Highlights

• Most investors know that the price of a bond declines as its yield rises, and rises as its yield declines. But by how much will the price of a bond change in response to a given change in yield? The duration statistic gives you a good estimate.

• Duration is an estimate of how much the price of a bond will change as yields change. The duration of a bond is higher the lower the coupon, the longer the maturity and the lower the yield of the bond.

• Convexity measures how duration changes as yields change. For a positively-convex bond, duration increases as the yield declines, and decreases as the yield rises. Positive convexity means that the price increase for a given decline in yields is greater than the price decrease for the same rise in yields.

• Non-callable bonds are positively-convex. Bonds with traditional call options, such as preferreds, and mortgage-backed securities are generally negatively-convex. That means that their price will rise less for a given decline in yields than it will decline for the same rise in yields. The prospect of a call at a given price limits the upside potential in the price when yields decline.

• If you expect yields to rise, you should de-emphasize bonds with long duration, unless the yield appears high enough to compensate. If you expect yields to decline, you should generally favor bonds with longer duration. Bonds with low or negative convexity (typically callable bonds) generally have an advantage in periods of low volatility in yields and generally underperform positively-convex bonds when yields are more volatile.

Chart 1: The impact of instantaneous yield changes on bond prices, 3% coupon, par price

Source: BofA Merrill Lynch Global Research
Overview

Most investors know that the price of a bond declines as its yield rises, and rises as its yield declines. But by how much will the price of a bond change in response to a given change in yield? The answer depends upon the duration of the bond.

The responsiveness of the price of a bond to a change in yield—measured by the duration of the bond—changes as its yield changes. That relationship is measured by convexity.

Duration and convexity can also help you compare the performance characteristics of different types of bonds. For example:

- Why is the price of a 30-year bond more sensitive to changes in yield than the price of a two-year bond? (See pages 5 and 6.)
- Why could the price of a 15-year zero-coupon bond be more sensitive to changes in yield than the price of a 20-year coupon-paying bond? (Page 6.)
- Why are bonds with traditional calls, including mortgage-backed securities, less likely to share in bond market rallies than non-callable securities? (See page 9.)
- Why does the price of a non-callable bond fall by less for a given rise in yields than it rises for the same decline in yields? (See page 9.)
- How can you estimate how the value of your entire bond portfolio would change if yields change? (See page 7.)

Duration and convexity are tools that give investors information about the price risk of fixed-income securities. Investors can assess that price risk in relation to the return prospects that the securities offer.

The next page contains the “Essentials“, a brief summary of the key points about duration and convexity. Readers who want just the basics can stop there. Those who want more detail can select among the sections that begin on page 4.
The essentials

What follows is a sketch of the key points in this publication. These points are expanded upon in the next sections.

What is duration?
The modified duration statistic gives an estimate of how the price of a bond will change for an instantaneous change in yield. The higher the duration, the greater the increase in the price of the bond will be for a given decline in yields, and the greater the decline in price will be for a given rise in yields. The formula is:

**Approximate change in price = -100 * duration * percentage point change in yield.**

For example, if a bond has a modified duration of 1.96, its price would decline by about 1.96% for an instantaneous one percentage point rise in yields (from 3.0% to 4.0%, for example).

The duration of a bond is greater the lower its coupon, the longer its maturity, and the lower its yield. That means that, other things equal, the price of a zero-coupon bond will show a greater movement, both up and down, for a given change in yield, than the price of a coupon-paying bond. Likewise, a longer maturity bond will show a greater price change for a given change in yield than an otherwise similar bond of shorter maturity.

What is convexity?
Convexity is a measure of how duration changes as yields change. For a positively-convex bond, the duration increases as the yield declines, and decreases as the yield rises. In other words, for a positively-convex bond, the price increase for a given decline in yields exceeds the price decrease for the same rise in yields. Bonds that do not have call options are generally positively-convex.

Bonds with traditional calls, such as preferreds and mortgage-backed securities, are generally negatively-convex. That means that their price will rise less for a given decline in yields than it will decline for the same rise in yields. Negative convexity arises because of call features. The prospect of a call at a given price limits the upside potential in the price when yields decline.

How do I use duration and convexity in building a bond portfolio?
If you expect yields to rise, you should de-emphasize bonds with long duration, such as those with longer maturities and lower coupons, and favor bonds that have shorter duration. If you expect yields to decline, you should generally favor bonds with longer duration, other things equal and avoid callable bonds. In general, you should favor bonds with low or negative convexity (i.e., callable bonds) in periods when you expect little volatility in yields.

