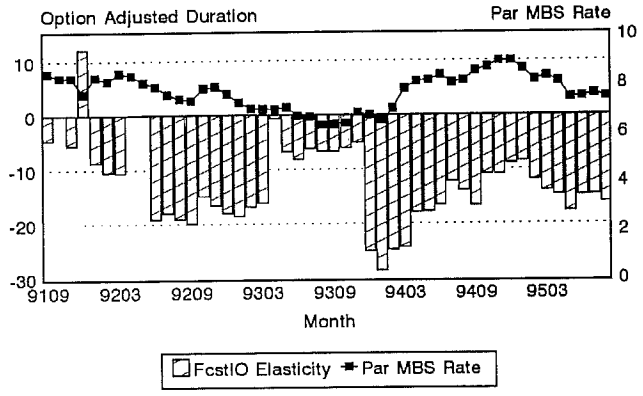
As we'll see in Section II, given the form expected for the option cost function, this is not quite as surprising and implausible as it seems, although it is unusual and causes legitimate concerns among portfolio managers.

Despite their differences, both Goldman Sachs and J.P. Morgan found the 10% IOs to have about 1,000

EXHIBIT 7B ■ J.P. Morgan, 8.0% Interest-Only Option-Adjusted Duration ■ Monthly September 1991-August 1995



J.P. Morgan, 9.0% Interest-Only Option-Adjusted Duration ■ Monthly September 1991-August 1995



J.P. Morgan, 10.5% Interest-Only Option-Adjusted Duration ■ Monthly September 1991-August 1995

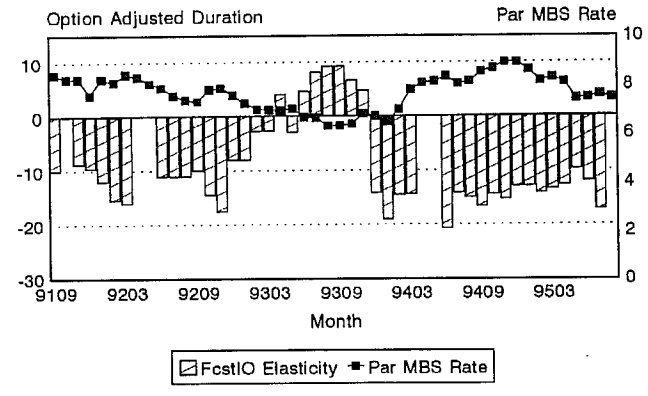
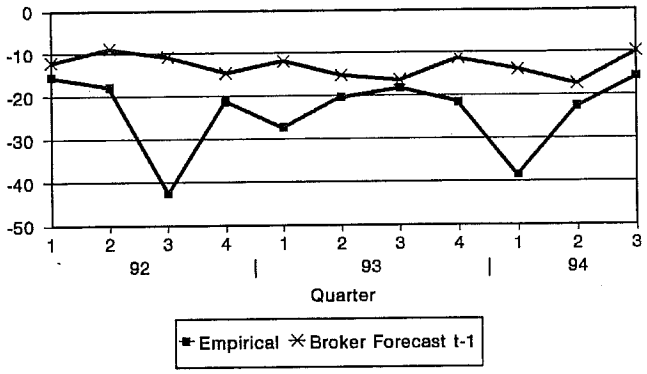


EXHIBIT 8 ■ FNMA Interest-Only Strips: Average 8%-10% ■ Empirical Durations versus Median Broker Forecasts



bp of better convexity than did the 8s. Prudential, however, projected +19 bp and –202 bp of option cost for the 8s and 10s, respectively, for an option cost advantage to the 10s of only 221 bp. Thus, there are wide differences in brokers' views on the general magnitudes and coupon structures of IOs' option costs.

Exhibits 11A, 11B, 11C, and 11D show four brokers' estimates of option costs for IO coupons of 7%, 8%, 9%, and 10%. Scanning these charts, we do see a generally positive correlation of brokers' estimates of option costs and benefits for IOs (8s generally positive, 10s negative in 1991-1993) , but there are still very wide differences for the brokers cross-sectionally, as well as through time.

Prepayment and valuation model revisions have

EXHIBIT 9 ■ FNMA Interest-Only Strips ■ Empirical Durations versus Median Broker Forecasts

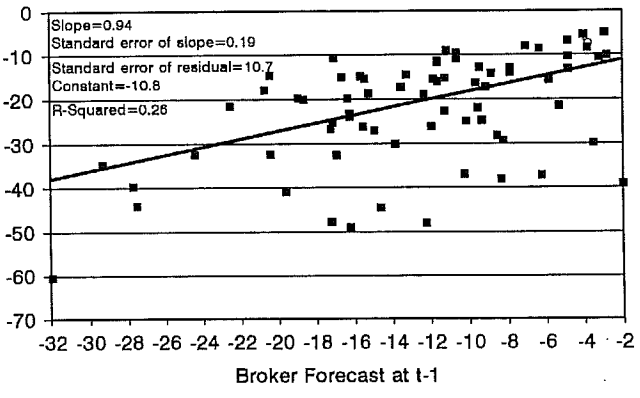


EXHIBIT 10 ■ Broker Forecasts ■ Option Costs and OAS for Interest-Only Strips

December 31, 1991 (MBS Par Yield = 7.55%)
FH/FN Max Prep = 38%)

	Estimated Option Cost (Benefit)			Estimated OAS		
	#1	#2	#3	#1	#2	#3
	GS	Pru	J.P.	GS	Pru	J.P.
8.0	(169)	19	766	110	116	35
8.5	(344)	(36)	1,104	469	191	365
9.0	(776)	(139)	301	568	(2)	496
9.5	(933)	(198)	128	691	43	634
10.0	(1,153)	(202)	(366)	661	49	904
10.5		(219)	(671)		226	1,004

December 31, 1992 (MBS Par Yield = 7.55%)
FH/FN Max Prep = 57%)

	Estimated Option Cost (Benefit)			Estimated OAS		
	#1	#2	#3	#1	#2	#3
	GS	Pru	J.P.	GS	Pru	J.P.
8.0	120	192	840	623	179	(65)
8.5	163	47	551	968	370	500
9.0	280	(41)	(116)	982	295	717
9.5	335	(70)	(970)	931	372	693
10.0	366	(76)	(1,174)	684	454	426
10.5		(123)	(631)		988	128

December 31, 1993 (MBS Par Yield = 6.67%)
FH/FN Max Prep = 70%)

	Estimated Option Cost (Benefit)			Estimated OAS		
	#1	#2	#3	#1	#2	#3
	GS	Pru	J.P.	GS	Pru	J.P.
8.0	322	93	965	529	1,555	1,400
8.5	(84)	41	390	1,093	2,487	1,233
9.0	(106)	35	(324)	1,482	2,343	760
9.5	(168)	12	(302)	1,420	1,747	769
10.0	(215)	25	(233)	1,286	1,931	808
10.5			210			1,042

occurred at all mortgage research firms during this volatile period, dramatically affecting a research group's option cost estimates. Exhibits 12A and 12B show the option cost estimates of Goldman, Sachs, which is acknowledged by most researchers as one of the leaders in mortgage research, particularly on IOs and POs.

Without having been privy to model changes, we can see that the discontinuities in option cost estimates for both 8.5% and 9.5% coupons (and others not shown) clearly indicate a model revision implemented

EXHIBIT 10 ■ Continued

December 31, 1994 (MBS Par Yield = 8.88%)
FH/FN Max Prep = 19%)

	Estimated Option Cost (Benefit)		Estimated OAS	
	#1	#3	#1	#3
	Goldman	J.P. Morgan	Goldman	J.P. Morgan
6.5	46		46	
7.0	70	334	70	(17)
7.5	100	430	100	(16)
8.0	141	560	141	(52)
8.5	127	603	127	27
9.0	182	589	182	98
9.5	195	574	192	184
10.0	153	475	153	140
10.5		271		129

December 31, 1995 (MBS Par Yield = 6.79%
FH/FN Max Prep = 32%)

	Estimated Option Cost (Benefit)		Estimated OAS	
	#1	#4	#1	#4
	Goldman	Salomon	Goldman	Salomon
6.5	178	242	423	297
7.0	384	444	611	415
7.5	616	628	668	481
8.0	682	254	680	583
8.5	401	68	833	683
9.0	244	52	752	504
9.5	171	59	848	661
10.0	121	82	1,088	724
10.5		104		922

June 30, 1996 (MBS Par Yield = 7.80%)
FH/FN Max Prep = 26%)

	Estimated Option Cost (Benefit)		Estimated OAS	
	#1	#4	#1	#4
	Goldman	Salomon	Goldman	Salomon
6.5	69	108	135	62
7.0	126	139	189	129
7.5	191	189	239	220
8.0	260	260	376	310
8.5	251	291	432	407
9.0	250	205	478	304
9.5	157	98	511	349
10.0	114	43	622	371
10.5		20		462

EXHIBIT 11A ■ Four Brokers: 7.0% Interest-Only Option Costs ■ Monthly April 1991-June 1996

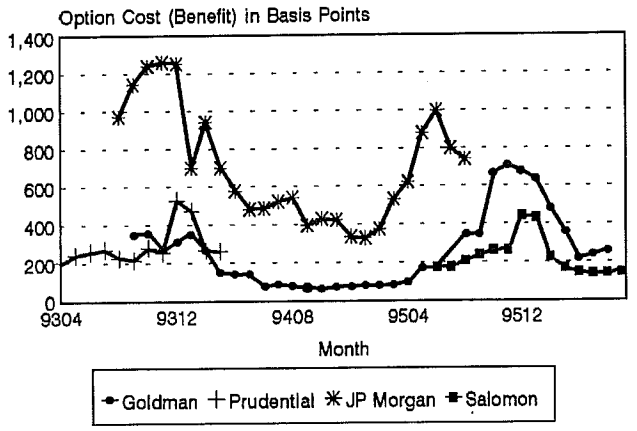
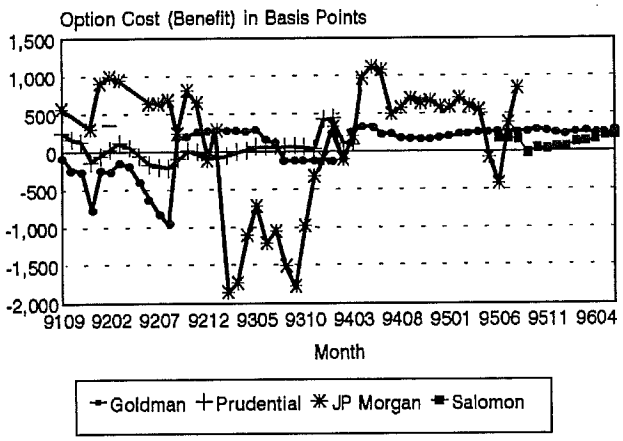


EXHIBIT 11C ■ Four Brokers: 9.0% Interest-Only Option Costs ■ Monthly September 1991-June 1996



in August 1992. For the 9.5s, an option cost (benefit) estimate of over −1,000 basis points in July 1992 turns into an estimate of option cost of over +200 basis points the next month, with relatively little intervening movement in interest rates. These model revisions were common at many firms, as researchers dealt with non-stationarities, non-linearities, and prepayment movements never seen before.

Our main point is to show that analysis of these mortgage derivatives is not easy, and that there are many interesting questions to examine.

1. From finance theory, what do we expect to be the scale and pattern across coupons of durations and option costs for IOs?
2. How can we empirically estimate durations and option costs, and how do the results of those estimates conform to the theory?
3. Do the forecasts of the brokers' research groups conform to either the theory or the data?

