Chapter 1 made it clear that the financial environment today is a lot riskier than it was prior to 1972. The variance—volatility—of interest rates, foreign exchange rates, and commodity prices is much greater today. The second message of Chapter 1 was that this increased volatility has had the effect of putting some otherwise well-managed firms into financial distress.

Although the CEO or CFO of a firm might find this discussion of the altered financial environment intellectually appealing, managers are usually more pragmatic, reacting with more specific questions: "Is my firm one of those that can be put out of business by this increased volatility? Is my firm exposed to interest rates? Foreign exchange rates? Commodity prices?"

It is these questions that this chapter addresses. We begin by describing the risk profile, a vehicle for summarizing the impact of financial price risk on a firm. Then we describe methods of actually measuring a firm’s exposure, first looking at the special case of a financial institution’s exposure to interest rate risk, and then broadening our scope to consider a general methodology.

The Risk Profile

Chapter 1, U.S. Savings and Loan institutions were cited as classic examples of firms subject to—and, indeed, ultimately damaged by—interest rate risk. With assets that had long maturities (e.g., 30-year rate mortgages) and liabilities that were repriced frequently (e.g., checking deposits), the value of the S&L was inversely related to interest
rates: as the interest rate rose—as the term structure shifted upward—the value of the S&L's assets declined significantly while the value of its liabilities changed little. The relation between interest rates and the value of the S&L is portrayed graphically in Figure 2.1. As interest rates rose (Δr > 0), that is, as actual interest rates, r, rose above the expected rates, r∗, the value of the firm declined (ΔV < 0). The risk profile summarizes this relation.1

For the S&Ls, the exposure to interest rates was apparent in a firm’s balance sheet; the exposure was due to a mismatch of maturities for assets and liabilities. However, a firm may have economic exposures that are not reflected in the balance sheet. For example, for a forest products firm, increases in interest rates decrease the demand for housing, thereby

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1. In fact, the relation between the value of the firm and the interest rate is non-linear. However, in this text we will, for simplicity of exposition, assume the relation to be linear; that is, we ignore the issue of convexity.

Figure 3.1. The Risk Profile for a U.S. S&L.

As actual interest rates, r, rise above expected rates, r∗ (Δr>0) the value of the S&L's assets declines relative to the value of its liabilities; thus the value of the firm declines (ΔV<0).
identifying and Measuring Financial Risk 23

decreasing the demand for lumber. Thus, as cash inflows decline, the value of the forest products firm declines. However, this economic exposure, illustrated in Figure 2-2, will not appear on the firm's balance sheet.

We observe the same kind of relation in the case of foreign exchange risk. In some instances, the foreign exchange exposure is apparent. For example, the following is a case of a transaction exposure: A U.S. importer orders products from Germany, paying in deutsche marks (DM) when the products are delivered within 90 days. If, during the 90 days, the price of a DM rises (the value of the dollar declines), the U.S. importer will have to pay more for the product. In this case, illustrated in Figure 2-3, an increase in the price of the foreign currency leads to a decrease in the value of the importer.

Figure 2-2. The Risk Profile for a Forest Products Firm.

\[ \Delta / r - r^e \]

Risk profile

As actual interest rates, \( r \), rise relative to the rate expected, \( r^e \), the demand for housing declines. Consequently, housing starts decline and the demand for lumber drops. As cash inflows to the forest products firm decrease, the value of the firm decreases (\( \Delta V < 0 \)).
Firms with international operations have become adept at dealing both with these transaction exposures and with the translation exposures that result from the translation of overseas assets and liabilities into a company's domestic currency for accounting purposes. However, a more subtle problem is the recognition of a firm's economic exposures— also referred to as competitive exposures. For example, Eastman Kodak's exchange rate risk management policy is based on the recognition of its economic exposures.\(^2\) When the value of the yen rises, Kodak film becomes more competitive with Fuji film in Japan, while Fuji becomes less competitive in Kodak's domestic market. This exposure is illustrated in Figure 2-4.

Not surprisingly, the same kinds of relations appear with respect to commodity price risk. In some cases, the exposures are apparent. For

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\(^2\) This example is based on Paul Dickens, "Daring to Hedge the Unhedgable," *Euracemy Corporate Finance* no. 45 (August 1988): 11–13.
As the price of the yen rises (\(\Delta P_y > 0\)), Kodak's ability to market more effectively in Japan while Fuji is put at a disadvantage in the United States.

example, as the price of oil rises and revenues to oil producers rise, the value of an oil producer rises (see Part (a) of Figure 2.5). However, rising oil prices mean rising costs for an airline; rising oil prices are thus linked to falling firm values (see Part (b) of Figure 2.5).

Alternatively, the exposures can be subtle. Consider the aluminum production example introduced in Chapter 1. A primary input to aluminum production is electrical energy. Aluminum manufacturers in Iceland use electricity generated by that country's abundant geothermal energy. As the price of oil rises, the costs to competitors rise but the cost for Icelandic producers remain unchanged. Hence, as oil prices

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3. This presupposes that the demand for oil is price-inelastic.
4. There is no doubt that the value of an oil-producing firm is positively related to the price of oil. However, we would be remiss if we failed to note indications that this positive relation may be becoming weaker. See, for example, Alanna Sullivan, "Restructured Oil Firms Suffer Linebackers as Crude Prices Plunge," The Wall Street Journal, October 3, 1998, p. A7.
Figure 2-5 (a) The Risk Profile for an Oil Producer. (b) The Risk Profile for an Oil User.