How do I find out the duration of a bond?
The duration statistic for a particular bond, along with its convexity, can be determined with a Bloomberg terminal. Also, many spreadsheet software packages, such as Microsoft Excel, have statistical functions that will compute duration for a specific set of bond characteristics. Likewise, information on the duration of mutual funds, closed end funds and exchange traded funds is usually available on the manager’s web page. We detail the calculation of both duration and convexity in the Appendix.
Duration

A bond provides a series of cash flows to investors: coupon payments and the return of principal. Mathematically, duration is a measure of the timing of cash flows. Practically, duration can be used to approximate the instantaneous percentage price decline (increase) for a given rise (decline) in yields.

**Macaulay duration: A measure of the timing of cash flows**

The cash flows from bonds can differ, even for bonds with the same maturity. For example, a 10-year security with a high coupon rate provides a large proportion of its payments prior to maturity. In contrast, a 10-year zero-coupon bond provides no payments prior to maturity. The bonds mature at the same time, but their differing payment characteristics affect the nature of the return that they provide.

The simplest form of duration, known as Macaulay’s duration, takes into account the timing and magnitude of a bond’s payment stream, as well as the time value of money. Macaulay’s duration is the weighted-average maturity of a bond, with the weights calculated in present value terms. In the Appendix on pages 14-15 we detail the calculations.

One way to graphically illustrate duration is to stretch out the present value of the cash flows along a timeline. (See Chart 2.) For our example, we use a 10-year bond with a 5% coupon paid semi-annually. For a $1,000 par value, the bond pays $50 in annual coupon payments and $1,000 at maturity. The Chart shows the present value of the cash flows (i.e., adjusting for the time value of money). The duration statistic is based upon a weighted-average of these cash flows.

**Chart 2: Present value of Cash Flows of a 10-Year Bond With 5% Coupon**

![Chart 2](chart.jpg)

Source: BofA Merrill Lynch Global Research

**Modified Duration: A measure of price sensitivity**

With a minor adjustment, Macaulay duration can be restated into modified duration. (See the Appendix on pages 14-15.) In bond market parlance, “duration” typically refers to modified duration rather than Macaulay duration. We will follow that convention for the rest of this publication.

Modified duration is an estimate of a security's price sensitivity to instantaneous changes in yield. Price sensitivity is measured as the percentage change in a bond’s price for a given change in yield (specifically, a parallel shift in the yield curve). In other words, duration is an
estimate of the instantaneous percentage change in the price of a bond for a one-
percentage-point (100-basis-point) change in yield.

Specifically:

\[
\text{Approximate \% Change in Price} = -100 \times \text{duration} \times \text{percentage point change in yield}
\]

Table 1 shows the duration for non-callable\(^1\) par-priced bonds of various maturities with
a 3% coupon/yield.

For securities with uncertain cash flows, such as callable preferreds and mortgage-
backed securities, price sensitivity measures should account for embedded options. This
is measured by the *effective duration* statistic. See page 7.

Table 1: Duration for non-callable par-priced bond, 3% coupon / yield

<table>
<thead>
<tr>
<th>Maturity (Years)</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.98</td>
</tr>
<tr>
<td>2</td>
<td>1.93</td>
</tr>
<tr>
<td>3</td>
<td>2.85</td>
</tr>
<tr>
<td>5</td>
<td>4.61</td>
</tr>
<tr>
<td>10</td>
<td>8.58</td>
</tr>
<tr>
<td>30</td>
<td>19.69</td>
</tr>
</tbody>
</table>

Source: BofA Merrill Lynch Global Research

Using duration to estimate the bond price change for a given yield change

To illustrate the use of duration as a measure of price sensitivity, consider the duration
of 1.93 for the two-year security, and 19.69 for the 30-year security shown in Table 1.
Suppose the yield on both the two-year and the 30-year securities fell by one
percentage point, to 2%. Using the formula above, we can expect the price of the two-
year security to rise by approximately 1.93%, and the price of the 30-year security to
rise by 19.69%. These calculations illustrate that the price of shorter maturities tends to
be less sensitive to changes in yield.