II. REVIEW OF THEORETICAL PREDICTIONS OF RISKS IN INTEREST-ONLY STRIPS

The theory on durations and option risks for IOs precedes all the empirical data examined, so if it explains much of what we subsequently observed in

EXHIBIT 11B ■ Four Brokers: 8.0% Interest-Only Option Costs ■ Monthly September 1991-June 1996

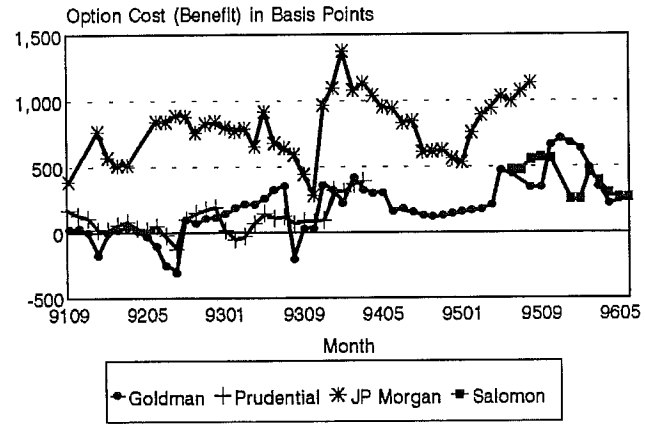


EXHIBIT 11D ■ Four Brokers: 10.0% Interest-Only Option Costs ■ Monthly September 1991-June 1996

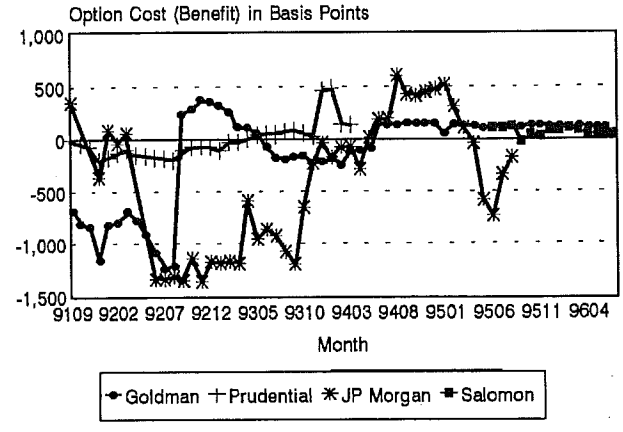


EXHIBIT 12A ■ Goldman Sachs, 7.5% Interest-Only Option Costs ■ Monthly September 1993-June 1996

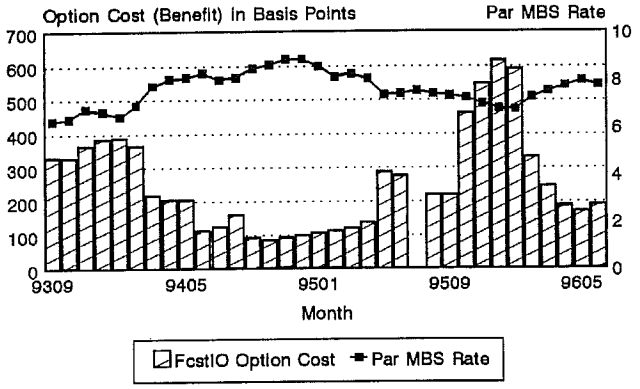


EXHIBIT 12B ■ Goldman Sachs, 8.5% Interest-Only Option Costs ■ Monthly September 1991-June 1996

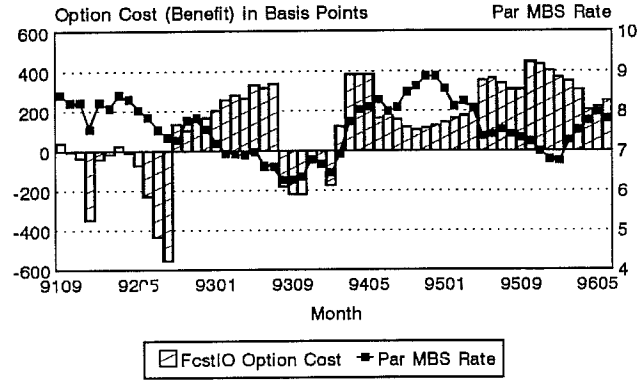
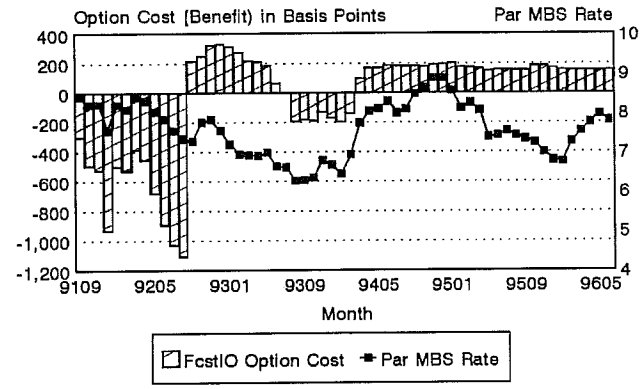


EXHIBIT 12C ■ Goldman Sachs, 9.5% Interest-Only Option Costs ■ Monthly September 1991-June 1996



this volatile period, it is a nice victory for the theorists and, indeed, shows the power of theory (much as Fischer Black believed and implemented).

Richard Roll produced the major pathbreaking work on stripped mortgage-backed securities in 1986, while working at Goldman, Sachs. His work was followed by fine work by his colleagues, Michael Asay and Timothy Sears [1988]. As all the data examined in this article come from the 1988-1996 period, their theoretical work clearly precedes all the empirical results. What is described in subsequent sections is impressive support for their theory.

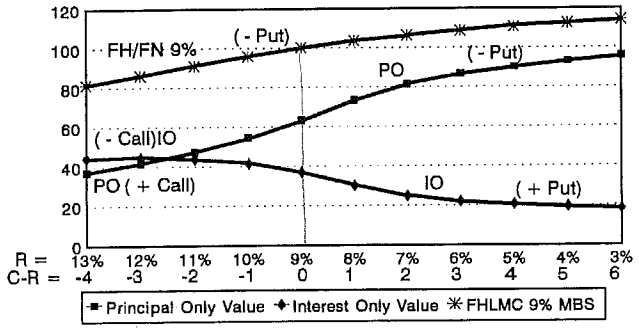
An illustration of a prepayment function and pricing for a FNMA 9% fixed-rate mortgage and its interest-only and principal-only strips is in Exhibit 13. For research on mortgage prepayment functions, see Richard and Roll [1988], Patruno [1994], and Hayre [1994]. Valuations for the mortgage, the IO, and the PO are normally achieved with a Monte Carlo model, as is common in mortgage research, building on the approach of Black, Derman, and Toy [1990].

Exhibit 14 graphs the prices of these securities for par mortgage rates from 3% to 13% and indicates the option-like payoffs that these investments have at different interest rate levels. At very low interest rates, when prepayments are near their peak level on their S-curve, for example, an IO sells for a very low price, but has a favorable asymmetric return pattern (positive convexity). At that low price, the IO has little to lose (as prepays are near their peak and unlikely to increase

EXHIBIT 13 ■ FHLMC/FNMA 9% Illustration ■ Interest-Only and Principal-Only Strip Values

Current-Coupon Mortgage Rate (%)	Coupon – Refi Rate (%)	Assumed Prepay Rate (%)	Principal-Only Value	Interest-Only Value	FHLMC 9% MBS
3.00	6	37.4	95.83	18.21	114.0
4.00	5	35.1	93.16	19.36	112.5
5.00	4	33.4	90.16	20.52	110.6
6.00	3	32.2	86.59	22.03	108.6
7.00	2	30.0	81.51	24.88	106.3
8.00	1	20.5	73.52	30.19	103.7
9.00	0	9.0	63.20	37.00	100.2
10.00	–1	6.3	54.42	41.35	95.77
11.00	–2	5.3	47.32	43.66	90.98
12.00	–3	4.8	41.68	44.50	86.18
13.00	–4	4.4	37.15	44.43	81.58

EXHIBIT 14 ■ FHLMC/FNMA 9% MBS Illustration Prices of Interest-Only and Principal-Only Strips



much more with lower rates), but much to gain (as prepays will fall dramatically if rates increase).

Thus, at very low interest rates the IO has a limited downside in price, but a substantial potential upside if rates increase, very much like a put option on bond prices. Corresponding to this, at low rates the IO has a substantial option benefit of positive convexity, rather than an option cost of negative convexity, as a normal MBS has.

At very high interest rates, the situation is reversed for the IO, in that prepayment rates are then extremely low (near their minimum on their S-curve), and IO prices are quite high, but have limited upside for rate increases, and a very substantial downside if rates drop. At high rates, the payoff pattern for the IO resembles having written a call option on bond prices, in that, if rates increase and bond prices decline, the position has small gains, but if rates decline and bond prices increase, the position has large losses (as the call is in the money). Thus, at high rates the IO has negative convexity and a substantial option cost.

It is important to note that the effective duration of an IO can actually change signs (to be positive, i.e., bond-like) both at very high and very low interest rates. At very low rates, as prepayments peak out quickly, additional drops in rates might not accelerate prepayments, but will benefit the IO by a lower discount rate for its cash flows (a standard positive duration effect). Similarly, at very high rates, when prepayment rates near their minimum levels, additional rate increases will not benefit the IO much with lower prepays, but will decrease the value of the IO as its cash flows are discounted at higher rates. Thus, while IOs usually have a large negative duration, their durations can become small negative and even positive at rates that are both very high and very low (as measured by the coupon minus refinancing rate (C – R) for the IO coupon).

Theoretical option-adjusted durations for interest-only and principal-only strips are illustrated in Exhibit 15. Note that coupons that are 100 to 200 basis points above the current refinancing rate should have the greatest negative duration, as they are on the cusp of the prepayment curve and have values most sensitive to interest rates. Both very high premiums (e.g., C – R = 4%) and discounts (C – R = –1% or –2%) have much lower durations (in absolute value), as their prepayments are at relatively flat segments of the prepayment curve — either near maximum prepayment levels or near minimum prepayment levels. Note that the IO duration curve is approximately V-shaped (we examine brokers' forecasts and empirical estimates for these in Section III).

Theoretical option costs for IOs and POs are illustrated in Exhibit 16. Note that IOs on discount mortgages have negative convexity and a projected positive option cost. In contrast, IOs on premium mortgages have positive convexity and therefore projected negative option costs, or option benefits. The crossover point from positive to negative option cost in this illustration is at a premium of 100 basis points, but bear in mind that this is related more to the prepayment function than it is to interest rates (Exhibit 4 showed the substantial shifts in the prepayment function over time).