Table 2 below gives a better idea of how close the duration statistic comes to
measuring the actual change in price for a given change in yields. For a 1% rise in the
yield on the three-year security, the duration calculation suggests a 2.85% decline in
price (i.e., \(-100 \times 2.85 \times 1\)%). The actual price change is \(-2.80\)%. Duration comes closer
to measuring the actual change in price the smaller the change in yields and the shorter
the time period for the yield change. Duration and convexity together, as we will discuss
later, get us closer to the actual percentage change in price and also reveals other
important characteristics about the price performance of the bond.

Table 2: Estimating instantaneous price changes with duration
(Non-callable par-priced bond, 3% coupon/yield), 1% rise in yield

<table>
<thead>
<tr>
<th>Maturity (years)</th>
<th>Duration</th>
<th>Price chg estimated by duration</th>
<th>Actual price chg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.98</td>
<td>-0.98%</td>
<td>-0.97%</td>
</tr>
<tr>
<td>2</td>
<td>1.93</td>
<td>-1.93%</td>
<td>-1.90%</td>
</tr>
<tr>
<td>3</td>
<td>2.85</td>
<td>-2.85%</td>
<td>-2.80%</td>
</tr>
<tr>
<td>5</td>
<td>4.61</td>
<td>-4.61%</td>
<td>-4.49%</td>
</tr>
<tr>
<td>10</td>
<td>8.58</td>
<td>-8.58%</td>
<td>-8.18%</td>
</tr>
<tr>
<td>30</td>
<td>19.69</td>
<td>-19.69%</td>
<td>-17.38%</td>
</tr>
</tbody>
</table>

Source: BofA Merrill Lynch Global Research

---

\(^1\) More precisely, the calculations apply to option-free bonds (bonds with neither call nor put options).
Characteristics that influence duration

For a bond that pays fixed and regular coupons, duration is higher: the lower the coupon, the longer the maturity, and the lower the yield. We will discuss each below.

For a given maturity and yield, the lower the coupon, the higher the duration

When the coupon rate is low, the return of principal at maturity represents a relatively large portion of the total payments. Therefore, the payments are skewed toward the future, making for a longer duration. In contrast, with a high coupon, a larger share of the payments comes before maturity, making the duration shorter.

For example, a 15-year zero-coupon bond provides only one cash payment, in year 15. The weighted-average maturity of all cash flows, which is the duration, is also 15 years.

Viewed another way, if the coupon payments represent a small part of cash flows relative to the principal payment, the market price would be more sensitive to the present value of the future principal payments. See Chart 3 above left for an illustration of how duration varies with the coupon payment for a given yield.

For a given coupon and yield, duration increases with maturity

The longer the maturity of a security, the longer it takes an investor to receive all the security’s cash flows and, therefore, the longer the weighted-average maturity of all cash flows. The opposite is true for shorter maturity issues. Accordingly, duration decreases with calls and prepayments, as calls and prepayments shorten the potential maturity. See Chart 4 above middle. The reasoning is similar to that above: the further into the future the payments come, the more sensitive the market price is to the present value of those future payments.

For a given coupon and maturity, duration rises as yield declines

Recall from page 4 that present values, which are a function of yield, played a role in our duration calculation — they dictate the weight that each cash flow maturity receives. Since a higher yield reduces the present value of future cash flows, it also reduces the duration, See Chart 5 above right. For more details, see the calculation in the Appendix on page 14-15.

See Table 8 on page 15 for a numerical Table showing how the duration of a par-priced bond varies with its coupon and maturity.
For callable bonds: Duration to worst and effective duration

The tricky part about callable bonds is that you don’t know when the bonds will be redeemed. That limits the usefulness of the modified duration statistic that we have been emphasizing so far, because that calculation assumes the bond is redeemed at maturity. The duration to worst and effective duration measures apply to bonds that have traditional call options.

Duration-to-worst aligns with the maturity that corresponds to the yield to worst (YTW), which is the lower of the yield to maturity (YTM) and yield to call (YTC). If the price of a callable security exceeds its call price, then the YTC is the YTW. The duration-to-worst calculation would then use the YTC as the yield and the next call date as the maturity. If the price is below the call price, the duration-to-worst calculation uses the YTM and maturity date.

Effective duration, sometimes called adjusted duration, uses the option-adjusted spread methodology to estimate different paths of cash flows on a callable bond, based on a range of projected paths for interest rates. At one extreme, the calculations assume that if rates decline enough, the bond will be redeemed at the next call date. At the other extreme, if rates rise, the bond will be outstanding through maturity. In between lie varying paths of rates that imply different prospects for a call prior to maturity. Most fund managers provide the effective duration for their portfolios on their web pages.

The drawback with both of these measures is that they can underestimate how prices will decline as yields rise. If yields rise such the price of the bond falls below the call price, the maturity used in the duration to worst statistic will extend from the call date to the maturity date. The result could be an appreciable increase in duration. The same logic applies to effective duration, although the shift is not as abrupt. Effective duration will rise as the probability of a call diminishes.

We suggest that when assessing the interest rate risk of callable bonds investors consider modified duration along with either effective duration, if it’s available, or duration to worst. Modified duration gives an upper bound estimate of the interest rate risk. Duration to worst and effective duration give a more reasonable estimate based upon present market conditions.

Calculating Duration

We detail the calculation of both duration and convexity in the Appendix. The statistics for a particular bond can be found with a Bloomberg terminal. Also, many statistical software packages, such as Microsoft Excel, have functions that enable the user to calculate the duration for a given set of bond characteristics. Fund managers usually provide duration statistics on their web page.

Calculating the duration of a bond portfolio

It is a small step to go from the duration of an individual security to an estimate of the duration of a bond portfolio. Doing so is useful for investors because price risk should be viewed in the context of the whole portfolio, rather than just an individual security.

The duration of a portfolio is the duration of the individual securities weighted by the share of the total market value of the portfolio that each security represents. Table 3 gives an example. We multiply each security’s share of the portfolio by the duration of that security (the middle two columns). The duration of the portfolio is sum of the weighted duration figures in the last column.

Note though, that this calculation assumes that all yields change by the same amount. For that to happen requires a parallel shift in the yield curve and stable credit spreads.

Under those assumptions, the duration of the portfolio shown in Table 3 is 6.74. That means that an instantaneous one-percentage-point rise (decline) in the yield on each of the securities in the portfolio would reduce (raise) the value of the portfolio by about 6.74%.
Table 3: Calculating the duration of a portfolio

<table>
<thead>
<tr>
<th>Bond holding</th>
<th>Market Value</th>
<th>% of Portfolio</th>
<th>Duration</th>
<th>Contribution to Portfolio Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond 1</td>
<td>$50,000</td>
<td>20%</td>
<td>3.53</td>
<td>0.71</td>
</tr>
<tr>
<td>Bond 2</td>
<td>$75,000</td>
<td>30%</td>
<td>12.37</td>
<td>3.71</td>
</tr>
<tr>
<td>Bond 3</td>
<td>$125,000</td>
<td>50%</td>
<td>4.65</td>
<td>2.33</td>
</tr>
<tr>
<td>Total Portfolio</td>
<td>$250,000</td>
<td>100%</td>
<td></td>
<td>6.74</td>
</tr>
</tbody>
</table>

Source: BofA Merrill Lynch Global Research

Dollar duration

We have expressed the change in the portfolio value for a given change in yields in percentage terms. To estimate the instantaneous change in dollars for a given change in yield, take the negative value of the duration and multiply by the initial price and the percentage point change in yield. For example, consider a bond with a price of 103.00 and duration of 5.5. For a one-percentage-point rise in the yield, the change in the price of the bond would be:

\[-5.5 \times \$103.00 \times 1\% = -\$5.665\]

That means that for each one-percentage-point change in yield, the price of the $103 priced bond would change by about $5.67. Suppose that the investor holds $100,000 in par value of the bond. The initial market value would be $103,000. The price decrease would be $5.665 per $103.00 of market value, or:

\[-5.665 \times $103,000/$103.00 = -\$5,665.\]

Limitations of duration

Duration provides a good first pass estimate of the sensitivity of the price of a bond or bond fund to changes in yield. But there are at least three problems with focusing only on duration in assessing potential returns as yields change.

- The larger the change in yield or the longer the time period over which the change in yield occurs, the less accurate duration is as an estimate of the price change. The duration statistic applies to small and instantaneous small changes in yield.

- Focusing only on duration ignores the income that the bond pays. Bonds with long duration might also have higher yields, which would at least partially compensate for the extra interest rate risk. Income becomes an especially important consideration when evaluating the potential performance of a bond over time.

- The sensitivity of a callable bond to changes in yield will fluctuate over time as yields change and the probability of a call changes. For callable bonds, including mortgage backed securities, the effective duration and duration to worst measures are better measures than modified duration, but are still imperfect. See page 7. Some of these limitations can also be addressed by taking into account the negative convexity of callable securities. We turn to that next.
Convexity

Convexity: How duration changes as yields change

The duration of a bond changes as its yield changes. Convexity measures the sensitivity of duration to changes in yield.