Thus, without the benefit of seeing the future, it was entirely reasonable for some researchers to project positive option costs in 1991-1993, while others projected negative option costs for coupons that are slight premiums and near the (changing) cusp of the prepay-

EXHIBIT 15 ■ FHLMC/FNMA 9% MBS Illustration ■ Option-Adjusted Durations for Interest-Only and Principal-Only Strips

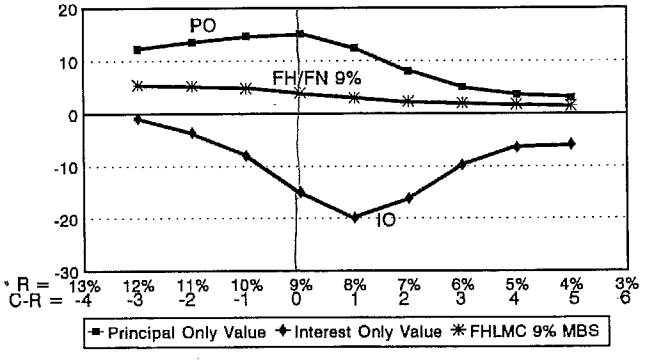
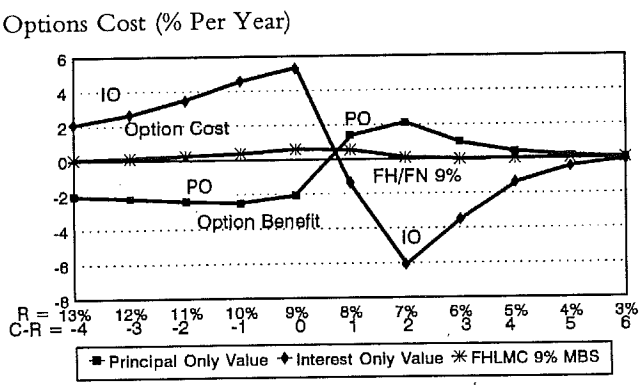


EXHIBIT 16 ■ FHLMC/FNMA 9% MBS Illustration ■ Whipsaw Option Costs for Interest-Only and Principal-Only Strips



ment function. Note that the shape of the projected option cost function is a bit like a "sine wave" located to cross from positive to negative. (We examine brokers' forecasts and empirical estimates of IOs' option costs in Section IV.)

III. EMPIRICAL IO PRICE AND DURATION FUNCTIONS

Prices of interest-only strips are expected to form an S-curve, with the steep slope located between par and refinancing rates where the coupon is 200 to 300 basis points over the refi rate, as that's where prepayments are most elastic with respect to interest rates. Exhibit 17 shows the IO strip price curves observed, using monthly data for 1987-1996 collected by Smith Breeden Associates from a variety of sources. While the lower coupons trace out only a segment of the price curve, due to their more recent existence, the 9s to 10.5s have data for the entire period, which traces out a greater range in the IO price function. Both the positive and negative convexities anticipated by the theory (Exhibit 14) are demonstrated in these observed price curves for the higher coupons.

Brokers' forecasts of IOs' option-adjusted durations were collected, and Exhibit 18 presents the medians of brokers' forecasts of those durations quarterly for 1991-1996. Empirical durations for IOs (or "price elasticities") are estimated by regressing five-day IO returns on five-day changes in the ten-year Treasury note rate, and they are in Exhibit 19. Exhibits 20 and 21 plot those values sorted by their "relative coupon," i.e., C – R = Coupon – Refinancing Rate. The V-shaped pattern

EXHIBIT 17 ■ Panel A. FNMA 7.5 Interest-Only Prices versus Rates ■ Monthly Data January 1994-July 1996

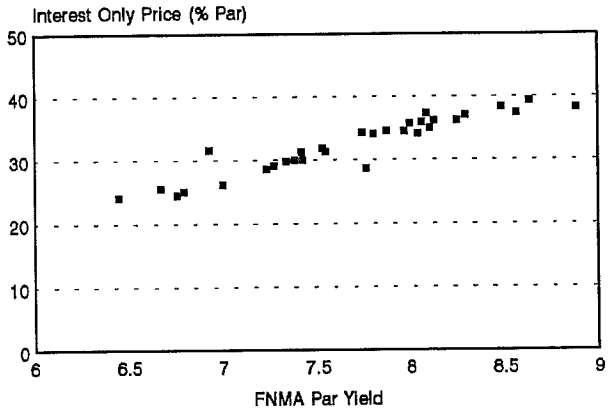


EXHIBIT 17 ■ Panel B. FNMA 8.5 Interest-Only Prices versus Rates ■ Monthly Data June 1992-July 1996

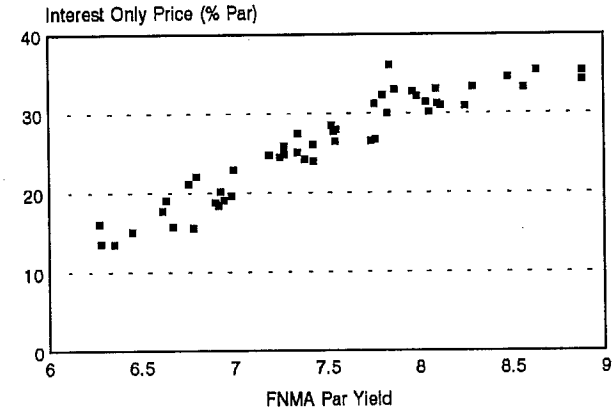


EXHIBIT 17 ■ Panel C. FNMA 9.0 Interest-Only Prices versus Rates ■ Monthly Data July 1987-July 1996

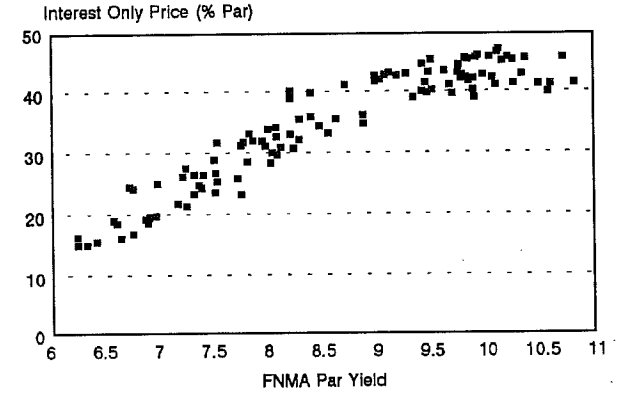


EXHIBIT 17 ■ Panel D. FNMA 9.5 Interest-Only Prices versus Rates ■ Monthly Data May 1987-June 1996

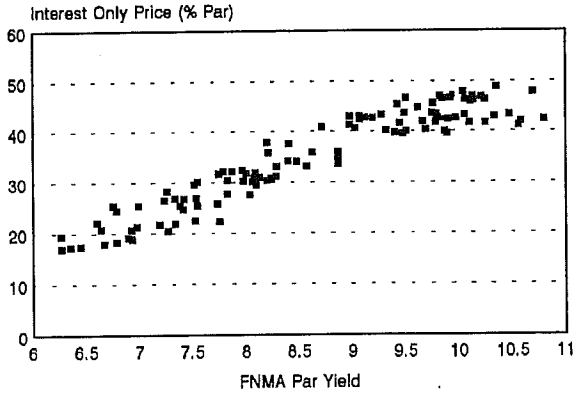


EXHIBIT 17 ■ Panel E. FNMA 10.0 Interest-Only Prices versus Rates ■ Monthly Data July 1987-July 1996

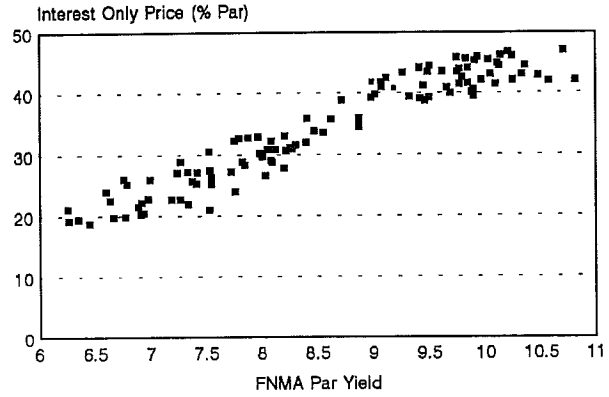
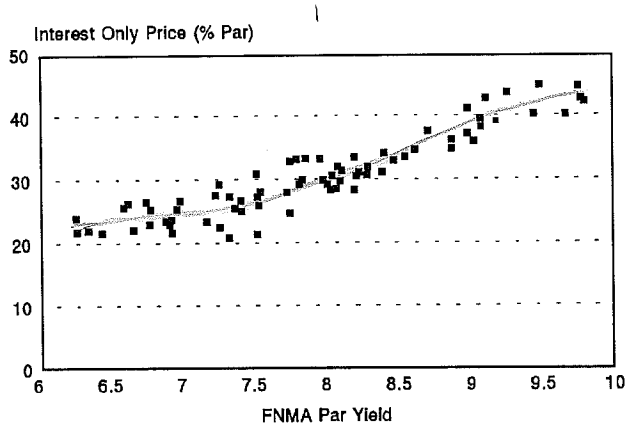


EXHIBIT 17 ■ Panel F. FNMA 10.5 Interest-Only Prices versus Rates ■ Monthly Data June 1990-July 1996



predicted by the theory is present in the scatter plot.

The V-shaped pattern for IO durations is much easier to see in Exhibits 22 and 23, which graph the mean IO durations for coupons that fall into different "C – R buckets." For example, the 0.5 bucket contains the average duration estimate or empirical for coupons with C – R between 0.25 and 0.75. Note that the largest predicted durations by the brokers are for coupons with C – R = 1% to 2%, which conforms to the theory's illustration in Exhibit 15. Similarly, the empirical durations are also highest for coupons in that cusp range. The major inconsistency is that the brokers' maximum median forecast of duration averages only about negative sixteen years, while the maximum empirical duration averages negative twenty-eight years.

It is intuitive from the V pattern of option-adjusted durations in Exhibits 22 and 23 to see how option costs and benefits are generated by dynamic hedging strategies for IOs. As IOs usually have negative durations, proper hedges will go long bond futures. For IOs on discount and near par securities, we are traveling along the left side of the pattern, meaning that as rates decrease, C – R increases and the IO duration increases in absolute value.

This means the long hedge will have to get longer by purchasing more bond futures when rates are lower and bond prices higher. Similarly, the hedge will sell futures as rates increase, i.e., when bond prices are low. This dynamic hedging strategy generates "whipsaw" losses due to negative convexity if rates move away from and then back to their starting point. This corresponds to the prediction that discount and current coupon IOs will have positive option costs.

For high-premium IOs (with C – R > 1.0), the dynamic hedging strategy is shifting according to the right side of the in Exhibits 22 and 23. For these, as rates decrease and C – R increases, the proper hedge becomes smaller. To accomplish this, bond futures are sold when rates decrease and bond prices increase. This dynamic hedging strategy generates "whipsaw gains" due to the positive convexity of the high-premium IOs. Thus, these IOs have an option benefit, as is discussed further in the next section.