The curved line in Chart 6 shows the relationship between the price and yield for a non-callable bond. The slope at any point along the curve represents the duration for that price/yield combination. The line is negatively sloped, meaning that the price declines as the yield rises. But the line has a convex shape: it becomes steeper at lower yields and coupons. That means that bond prices are more sensitive to changes in yields when market yields are lower.

Chart 2: Bond prices as yields change (30 yr maturity, 4% coupon)

Bigger price changes at lower yields

The slope of the line is linked to its duration: it represents how much the price changes as the yield changes. Lines AA and BB depict the slope of the price/yield relationship at different yield levels. Line AA, which applies to the lower yield, is steeper, indicating that a larger price change for a given change in yields.

The Chart illustrates that the change in price for a given change in yields is greater at lower yields. That same point is illustrated in the duration/yield chart at the top of page 6. The corollary is that the price change for a given rise in yields is less than the price change for the same decline in yields. Referring again to Chart 5, since the slope of the line flattens as the yield increases, an increase in yields would imply a smaller price change than the same decrease in yields.

The pattern of how duration changes with yield is a characteristic of positive convexity. For a positively-convex security, duration rises as the yield falls. Positive convexity means that the price increase for a given decline in yields exceeds the price decrease for the same rise in yields. Viewed another way, positive convexity means that changes in duration work in your favor: the price of the bond becomes less sensitive to yield changes when yields rise (and the price declines), and more sensitive when yields decline (and the price rises).

Taking a more mathematical tack, duration is based upon the first derivative of the price-yield relationship. It shows how the price changes as the yield changes. Convexity is the second derivative. It shows how duration changes as yields change.

Negative convexity: duration rises as yields rise

For a negatively-convex security, duration decreases as yields fall and increases as yields rise. Negative convexity arises when long maturity cash flows receive less weight when yields decline and more weight when yields rise.
Chart 7: Price performance of callable vs. non-callable bonds

Chart 7 compares the performance of a 10-year non-callable bond with a 10-year bond that the issuer can call at par in three months. Both bonds have 5% coupon rates. When the market yield declines below the coupon rate:

- The price of the non-callable bond rises, and the slope of the price/yield line steepens, meaning that the sensitivity to price changes rises. That reflects positive convexity.

- The rise in the price of the callable bond is limited, because the price of the security has little room to rise above the call price. The slope of the line flattens as the yield falls below the coupon rate, meaning a reduced sensitivity of the price to changes in market yields as yields decline. That reflects negative convexity.

Most mortgage-backed securities, bonds with traditional calls, and preferred shares have negative convexity. For mortgage-backed securities, when yields decline, homeowners tend to refinance their mortgages — they repay their existing, high-rate mortgages in order to take advantage of lower mortgage rates. As these high-rate loans are repaid, the average maturity of the loans is reduced because principal payments will be received more quickly. In other words, the duration declines as yields decline. Conversely, when yields rise, prepayments decline, and the timing of the cash flows is extended further into the future, raising the duration.

The same logic applies to a corporate bond that has a traditional call (not a make whole call). As rates decline, companies are more likely to call the security. That limits how much the market price could exceed the call price as market yields decline. The cash flows come sooner, reducing the duration.

Note the essential difference between positive and negative convexity.

- With positive convexity, the sensitivity of the price to yield changes (i.e., duration) works in your favor. The price is more sensitive to changes in yields when yields are declining than when they are rising.

- With negative convexity, duration works against you. The price of the bond becomes more sensitive to yield changes when yields are rising than when they are falling.
The disadvantage of negative convexity is more pronounced the greater the volatility in yields. That is, the more yields fluctuate, the more the asymmetric price performance of negatively-convex bonds comes into play.

Negatively-convex bonds usually have higher yields than otherwise similar bonds that are positively-convex. Investors must judge if the extra yield suffices to compensate for the uncertainty and poorer price performance of the callable issue. The expected change in yields is one consideration in making that judgment. The less volatile you expect yields to be, the greater the appeal of negatively-convex securities.

Bonds that have make whole calls and do not have traditional call options are generally positively-convex. The call price on a bond with a make whole call provision typically rises along with a decline in market yields, because the call price is based on the yield that corresponds to a specific spread over a Treasury security.

Combining duration and convexity

One advantage of looking at duration and convexity together is simply computational: combining the two measures gives a better estimate of how the price will change for a given change in yields.

Table 4 breaks down the price changes for bonds of different maturities for a one-percentage-point rise in yields into the parts attributable to duration and convexity. The last two columns compare the price change estimated by combining duration and convexity with the actual price change. The estimated price changes are much closer to the actual than in Table 2 on page 5, which showed the impact of duration alone.

Table 4: Estimating price change with duration and convexity
(Non-callable par-priced bond, 3% coupon/yield), 1% rise in yield

<table>
<thead>
<tr>
<th>Maturity</th>
<th>Duration</th>
<th>Price Chg Estimated by Duration</th>
<th>Convexity effect</th>
<th>Combined Price Chg Estimate</th>
<th>Actual Price Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 year</td>
<td>0.98</td>
<td>-0.96%</td>
<td>0.01%</td>
<td>-0.97%</td>
<td>-0.97%</td>
</tr>
<tr>
<td>2 years</td>
<td>1.93</td>
<td>-1.93%</td>
<td>0.02%</td>
<td>-1.90%</td>
<td>-1.90%</td>
</tr>
<tr>
<td>3 years</td>
<td>2.85</td>
<td>-2.85%</td>
<td>0.05%</td>
<td>-2.80%</td>
<td>-2.80%</td>
</tr>
<tr>
<td>5 years</td>
<td>4.61</td>
<td>-4.61%</td>
<td>0.12%</td>
<td>-4.49%</td>
<td>-4.49%</td>
</tr>
<tr>
<td>10 years</td>
<td>8.58</td>
<td>-8.58%</td>
<td>0.42%</td>
<td>-8.16%</td>
<td>-8.18%</td>
</tr>
<tr>
<td>30 years</td>
<td>19.69</td>
<td>-19.69%</td>
<td>1.76%</td>
<td>-17.93%</td>
<td>-17.38%</td>
</tr>
</tbody>
</table>

Source: BofA Merrill Lynch Global Research

The estimate derived from combining duration and convexity gets closer to the mark than the estimate from duration alone. Notice that the price change attributable to convexity for a non-callable bond is positive. As mentioned before, with a non-callable bond, convexity works in the investor’s favor when yields change: reducing the price decline when yields rise, and raising the price increase when yields decline.

Evaluating bond performance

Chart 8 on the next page illustrates the combined effects of duration and convexity on performance. We show the price/yield line for 2, 10, and 30 year bonds with 3.0% coupons.

- **Both duration and convexity are greater for longer maturities.** The slope of the price/yield line in Chart 8 is steeper for longer maturities, which means that the change in price for a given change in yield is greater the longer the maturity. For the 2-year maturity, a yield decline from 3% to 2% brings a 1.9% price increase. For a 30-year maturity, the same yield change brings a 22.5% price increase.

- **Both duration and convexity are higher at lower yields.** The slope of the lines for each maturity is steeper at lower yields, meaning that the price change for any given change in yields is greater at lower yields. For example, as the yield on the 30-year bond rises from 4% to 5%, the price declines by 16.4%. But as the yield falls from 5% to 4%, the price increase is larger, at 17.4%.
The yield matters too!

Duration and convexity tell you about the interest rate risk of a security, and against the yield that the security offers, particularly when the investor plans to hold the security for a while.

When the yield curve is positively sloped, as it typically is, the extra price risk on longer maturities is countered to some degree by a higher yield.

Table 5 moves beyond instantaneous changes in price, to changes in total return (price change plus coupon income) over a 12-month period. Specifically, the Table shows how total return will vary with maturity and the change in yield over a 12-month period. Table 4 also considers a positively-sloped yield curve—yields rise with maturity.

Note the influence of convexity: for the 10-year security, when the yield rises by one percentage point, the total return is -3.2%. When the yield declines by the same amount, the total return is 11.8%. Taking out the 4.0% coupon that is part of the total return calculation, the price decrease for a one-percentage-point rise in yields is 7.2% (i.e., -3.2% - 4.0%), while the price increase for a one-percentage-point decline in yields is larger at 7.8% (i.e., 11.8% - 4.0%).

The longer the investment horizon, the more important coupon income is in determining the return of the bond. One reason is that the duration of a bond shortens as the time to maturity approaches. Also, the more positively-sloped the yield curve, and the longer the holding period, the more you get paid to take the extra price risk of longer maturities.