IV. BROKER FORECASTS AND EMPIRICAL OPTION COSTS FOR IOs

Medians of brokers' forecasts for the option costs of interest-only strips are in Exhibit 24, with a time

EXHIBIT 18 ■ Interest-Only Strips ■ Median Broker Forecasts of Option-Adjusted Durations

End of Quarter	Par Yield FNMA	FN IO 6.5 249	FN IO 7.0 215	FN IO 7.5 218	FN IO 8.0 203/54	FN IO 8.5 7/24	FN IO 9.0 1/6	FN IO 9.5 4	FN IO 10.0 2	FN IO 10.5 50
4Q90	9.27				–1.3	-2.7	–5.7	–8.1	–11.7	–15.9
1Q91	9.08				–1.0	-2.5	–5.7	–8.2	–11.7	–14.1
2Q91	9.19				1.4	0.0	–2.9	–4.9	–7.3	–9.9
3Q91	8.41				–1.2	-3.0	–6.7	–9.6	–11.7	–10.4
4Q91	7.55				–6.1	-8.6	–16.8	–16.9	–12.1	–7.7
1Q92	8.40				–1.8	–3.8	–9.2	–13.3	–16.4	–12.0
2Q92	7.84				–3.3	–6.0	–12.0	–16.9	–16.0	–7.1
3Q92	7.27				–10.4	–16.0	–17.0	–15.3	–15.0	–7.6
4Q92	7.55				–8.1	–9.9	–16.0	–14.7	–11.0	–8.0
1Q93	6.92				–19.4	–18.4	–16.1	–11.4	–10.9	–2.7
2Q93	6.63		–12.2	–20.1	–24.2	–20.5	–15.4	–11.4	–10.4	–4.6
3Q93	6.28		–20.2	–27.5	–29.1	–9.1	–9.3	–5.6	–3.0	–3.6
4Q93	6.67		–16.7	–27.3	–31.8	–14.4	–10.0	–8.3	–5.1	–4.6
1Q94	7.74	–4.3	–6.8	–11.4	–20.2	–22.3	–18.7	–13.6	–11.7	–13.0
2Q94	8.29	–2.1	–2.6	–4.6	–7.6	–9.4	–11.6	–8.9	–11.0	–15.2
3Q94	8.48	2.2	0.2	–2.5	–4.1	–2.8	–5.0	–7.9	–10.5	–12.8
4Q94	8.88	1.6	–0.4	–1.7	–3.1	–2.9	–6.3	–9.9	–11.8	–12.9
1Q95	8.25	1.1	–1.1	–2.8	–6.6	–8.8	–12.1	–14.1	–14.5	–13.5
2Q95	7.42	–1.2	–5.3	–10.6	–17.3	–26.4	–14.8	–12.5	–11.8	–10.2
3Q95	7.34	–0.9	–3.9	–8.6	–17.2	–19.7	–14.8	–12.2	–11.6	–10.7
4Q95	6.79	–6.1	–14.9	–25.0	–37.7	–23.4	–17.9	–14.5	–11.8	–11.2
1Q96	7.53	–1.4	–4.5	–8.0	–12.5	–16.1	–13.3	–12.2	–11.1	–10.3
2Q96	7.80	–1.0	–3.3	–6.7	–11.6	–14.1	–8.0	–6.7	–7.2	–6.5

EXHIBIT 19 ■ Interest-Only Strips ■ Empirical Data for Option-Adjusted Durations

End of Quarter	Par Yield FNMA	FN IO 6.5 249	FN IO 7.0 215	FN IO 7.5 218	FN IO 8.0 203/54	FN IO 8.5 7/24	FN IO 9.0 1/6	FN IO 9.5 4	FN IO 10.0 2	FN IO 10.5	FN IO 10.5 50
1Q92	8.40				–8.6	–14.2	–10.7	–25.3	–18.9		
2Q92	7.84				–39.2	–5.5	–12.8	–17.3	–15.0		
3Q92	7.27				–30.0	–37.4	–48.2	–47.9	–49.1		
4Q92	7.55				–10.9	–24.0	–26.8	–26.3	–18.7	–13.0	
1Q93	6.92				–38.2	–25.0	–23.3	–27.1	–22.8	–29.4	
2Q93	6.63				–41.0	–20.1	–19.9	–11.7	–9.0	–5.0	
3Q93	6.28				–32.6	–17.9	–14.8	–16.0	–9.6	–6.8	
4Q93	6.67		–32.5	–39.7	–34.8	–24.8	–22.0	–15.6	–10.6	–8.4	
1Q94	7.74		–32.7	–44.2	–60.5	–44.6	–37.1	–28.3	–21.5	–13.2	
2Q94	8.29		–8.0	–11.4	–14.6	–21.6	–19.8	–30.2	–26.2	–14.5	
3Q94	8.48	–7.0	–10.1	–10.4	–14.0	–16.3	–15.5	–17.2	–15.2	–15.4	
4Q94	8.88		–12.2	–11.6	–11.3	–13.8	–13.5	–14.9	–15.3	–17.9	–16.8
1Q95	8.25		–5.5	–6.5	–6.1	–17.4	–16.8	–17.1	–16.0	–16.7	–15.8
2Q95	7.42		–8.4	–9.8	–11.7	–22.8	–21.0	–19.4	–19.5	–19.5	–17.7
3Q95	7.34		–15.1	–19.3	–29.6	–31.5	–25.3	–22.5	–21.0	–17.1	–15.5
4Q95	6.79		–21.0	–26.8	–26.0	–29.9	–27.7	–29.2	–25.9	–24.2	–22.2
1Q96	7.53		–19.8	–23.9	–24.0	–30.5	–20.1	–18.1	–17.6	–17.7	–16.3
2Q96	7.80		–21.2	–20.3	–20.2	–21.1	–24.0	–23.0	–22.9	–24.3	–23.1

EXHIBIT 20 ■ Interest-Only Strips: Quarterly by Coupon, 1991-1996 ■ Median Broker Option-Adjusted Duration Forecasts versus C – R

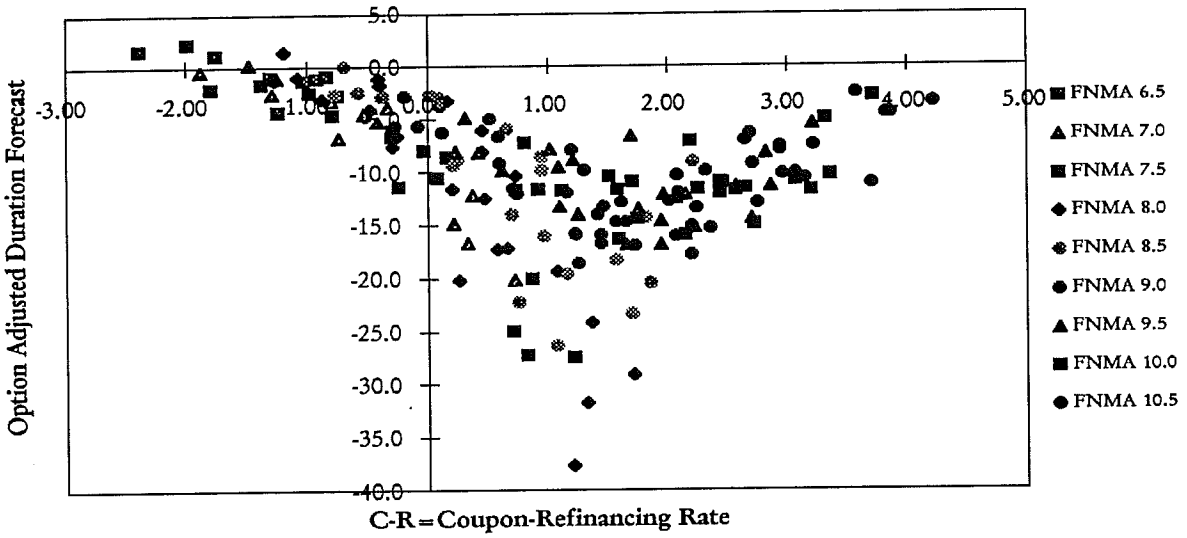
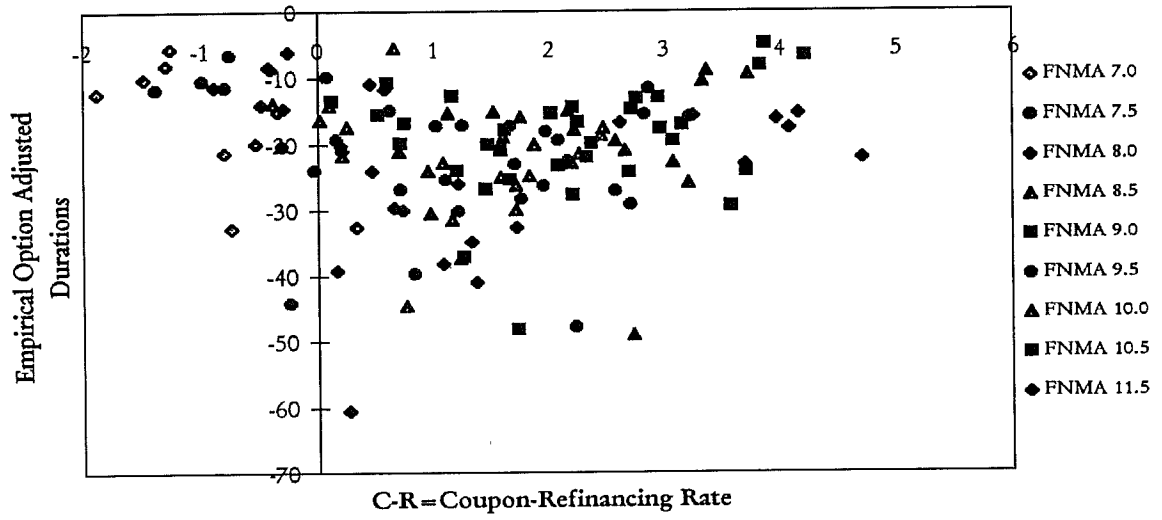


EXHIBIT 21 ■ Interest-Only Strips: Quarterly by Coupon, 1992-1996 ■ Empirical Option-Adjusted Durations versus C – R



series plot as Exhibit 25. A scatterplot of those data sorted by C – R is in Exhibit 26, and the means of the C – R buckets are in Exhibit 27. (In Exhibits 26 and 27, 3.00 represents 300 basis points.)

Note that the brokers' forecasts of option costs do have a rational pattern, according to the theory of Section II, in that they have the "sine wave" shape. Discount and small-premium IOs are predicted to have significant option costs, while higher-premium (C – R > 2) are predicted to have option benefits (positive convexity). This squares with the theory, although the brokers' crossover point appears to be at a slightly higher C – R than the illustration of Section II.

Empirical option creation costs are estimated as in Breeden [1991]. For 1991-1996, the median broker forecasts of durations are used quarterly to hedge IO returns with ten-year Treasury note futures, with durations changing quarterly. For 1988-1990, Smith Breeden's IO duration forecasts are used to estimate the IO option cost through the same dynamic hedging

EXHIBIT 22 ■ Median IO Duration Broker Forecasts versus Coupon – Refinancing Rate ■ Composite of FNMA 6.5-10.5 Coupons

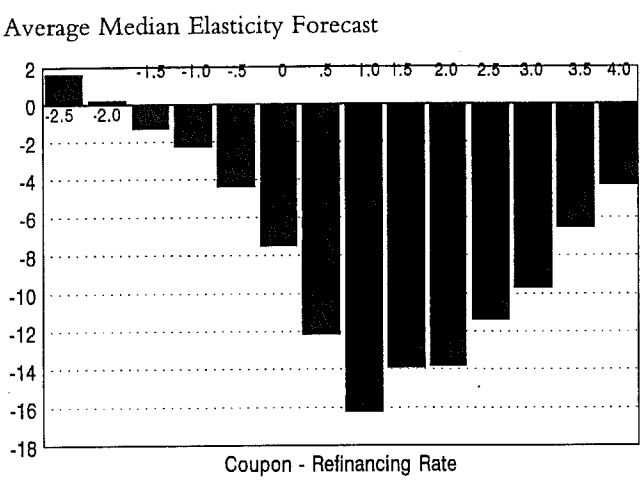
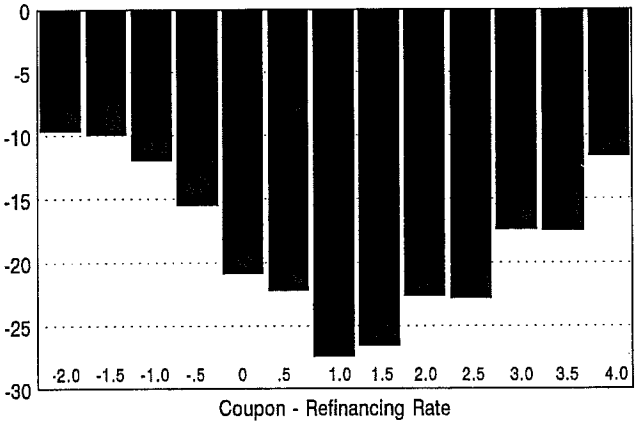


EXHIBIT 23 ■ Empirical Durations versus Coupon – Refinancing Rate for IOs ■ Average of FNMA 6.5-10.5 Coupons, Quarterly Estimates, 1991-1996



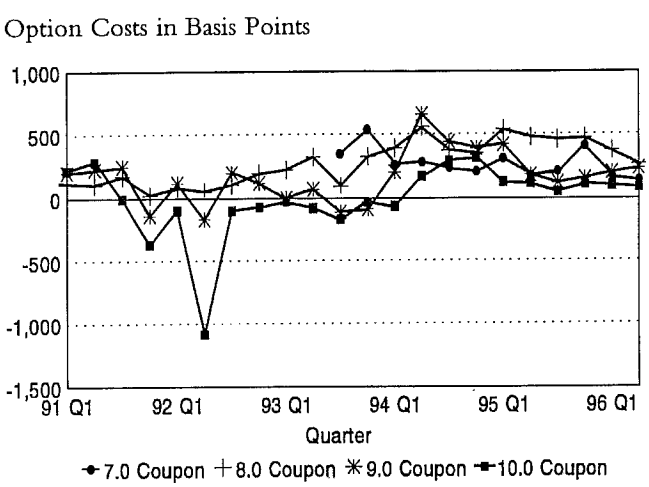
strategy. The return from the dynamic hedging strategy is then compared to the return that would have been earned if one had hedged with the ex post average duration forecasted.

Thus, if this were a normal mortgage with negative convexity, the dynamic strategy would do worse, due to the "whipsaw" that occurs with buying high and selling low to recreate the prepayment call option

EXHIBIT 24 ■ Median Broker Forecasts ■ Option Costs for Interest-Only Strips

End of Quarter	ParYld FNMA	# of Brokers	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5
1Q91	9.08	1				120	144	203	208	217	208
2Q91	9.19	2				106	154	227	267	285	300
3Q91	8.41	3				171	157	246	170	–8	–120
4Q91	7.55	3				19	–36	–139	–198	–366	–671
1Q92	8.40	3				83	84	114	–13	–100	–706
2Q92	7.84	3				49	–80	–169	–777	–1,086	–919
3Q92	7.27	3				101	132	195	218	–104	–542
4Q92	7.55	3				192	163	116	–70	–76	–375
1Q93	6.92	3				217	276	–4	–33	–31	–296
2Q93	6.63	3				322	62	64	40	–83	
3Q93	6.28	3		349	330	86	–218	–117	–179	–169	
4Q93	6.67	3		529	477	322	405	–93	–105	–38	
1Q94	7.74	3		260	433	389	381	198	97	–72	
2Q94	8.29	2		281	388	552	645	652	489	165	
3Q94	8.48	2		230	291	370	401	436	406	287	
4Q94	8.88	2		202	265	350	365	385	385	314	
1Q95	8.25	2		305	410	535	372	415	294	120	
2Q95	7.42	3		172	276	473	305	174	126	110	
3Q95	7.34	2	8	187	309	456	270	115	71	45	
4Q95	6.79	2	210	414	622	468	234	148	115	102	
1Q96	7.53	2	96	163	257	371	277	195	123	94	
2Q96	7.80	2	89	132	190	260	271	227	127	78	

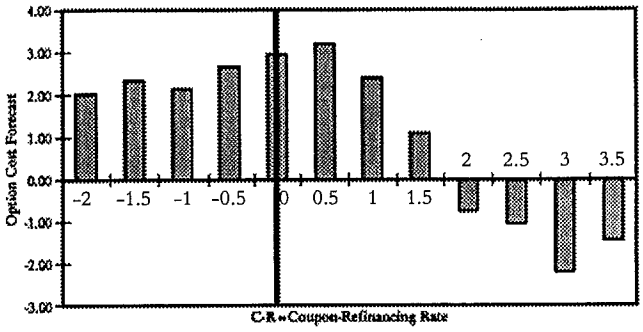
EXHIBIT 25 ■ Median Broker Forecasts Interest-Only Strips: Option Costs ■ End of Quarter: March 1991-June 1996



in the hedge. Of course, if the underlying instrument had positive convexity, the whipsaw option cost should be negative, i.e., an option benefit.

Exhibit 28 shows the numerical empirical option costs for IOs, where 12.93 represents 1,293 basis points. Exhibit 29 shows the scatterplot of these empirical option costs sorted by C – R, and Exhibit 30 shows the bucketed means. Note that the shape of the relationship is that predicted by the theory, and the crossover point from negative to positive convexity is

EXHIBIT 27 ■ Interest-Only Strips: Composite of FNMA 6.5-10.5, 1991-1996 ■ Median Broker Option Cost Forecasts versus C – R



similar to the brokers' forecasts. Thus, the theory, the brokers' forecasts, and the empirical data all have the same shape for the option costs.

The scale of the option cost is a remaining point of dispute, however. Exhibits 31 and 32 show the bucketed means for the option cost from Goldman Sachs and J.P. Morgan. Both have sensible shapes, in accord with the theory and the data. Note that the amplitudes of the option cost fluctuations differ considerably, as Goldman's are in a range of ±200 basis points, while J.P. Morgan's are in a range of ±800 basis points. From Exhibit 27, the median broker's forecast is in a range from –200 to +300 basis points. What are the empirical estimates?

From Exhibit 30, the empirical estimates of option costs range approximately from +600 basis

EXHIBIT 26 ■ Interest-Only Strips: Quarterly by Coupon, 1991-1996 ■ Median Broker Option Cost Forecasts versus C – R

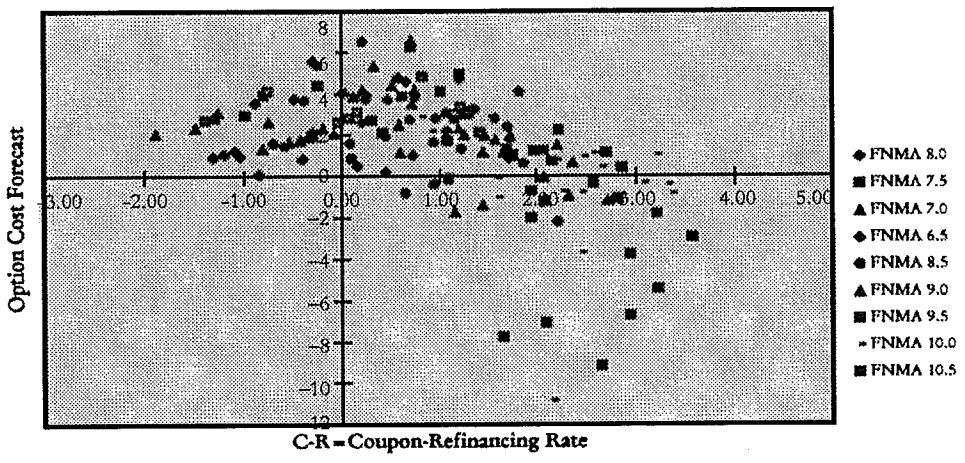


EXHIBIT 28 ■ Interest-Only Empirical Option Costs from Dynamic Hedging ■ Quarterly Median Broker Duration Adjustments

Year End	Par MBS Yield 8.82	TNote Volatility	TNote Rate	FNMA 7.0 T257	FNMA 7.5 T254	FNMA 8.0 T203	FNMA 8.5 T7	FNMA 9.0 T6	FNMA 9.5 T4	FNMA 10.0 T2	FNMA 10.5 T50
1987	10.19	4.2	0.63								
1988	10.56	4.5	–0.02			1.75	5.77	4.40			
1989	9.51	3.8	–1.15			5.10	–1.31	–4.07			
1990	9.33	3.5	0.12			2.64	3.00	3.26			
1991	7.59	2.7	–1.79			1.00	1.06	2.19	4.18		
1992	7.59	3.9	–0.63			7.27	1.07	–4.02	–1.49		
1993	6.72	2.8	–1.67		–2.69	4.70	–5.68	–5.59	–2.07		
1994	8.92	3.5	1.47		12.93	14.00	4.17	0.63	–0.16	–3.14	–5.22
1995	6.82	2.9	–2.67	2.35	4.33	6.09	10.17	2.04	–0.42	–1.16	–1.72
6/95-6/96	7.81	3.2	0.26	8.17	11.93	14.64	0.99	2.08	1.68	0.03	0.40
Average	8.53	3.50	–0.55	5.26	9.73	11.58	3.16	1.98	0.56	–0.90	–0.99

Smith Breeden Associates, Inc. elasticities are used for 1988-1990.

points to –550 basis points, roughly between the Goldman and the J.P. Morgan estimates, but above the median broker estimates. From the results obtained and shown in Exhibit 28, forecasts of option costs of 1,000 basis points or more are not out of line in some years for IOs on lower coupons. Option benefits of 500 basis points or more have also occurred. Thus, IOs certainly display non-trivial positive and negative convexities.

V. DURATIONS AND EMPIRICAL OPTION COSTS FOR CONVENTIONAL MBS

This section presents the results of similar analysis for conventional mortgage-backed securities, using data on FHLMC and FNMA coupons. Exhibits 33, 34, and 35 present our survey results for the median broker forecasts of option-adjusted spreads, price elasticities (or option-adjusted durations), and option costs. Compar-

EXHIBIT 29 ■ Interest-Only Strips: Yearly by Coupon, 1988-1996 ■ Empirical Option Costs versus C – R

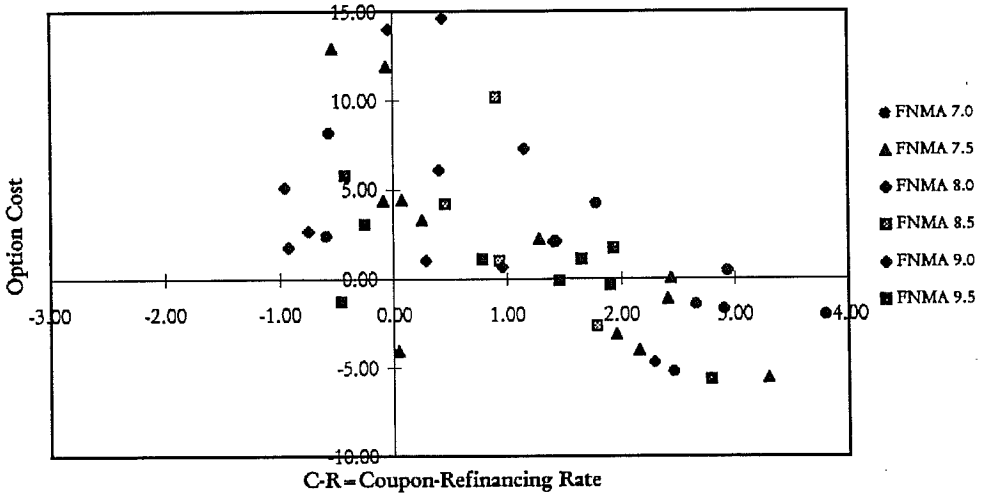
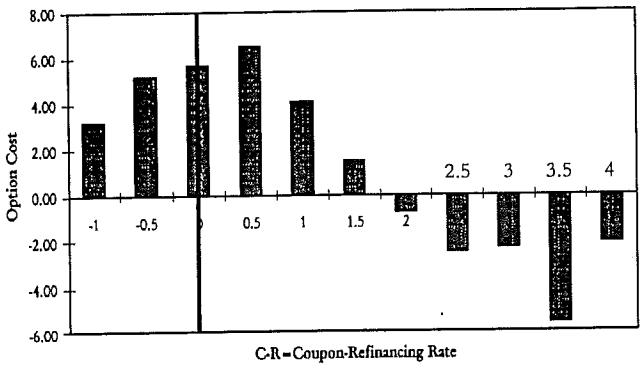


EXHIBIT 30 ■ Interest-Only Strips: Composite of FNMA 7.0-10.5, 1988-1996 ■ Empirical Option Costs



ing Exhibits 33 and 35, we see that the option costs are similar in magnitude to option-adjusted spreads, but estimated option costs are in a much more narrow range for standard MBS than for IOs. Most of the option cost estimates fall between 25 and 75 basis points for conventional MBS.