Table 5: Sensitivity of total returns to changes in market yields, non-callable par-priced bond (one-year horizon)

<table>
<thead>
<tr>
<th>Maturity</th>
<th>Coupon/Yield</th>
<th>Change in Yield (Percentage points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 years</td>
<td>1.50%</td>
<td>-2 0.5% -1 1.5% 0 0.5% +1 -0.4%</td>
</tr>
<tr>
<td>3 years</td>
<td>2.00%</td>
<td>NA 2.5% 6.0% 4.0% 2.0% 0.1% -1.8%</td>
</tr>
<tr>
<td>5 years</td>
<td>3.00%</td>
<td>10.8% 10.8% 6.8% 6.8% 3.0% -0.7% -4.2%</td>
</tr>
<tr>
<td>10 years</td>
<td>4.00%</td>
<td>20.4% 20.4% 11.8% 11.8% 4.0% -3.2% -9.8%</td>
</tr>
<tr>
<td>30 years</td>
<td>5.00%</td>
<td>43.6% 43.6% 22.1% 22.1% 5.0% -8.7% -19.7%</td>
</tr>
</tbody>
</table>

Source: BofA Merrill Lynch Global Research
Wrapping it up: duration, convexity, yield changes and performance
The price performance of your bonds will depend upon their duration and convexity and the direction of bond yields. Other things equal:

- If you expect yields to rise, you should favor bonds with shorter durations, because their price would decline by a smaller amount for a given rise in yields.

- If you expect yields to decline, emphasize bonds with longer durations, because they would show a bigger price increase for a given decline in yields, and avoid negatively-convex (callable) bonds, because the upside in price is limited by the call price.

- A stable yield environment presents a case for negatively-convex bonds. Negatively-convex bonds usually have higher yields than otherwise similar positively-convex bonds because of their inferior price return prospects when yields change.
Appendix: Calculating duration and convexity

In Table 7 we calculate the Macaulay duration of a 10-year issue, with a par price of $100, and a 5.00% coupon, paid semiannually. The issue is priced at par.

Table 7: Duration Calculation

<table>
<thead>
<tr>
<th>Period #</th>
<th>Payment ($)</th>
<th>Present Value ($)</th>
<th>Present Value as % of Bond Price</th>
<th>Maturity (Years)</th>
<th>Time-Weighted Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5</td>
<td>2.44</td>
<td>2.44%</td>
<td>0.5</td>
<td>0.0122</td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
<td>2.38</td>
<td>2.38%</td>
<td>1.0</td>
<td>0.0238</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>2.32</td>
<td>2.32%</td>
<td>1.5</td>
<td>0.0348</td>
</tr>
<tr>
<td>4</td>
<td>2.5</td>
<td>2.26</td>
<td>2.26%</td>
<td>2.0</td>
<td>0.0453</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>2.21</td>
<td>2.21%</td>
<td>2.5</td>
<td>0.0552</td>
</tr>
<tr>
<td>6</td>
<td>2.5</td>
<td>2.16</td>
<td>2.16%</td>
<td>3.0</td>
<td>0.0647</td>
</tr>
<tr>
<td>7</td>
<td>2.5</td>
<td>2.10</td>
<td>2.10%</td>
<td>3.5</td>
<td>0.0736</td>
</tr>
<tr>
<td>8</td>
<td>2.5</td>
<td>2.05</td>
<td>2.05%</td>
<td>4.0</td>
<td>0.0821</td>
</tr>
<tr>
<td>9</td>
<td>2.5</td>
<td>2.00</td>
<td>2.00%</td>
<td>4.5</td>
<td>0.0901</td>
</tr>
<tr>
<td>10</td>
<td>2.5</td>
<td>1.95</td>
<td>1.95%</td>
<td>5.0</td>
<td>0.0976</td>
</tr>
<tr>
<td>11</td>
<td>2.5</td>
<td>1.91</td>
<td>1.91%</td>
<td>5.5</td>
<td>0.1048</td>
</tr>
<tr>
<td>12</td>
<td>2.5</td>
<td>1.86</td>
<td>1.86%</td>
<td>6.0</td>
<td>0.1115</td>
</tr>
<tr>
<td>13</td>
<td>2.5</td>
<td>1.81</td>
<td>1.81%</td>
<td>6.5</td>
<td>0.1179</td>
</tr>
<tr>
<td>14</td>
<td>2.5</td>
<td>1.77</td>
<td>1.77%</td>
<td>7.0</td>
<td>0.1239</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>1.73</td>
<td>1.73%</td>
<td>7.5</td>
<td>0.1295</td>
</tr>
<tr>
<td>16</td>
<td>2.5</td>
<td>1.68</td>
<td>1.68%</td>
<td>8.0</td>
<td>0.1347</td>
</tr>
<tr>
<td>17</td>
<td>2.5</td>
<td>1.64</td>
<td>1.64%</td>
<td>8.5</td>
<td>0.1397</td>
</tr>
<tr>
<td>18</td>
<td>2.5</td>
<td>1.60</td>
<td>1.60%</td>
<td>9.0</td>
<td>0.1443</td>
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<tr>
<td>19</td>
<td>2.5</td>
<td>1.56</td>
<td>1.56%</td>
<td>9.5</td>
<td>0.1486</td>
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<tr>
<td>20</td>
<td>102.5</td>
<td>100.55</td>
<td>100.00%</td>
<td>10.0</td>
<td>6.2553</td>
</tr>
</tbody>
</table>

Sum = Bond Price 100.00 100.00% Macaulay Duration 7.99

Source: BofA Merrill Lynch Global Research

**Step 1:** Break the security down into its component cash flows. The cash flows provided by the 10-year security consist of 20 coupon payments of $2.50 every six months for 10 years plus a principal payment of $100 at the end of the tenth year. The payment sequence is listed in Column #1 and the dollar amount of each payment is listed in Column #2.

**Step 2:** Determine the present value of this payment stream. The present value formula for a bond with semi-annual coupon payments is:

\[ 1/(1+r/2)^t \]

where \( r \) is the coupon rate (expressed as a decimal), and \( t \) is the number of payment periods. The present values of the issue’s cash flows (discounted at a 2.5% semi-annual rate) are listed in Column #3.

**Step 3:** Express the present value of each individual cash flow as a percentage of the price of the issue. Divide the present value of each payment (Column #3) by the current price of the security (100). The results are listed in Column #4. These are the weights.

**Step 4:** Determine the “maturity” of each individual cash flow. The maturity of each cash flow is the point in time (in years) at which an investor will receive the payment. Our security pays its first cash flow, a coupon payment, in six months. The maturity of this payment is 0.5 years. The next coupon payment is made six months later, and thus the maturity of this cash flow is 1 year, and so forth. The maturity of each payment is listed in Column #5.

**Step 5:** Multiply each maturity (Column #5) by its weight (Column #4), and sum the results. The results of this calculation are presented in Column #6. Our security has a weighted average maturity, or Macaulay duration, of 7.99.
Step 6: Calculate the **Modified Duration** by the following formula:

Modified Duration = Macaulay Duration / (1 + y/2), where y is the yield on the bond.

In our example, y = 5%, so the modified duration is: 7.99/(1+.05/2) = 7.79. Table 8 below shows the duration statistic for par-price bonds with different maturities and yields.

**Additional formulas for option-free bonds with semi-annual coupons**

- **Convexity** (in years) = (1 x 2 x PVCF1 + 2 x 3 x PVCF2 + ... + n (n + 1) x PVCFn) / ((1 + y / 2)^2 x 2^2 x PVTCF x 100)

where PVCF_n is present value of cash flow in period n, PVTCF is the total of present values, and the security pays a semiannual coupon. In our example, the values for the formula are:

Convexity = 30,942.47/((1+.05/2)^2 x 2^2 x 100 x 100) = 0.73629 years.

- **Expected price change Using Duration and Convexity (%)** = - Percentage Point Change In Yield x Modified Duration + .5 x Convexity x Change In Yield^2 x 100

Using our example of the 10-year security with a 7.79 modified duration and 0.73629 convexity, the expected price change for a 1% decline in yields is:

Expected Price Change = -1% x 7.79 +.5 x .73629 x .01^2 x 100 = 8.16%.

In other words, the expected price change from duration alone is 7.79%. The expected price change from duration and convexity combined is 8.16%. These are the calculations that underlie the figures shown in Table 5 on page 11.

**Computed values of modified duration**

**Table 8: Modified duration for option-free, par-priced bonds, with semi-annual coupons**

<table>
<thead>
<tr>
<th>Maturity (years)</th>
<th>1%</th>
<th>2%</th>
<th>3%</th>
<th>4%</th>
<th>5%</th>
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<th>10%</th>
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<td>0.96</td>
<td>0.95</td>
<td>0.94</td>
<td>0.94</td>
<td>0.93</td>
<td>-----</td>
</tr>
<tr>
<td>2</td>
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<td>11.31</td>
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<td>9.46</td>
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</table>

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