One of the reasons for this study is the observation from studying portfolio returns in practice that the whipsaw option cost appears often to be greater than this 25-75-basis point range in practice. We'll see what the results are shortly.

If you study Exhibit 34, you find quite predictably that when rates decline, prepayments surge, and durations (and corresponding dynamic hedge positions) shorten. To make this easier to see, Exhibit

EXHIBIT 31 ■ Goldman Sachs Option Cost Forecasts versus C – R for Interest-Only Strips ■ Composite of FNMA 6.5-10.0 Coupons, 1991-1996

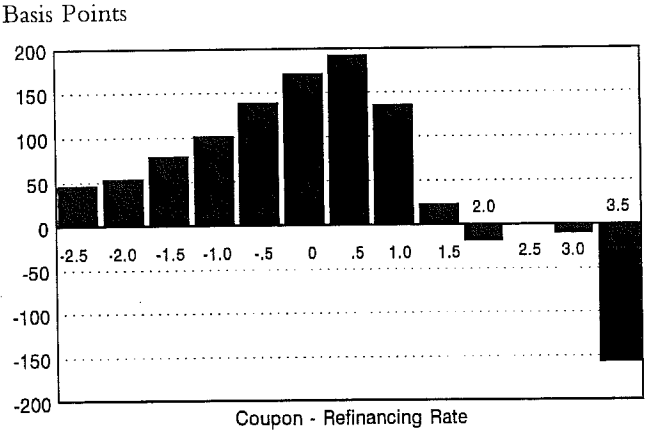
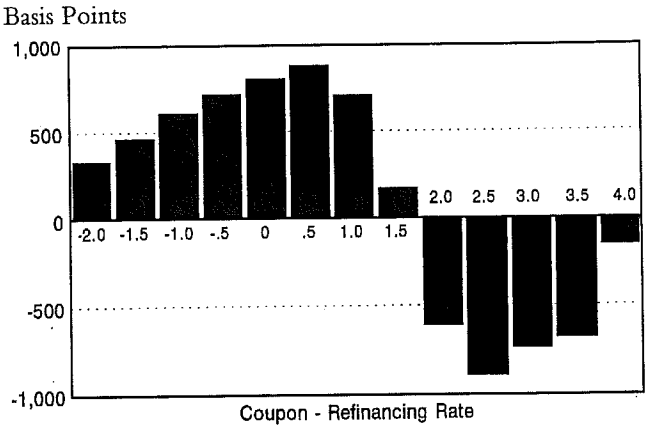


EXHIBIT 32 ■ J.P. Morgan Option Cost Forecasts versus C – R for Interest-Only Strips ■ Composite of FNMA 6.5-10.0 Coupons, 1991-1996



36 shows the coupon-by-coupon sensitivities of brokers' duration forecasts to changes in interest rates. As these have a positive slope, short hedges are reduced by buying futures when rates are low and prices high, and hedges increased by selling futures when rates are high and prices low. This dynamic hedging pattern generates whipsaw costs due to the negative convexities of standard MBS, as expected.

Exhibit 37 shows the relationship of option-adjusted durations (or price elasticities) to relative coupons. The higher coupons (relative to par) have lower elasticities, as is sensible. Exhibit 37 shows that brokers' forecasts of durations are closely and significantly related to empirical durations for MBS, with the fit being tighter in the more recent period (1991-1996) than in earlier years (1987-1990).

Exhibit 38 shows median broker forecasts of option costs for conventional MBS, along with a graph of the empirical estimates of option cost sorted by relative coupon. Note that the empirical whipsaw option costs are quite similar in magnitude to the brokers' forecasts over the entire period from 1988 to 1996. The empirical option costs are slightly higher than the brokers' forecasts on coupons near par, but slightly lower than the brokers forecasts on both superpremiums and deep discount securities.

Exhibit 39 gives the annual data on empirical estimates of the option cost in conventional fixed-rate MBS. From that data, we see that the realized whipsaw cost year by year can be much higher than projected by the brokers, with some years giving whipsaws of 100 to

EXHIBIT 33 ■ Median Broker Forecasts ■ FHLMC/FNMA Option-Adjusted Spreads

End of Quarter	Par Yld FNMA	# of Brokers	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
4Q87	10.11	2					112	106	103	102	93	89	85	78	70		
1Q88	9.76	4				99	95	84	75	71	49	36	28	11	32	11	
2Q88	9.83	5				78	74	72	63	54	44	38	32	20	9	9	–54
3Q88	9.91	3				82	86	81	70	60	46	41	29	32	29	68	
4Q88	10.48	4				95	84	88	84	82	74	92	60	79	54	62	
1Q89	10.81	5				97	97	103	102	91	91	64	59	76	71	76	10
2Q89	9.70	5				94	90	93	88	83	76	73	80	62	79	61	
3Q89	9.88	4				104	100	103	94	87	82	83	85	84	50	65	
4Q89	9.50	5				88	95	101	91	82	79	86	94	80	85	91	
1Q90	9.97	5				76	79	87	83	74	70	73	77	85	86	89	
2Q90	9.67	5				74	64	72	72	72	70	72	72	79	81	86	
3Q90	9.78	5				72	66	62	63	62	57	52	71	70	60	97	
4Q90	9.27	6				93	83	88	83	81	83	91	106	105	107	106	
1Q91	9.08	6				97	70	80	70	68	71	72	75	83	89	109	
2Q91	9.19	5				76	67	75	66	66	55	58	75	72	65		
3Q91	8.41	6			74	78	70	68	66	65	61	80	112	121			
4Q91	7.55	8				69	77	75	83	87	88	76	88	105	114	120	
1Q92	8.40	7			76	67	64	61	61	69	73	70	46	85	106		
2Q92	7.84	7			79	66	65	61	58	65	72	70	71	104	131		
3Q92	7.27	6			86	85	92	90	82	97	96	96	99	122	179		
4Q92	7.55	7			65	64	68	69	69	70	69	53	60	67			
1Q93	6.92	7			67	77	93	100	80	80	80	80	105	79			
2Q93	6.63	7		58	63	71	85	83	83	85	85	56	77	43			
3Q93	6.28	7	58	72	98	115	126	135	96	102	108	87	121	125			
4Q93	6.67	7	66	68	70	73	68	77	79	71	69	68	106	124			
1Q94	7.74	7	69	69	65	59	57	52	60	59	44	41	52	115			
2Q94	8.29	6	55	54	54	54	56	55	45	42	42	3	23				
3Q94	8.48	6	51	48	52	52	54	52	58	49	42	23	50				
4Q94	8.88	6	48	47	49	47	49	50	45	44	38	45	48	79			
1Q95	8.25	8	50	45	48	45	47	54	55	59	60	45	56				
2Q95	7.42	6	42	44	57	61	47	68	59	41	91	49	36				
3Q95	7.34	7	48	50	57	61	61	57	59	48	75	58					
4Q95	6.79	7	55	59	65	54	50	63	63	99	85	75	175	201			
1Q96	7.53	7	51	49	51	66	65	59	48	12	14	40	123	151			
2Q96	7.80	7	58	63	68	70	75	84	85	64	83	36	34				

EXHIBIT 34 ■ Median Broker Forecasts ■ FHLMC/FNMA Price Elasticities (Option-Adjusted Durations)

End of Quarter	Par Yld FNMA	# of Brokers	Slope	R^2	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0
1Q87	8.69	2							5.6	5.4	5.2	5.4	3.5	1.8	1.4		
2Q87	9.85	2	0.86	0.86					5.0	5.8	5.4	5.2	4.2	2.9	2.0		
3Q87	10.70	2	0.73	0.83					5.4	5.8	5.6	5.6	5.0	4.4	3.4	2.7	2.0
4Q87	10.11	2	0.58	0.50					6.1	5.8	5.6	5.2	5.0	4.0	2.8	2.2	1.6
1Q88	9.76	3	0.84	0.98				5.2	5.4	5.1	4.9	4.5	3.9	3.4	2.7	1.9	1.9
2Q88	9.83	4	0.87	0.98				5.2	5.5	5.2	5.0	4.6	4.0	3.5	2.8	2.1	1.0
3Q88	9.91	2	0.84	0.98				4.8	5.2	5.0	4.6	4.4	3.8	3.0	2.4	1.0	1.0
4Q88	10.48	4	1.03	0.88				5.8	5.4	5.1	4.7	4.2	4.0	3.2	2.8	2.3	1.8
1Q89	10.81	5	1.15	0.74				5.3	5.4	5.0	4.6	4.3	4.0	3.4	2.9	2.4	2.2
2Q89	9.70	5	0.73	0.97				5.1	5.2	4.6	4.1	3.9	3.5	2.9	2.2	2.0	1.6
3Q89	9.88	4	0.63	0.95				5.0	4.8	4.6	4.3	4.0	3.4	2.9	2.2	1.8	1.7

EXHIBIT 34 ■ Continued

End of Quarter	Par Yld FNMA	# of Brokers	Slope	R^2	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0
4Q89	9.50	5	0.63	0.95				5.0	5.1	4.7	4.0	3.7	3.3	2.4	1.8	1.7	1.6
1Q90	9.97	5	0.89	0.94				5.2	5.1	4.8	4.7	4.4	3.8	3.1	2.3	2.0	2.0
2Q90	9.67	4	1.01	0.99				5.2	5.4	5.1	4.8	4.4	3.8	3.2	2.6	2.3	2.4
3Q90	9.78	5	1.12	0.95				5.6	5.5	5.3	5.1	4.8	4.3	3.5	2.7	2.3	2.3
4Q90	9.27	5	1.14	0.98				5.2	5.3	5.2	4.8	4.3	3.6	2.7	2.7	2.8	2.7
1Q91	9.08	6	1.31	0.93				5.3	5.3	5.0	4.8	4.3	3.5	2.6	2.2	2.4	2.2
2Q91	9.19	5	0.96	0.93				5.2	5.2	5.2	5.0	4.4	3.8	3.0	2.4	2.2	2.5
3Q91	8.41	6	0.95	0.96				5.0	5.1	5.0	4.5	3.6	2.6	2.5	2.5	2.6	2.6
4Q91	7.55	8	1.20	0.95				5.6	5.0	4.8	3.9	2.8	2.0	1.8	1.9	1.6	2.4
1Q92	8.40	7	1.10	0.90				6.1	5.5	5.0	4.2	3.5	2.5	2.1	2.1	2.1	2.6
2Q92	7.84	7	1.00	0.93			6.2	6.2	5.7	4.8	3.6	2.7	1.9	1.8	1.4	1.9	2.6
3Q92	7.27	6	0.81	0.97			6.1	5.6	5.0	3.6	2.6	2.2	2.0	1.5	1.6	1.4	
4Q92	7.55	8	1.00	0.93			6.0	5.8	5.0	3.9	3.0	2.2	2.0	1.8	1.5	1.0	
1Q93	6.92	8	0.92	0.99		6.8	6.0	5.4	4.4	2.8	2.0	1.6	1.8	1.6	1.6	1.8	
2Q93	6.63	8	0.67	0.95		6.4	5.8	4.7	3.4	2.4	1.6	1.4	1.5	1.5	1.6	1.8	
3Q93	6.28	7	0.76	0.92	6.8	5.9	5.0	3.7	2.8	2.0	1.9	1.8	1.7	1.3	1.1	1.8	
4Q93	6.67	8	0.92	0.97	6.8	6.2	5.3	4.0	2.8	2.4	2.0	1.7	1.6	1.4	1.4	1.3	
1Q94	7.74	6	0.94	0.98	6.6	6.4	5.9	5.2	4.4	3.0	2.6	2.4	2.3	1.8	1.9	2.1	
2Q94	8.29	7	1.18	0.95	6.5	6.4	5.9	5.6	5.1	4.4	3.6	3.2	3.0	2.2	2.2		
3Q94	8.48	7	1.40	0.97	6.3	6.1	5.9	5.7	5.2	4.6	4.0	3.4	2.8	2.4	2.4		
4Q94	8.88	7			6.3	6.2	5.8	5.6	5.1	4.8	4.1	3.5	3.1	2.1	2.0	3.0	1.9
1Q95	8.25	7			6.3	5.9	5.5	5.0	4.4	3.7	3.7	2.7	2.6	2.3	2.7	2.7	1.8
2Q95	7.42	6			6.0	5.5	4.9	4.1	3.0	1.6	1.9	1.2	2.2	1.8	2.5	2.5	
3Q95	7.34	7			5.8	5.5	4.8	3.9	2.7	2.0	1.1	1.2	2.3	1.8	1.7	2.9	
4Q95	6.79	7			5.6	5.0	3.9	3.2	1.9	1.3	1.2	1.5	2.2	1.8	1.7	2.5	
1Q96	7.53	7			6.2	5.4	5.5	4.7	3.7	2.7	1.9	1.3	2.4	1.7	2.7	3.2	
2Q96	7.80	7			6.4	6.0	5.6	4.9	4.1	3.3	2.5	1.6	2.7	1.7	2.2		

EXHIBIT 35 ■ Median Broker Forecasts ■ FHLMC/FNMA Option Cost (Basis Points)

End of Quarter	Par Yld FNMA	# of Brokers	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
4Q86	8.77																
1Q87	8.69	1															
2Q87	9.85	1				57	62	60	60	65	73	79	85	70	56		
3Q87	10.70	1				62	67	65	65	70	74	75	90	91	92		
4Q87	10.11	1				57	62	61	61	66	72	82	92	88	83		
1Q88	9.76	3				24	30	38	51	58	82	93	86	71	41	38	
2Q88	9.83	3				34	43	53	59	68	78	88	98	93	88	43	
3Q88	9.91	2				33	28	34	50	61	74	85	93	84	75		
4Q88	10.48	3				36	45	50	58	68	82	91	78	56	38	33	
1Q89	10.81	3				32	42	46	57	67	88	91	99	108	116	69	
2Q89	9.70	3				44	48	53	66	79	94	105	112	101	84	70	
3Q89	9.88	2				8	20	23	33	44	56	68	48	45	47	49	
4Q89	9.50	2				19	20	28	34	42	53	62	55	43	39		
1Q90	9.97	2				22	23	25	32	39	49	56	52	40	36		
2Q90	9.67	2				22	23	27	32	40	48	57	50	41	35		
3Q90	9.78	2				22	22	26	30	35	43	52	50	46	40		
4Q90	9.27	3				23	21	27	38	45	50	49	33	31	25	12	
1Q91	9.08	3				16	22	25	36	46	54	54	33	13	24	14	
2Q91	9.19	2				12	16	21	29	39	45	44	32	18	10		

EXHIBIT 35 ■ Continued

End of Quarter	Par Yld FNMA	# of Brokers	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
3Q91	8.41	3				14	9	21	35	40	38	23	12	10	7		
4Q91	7.55	4				4	11	32	37	34	30	28	17	3	1		
1Q92	8.40	3				14	20	41	43	42	31	13	4	–15	–24		
2Q92	7.84	3				2	42	43	42	26	11	7	3	–37	–49		
3Q92	7.27	3			25	4	14	20	36	32	39	31	50	46			
4Q92	7.55	4			9	29	40	54	67	63	59	54	72	75			
1Q93	6.92	4			19	31	44	66	56	58	61	41	49	51			
2Q93	6.63	4		14	20	31	47	50	42	37	34	34					
3Q93	6.28	4	17	20	29	42	50	30	25	15	19	36					
4Q93	6.67	5	10	18	41	50	52	55	49	33	34	50	56				
1Q94	7.74	5	13	24	36	50	64	73	71	56	40	52	52	48			
2Q94	8.29	5	15	22	29	39	53	61	69	63	57	64	58				
3Q94	8.48	5	17	19	23	28	39	50	47	49	41	23	31				
4Q94	8.88	5	10	18	25	35	42	52	63	54	53	52	38	33			
1Q95	8.25	4	18	24	32	43	52	59	72	71	41	33	27	24			
2Q95	7.42	4	37	36	51	68	74	72	77	47	19	14	11	12			
3Q95	7.34	4	22	35	32	69	88	77	77	47	36	14	15	12			
4Q95	6.79	5	45	49	62	80	83	53	15	65	17	39	4				
1Q96	7.53	5	28	30	38	49	59	70	73	78	34	16	11	–16			
2Q96	7.80	5	31	48	53	56	62	75	53	67	53	48	39				

133 basis points. In other quiet years with little change in rates, whipsaw can be smaller than forecasted, or even slightly negative if model changes occur that generate positive benefits of "model whipsaw." On the whole, the option costs for conventional MBS turn out to be very similar to the median of brokers' forecasts.

It is interesting that when these dynamic hedging costs are estimated using Smith Breeden's empirical duration forecasts, empirical option costs that result are higher than shown here for lower and middle coupons, with a peak of 170 basis points on FNMA 7.5s and 8s in 1993. For GNMAs, the Smith Breeden elasticities yield whipsaws of as much as 200 basis points in 1994.

Thus, once again we may have evidence of

EXHIBIT 36 ■ Median Broker Forecasts
■ Panel A. FHLMC 7.5% Option-Adjusted Durations

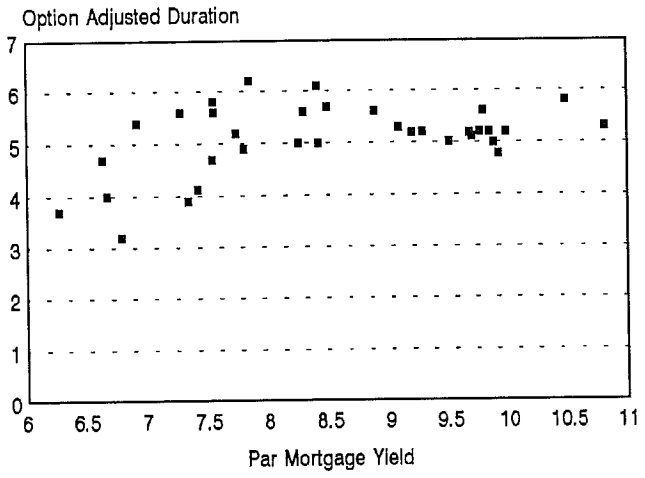


EXHIBIT 36 ■ Median Broker Forecasts
■ Panel B. FHLMC 8.0% Option-Adjusted Durations

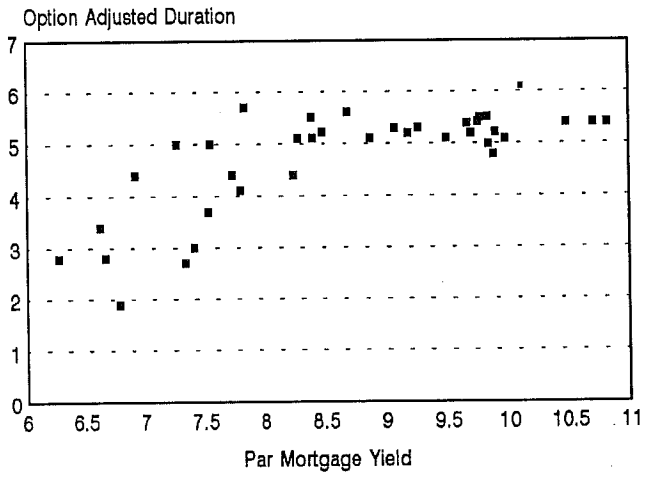
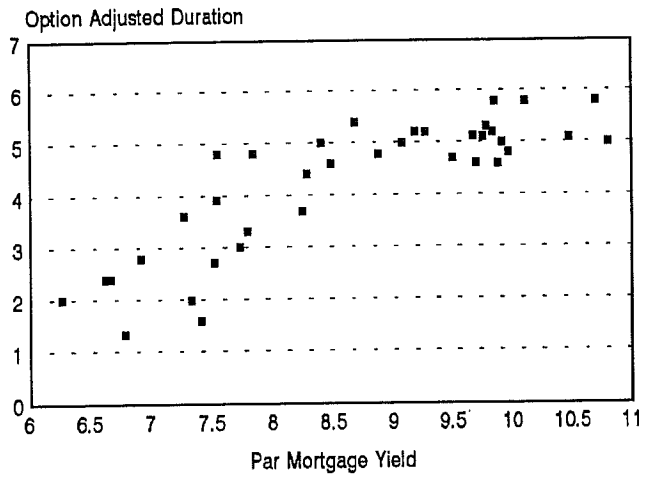
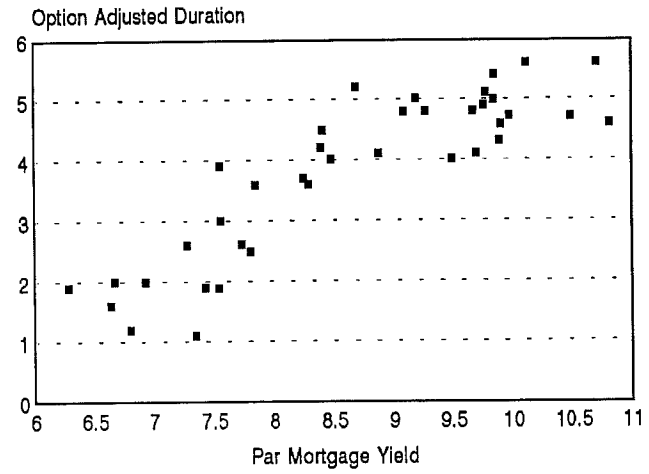


EXHIBIT 36 ■ Median Broker Forecasts

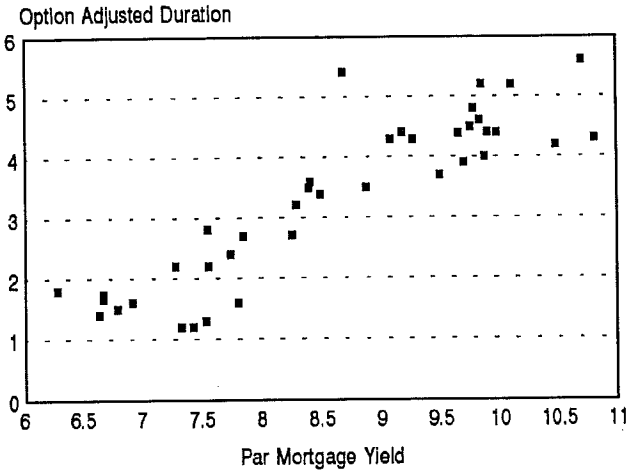
Panel C. FHLMC 8.5% Option-Adjusted Durations



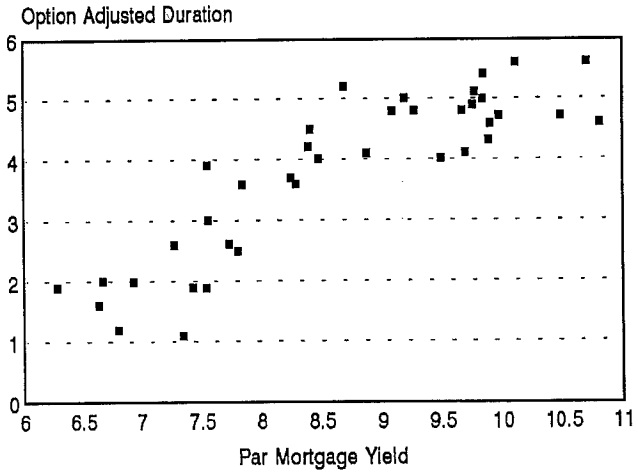
Panel D. FHLMC 9.0% Option-Adjusted Durations



Panel E. FHLMC 9.5% Option-Adjusted Durations



Panel F. FHLMC 10.0% Option-Adjusted Durations



"model whipsaw" that affects option costs in practice. Alternatively, it is possible that taking the medians in the broker survey series tends to lead to underestimates of the whipsaws experienced in practice. This may be plausible, given the lags that may appear in adjustments in our median broker forecasts.

VI. CONCLUSION

Theory says that interest-only strips should have large positive and negative option costs and benefits, due to their convexity patterns. While brokers clearly have some difficulty zeroing in on the proper costs of these, as well as the empirical durations, their forecasts appear rational in shape across coupons and time. The empirical option costs, however, exhibit somewhat greater amplitudes of fluctuation (larger positive and negative values) than did the median brokers' forecasts.

Given their size, option costs for interest-only strips and other high-risk mortgage derivatives deserve researchers' and traders' attention and continued study. Certainly, it would seem advisable that investors in high-risk derivatives put a band of error around their estimates of option-adjusted durations and whipsaw option costs and benefits. This probably is wise not just for IO strips, but also for many mortgage derivatives

EXHIBIT 37 ■ Median Broker Forecasts ■ Broker versus Empirical Elasticities by C – R

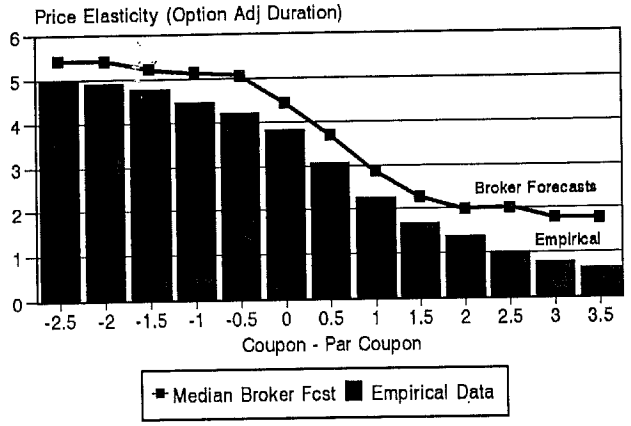
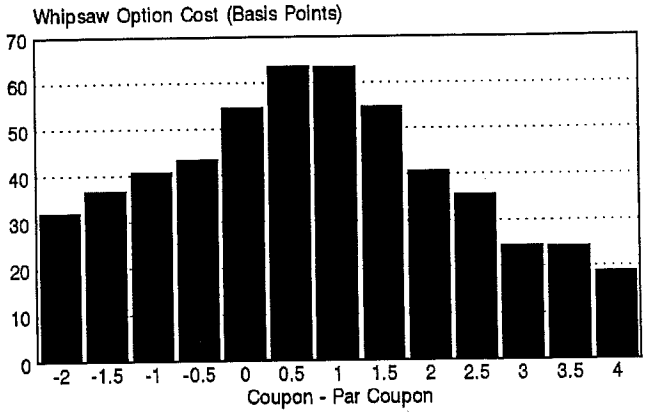
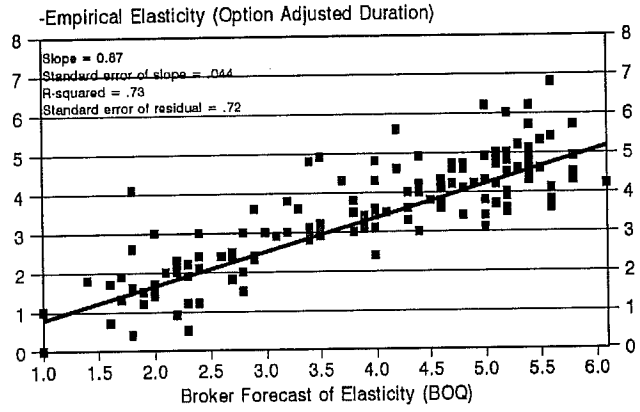


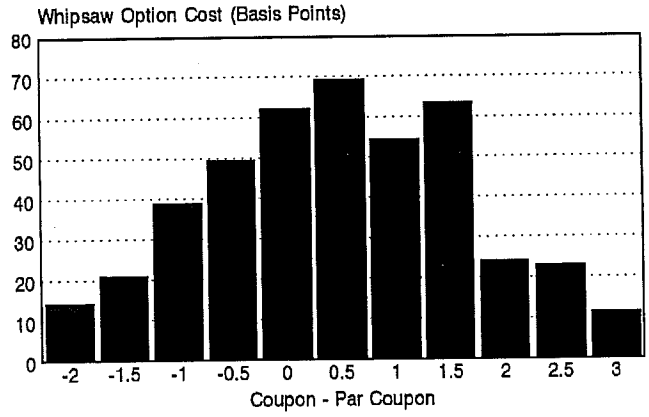
EXHIBIT 38 ■ Median Broker Forecasts 1987-1996 ■ FHLMC/FNMA Whipsaw Option Costs by C – R



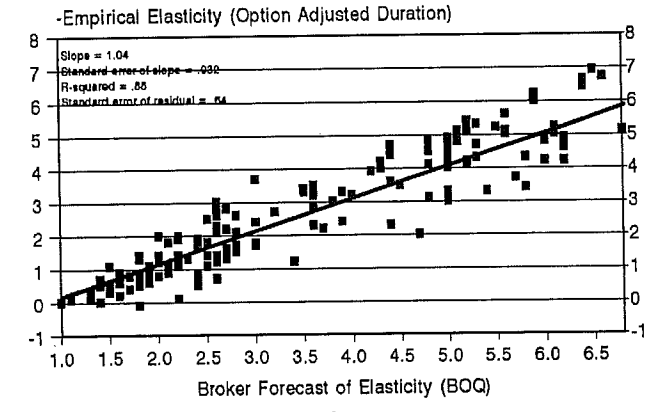
Broker Risk Estimates versus Empirical Risk ■ 1987-1990 Quarterly Data, Coupons: 7%-12%



Empirical Option Costs for FNMA 1988-1996 ■ Median Broker Quarterly OA Durations



Broker Risk Estimates versus Empirical Risk ■ 1991-1994 Quarterly Data, Coupons: 7%-12%



Empirical Option Costs versus Broker Forecasts ■ Median Broker Quarterly OA Durations

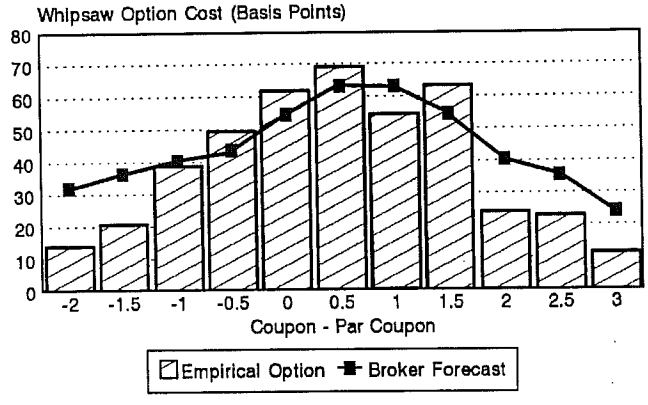


EXHIBIT 39 ■ FNMA Dynamic Option Hedging Cost ("Model Whipsaw")

	FNMA 6.5	FNMA 7	FNMA 7.5	FNMA 8	FNMA 8.5	FNMA 9	FNMA 9.5	FNMA 10	FNMA 10.5	FNMA 11	FNMA 11.5	FNMA 12
1987												
1988					0.23	0.29	0.23	0.35		0.11		0.08
1989					0.14	0.20	0.24	0.22		0.37		0.47
1990					0.32	0.72	0.75	0.69		0.51		0.34
1991					0.03	–0.02	–0.22	–0.24		0.04		0.13
1992			0.70	0.78	0.50	0.34	0.44	0.15	0.24	–0.20	0.53	
1993			1.33	1.33	1.06	0.51	0.13	0.14	0.30	0.31		
1994	0.04	0.33	0.90	1.28	1.13	0.96	0.86	0.71	0.48	0.49		
1995	0.24	0.35	0.54	0.81	1.25	0.99	0.88	0.27	0.25			
1996	0.39	0.57	0.42	0.48	0.34	–0.08	–0.24	0.04	0.02			
	0.22	0.42	0.78	0.94	0.56	0.43	0.34	0.26	0.26	0.23	0.53	0.26

that have volatile cash flow streams.

The results on option costs for conventional MBS show that the empirical dynamic hedging costs are similar in magnitude to those estimated by the brokers, although there is a great deal of annual fluctuation in the dynamic whipsaw experienced by portfolio managers. These fluctuations in the dynamic whipsaw cost of hedging mortgage prepayments are a return factor of the first order of magnitude for the returns on hedged mortgage portfolios.

ENDNOTE

The author thanks Dan Adler, Jenny Breeden, Andrew Cohen, Kerrie Hillman, and John Huff for research assistance and data for this project, which was presented at the Berkeley Program in Finance Conference in Honor of Fischer Black, Santa Barbara, California, September 29-October 1, 1996.

REFERENCES

Asay, Michael R., and Timothy D. Sears. "Stripped Mortgage-Backed Securities, Part I: Basic Concepts and Pricing Theory; Part II: Trading Strategies and Portfolio Applications." Goldman, Sachs & Co., January 1988.

Black, F., E. Derman, and W. Toy. "TITLE TO COME." PUBLICATION, 1990.

Breeden, Douglas T. "Complexities of Hedging Mortgages." *Journal of Fixed Income*, 4 (December 1994), pp. 6-41.

——. "Risk, Return and Hedging of Fixed-Rate Mortgages." *Journal of Fixed Income*, 1 (September 1991), pp. 85-107.

Diller, Stanley. "Parametric Analysis of Fixed Income Securities: Options, Passthroughs, Convexity, and Asset/Liability Management." Goldman Sachs Financial Strategies Group, June 1984.

Hayre, Lakhbir. "TITLE TO COME." PUBLICATION, 1994.

Patruno, Gregg. "Mortgage Prepayments: A New Model for a New Era." *Journal of Fixed Income*, 4 (December 1994), pp. 42-56.

Richard, Scott F., and Richard Roll. "Prepayments on Fixed-Rate Mortgage-Backed Securities." *Journal of Portfolio Management*, 15 (Spring 1989), pp. 73-82.

Roll, Richard., "Stripped Mortgage-Backed Securities." Goldman, Sachs & Co., Inc., October 1986.