For an oil producer, rising oil prices ($\Delta P_{oil} > 0$) and rising revenues lead to an increase in the value of the firm ($\Delta V > 0$).

(b) For an oil user, rising oil prices ($\Delta P_{oil} > 0$) mean increasing costs; so the value of the firm declines ($\Delta V < 0$).
rise, Icelandic producers' costs fall relative to those of their competitors; thus, the value of the Icelandic firms rises. It is when oil prices fall and their competitors' costs decline that the Icelandic aluminum producers worry (see Figure 2-6).

For any financial price risk—interest rate risk, foreign exchange risk, or commodity price risk—the risk profile is a useful means of summarizing the exposure of the firm. The question to be answered is: How is the slope of the risk profile (ΔW/ΔP) determined? That is, does one estimate how much the value of the firm changes for a given change in the financial price? It is in this question that the remainder of this chapter is addressed.

5. For this useful story about Icelandic aluminum producers, we are indebted to J. Nicholas Robinson of Chase Manhattan Bank.

Figure 2-6. Risk Profile for an Icelandic Aluminum Producer.

As the price of oil rises (ΔP_oil > 0) the costs for firms competing with Icelandic aluminum producers rise. Consequently, value for the Icelandic firm increases, leading to an increase in the value of the firm (ΔW > 0).
Quantifying Financial Price Risk: Interest Rate Risk for a Financial Institution

The S&L example is an extreme case—almost a caricature—of interest rate exposure for a financial institution. But because of the mismatches between the maturities of assets and the maturities of liabilities that occur as a normal course of business, all financial institutions face interest rate risk.

Maturity Gap

The method most financial institutions use to manage their exposure to interest rate changes is called the *maturity gap* approach. The approach is so named because the procedure is to determine the "gap" between the dollar amounts of rate-sensitive assets (RSA) and rate-sensitive liabilities (RSL):  

\[
\text{Gap} = \text{RSA} - \text{RSL} \tag{2-1}
\]

Changes in interest rates affect a financial institution via changing the institution’s net interest income (NII). Hence, if the gap is known, the impact on the firm of changes in the interest rate is given by:

\[
\Delta \text{NII} = \text{Gap} \times (\Delta r) \tag{2-2}
\]

To see how this works, consider the two hypothetical banks presented in Figure 2-7. Bank 1 is a "standard bank." Its assets are primarily business and mortgage loans with maturities of one year or longer; the bank’s liabilities are primarily demand and savings deposits with maturities less than a year. Within the one-year gapping period, the assets that are rate-sensitive—those that will be repriced—are the three-

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6. Our discussion of the maturity gap model is taken from Alden L. Toevs, "Measuring and Managing Interest Rate Risk: A Guide to Asset/Liability Models Used in Banks and Thrifts," Morgan Stanley Fixed Income Analytical Research Paper, October 1984. (An earlier version of this paper appeared in *Economic Review*, the Federal Reserve Bank of San Francisco, Spring 1983.) In this discussion, we consider only the basic model. For extensions of the model to the periodic gap model or simulation models, see the above-referenced work.

7. Assets and liabilities that are "rate-sensitive" are those that will be repriced during the gapping period.
Figure 2.7. Two Hypothetical Banks (all values in $ millions):

<table>
<thead>
<tr>
<th>Assets</th>
<th>Bank 1</th>
<th>Liabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-month or less</td>
<td>100</td>
<td>3-month or less</td>
</tr>
<tr>
<td>6-month</td>
<td>100</td>
<td>6-month</td>
</tr>
<tr>
<td>12-month</td>
<td>400</td>
<td>12-month</td>
</tr>
<tr>
<td>Over 12-month</td>
<td>400</td>
<td>Over 12-month</td>
</tr>
<tr>
<td>Total</td>
<td>1,500</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assets</th>
<th>Bank 2</th>
<th>Liabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-month or less</td>
<td>100</td>
<td>3-month or less</td>
</tr>
<tr>
<td>6-month</td>
<td>500</td>
<td>6-month</td>
</tr>
<tr>
<td>12-month</td>
<td>400</td>
<td>12-month</td>
</tr>
<tr>
<td>Over 12-month</td>
<td>400</td>
<td>Over 12-month</td>
</tr>
<tr>
<td>Total</td>
<td>1,000</td>
<td></td>
</tr>
</tbody>
</table>

Month assets ($100), the six-month assets ($100), and the twelve-month assets ($400); so RSA = $600. Within the one-year gapping period, the liabilities that are rate sensitive are the three-month liabilities ($400), the six-month liabilities ($300), and the twelve-month liabilities ($200); so RSL = $900. Hence, bank 1 has a gap of $300 million:

Bank 1: \[ \text{Gap} = \text{RSA} - \text{RSL} = $600 - $900 = -$300 \]

Bank 2 has precisely the same distribution of assets but this bank has concentrated on funding itself with one-year and longer-term CDs. Consequently, RSA for this bank remains at $600 but the liabilities that are rate sensitive during the one-year gapping period decline to $500, $100 in three-month liabilities, $100 in six-month liabilities, and $300 in twelve-month liabilities. Hence, bank 2 has a positive gap of $100 million:

Bank 2: \[ \text{Gap} = \text{RSA} - \text{RSL} = $600 - $500 = $100 \]

Once the gap is known, the impact of changes in the interest can be calculated directly using Equation (2-2). For instance, if interest rates increase by 1% (100 basis points), the NII for bank 1 will decrease by $3 million:

Bank 1: \[ \Delta \text{NII} = -300 \times 0.01 = -3 \]
and the NII for bank 2 will increase by $1 million:

Bank 2: $\Delta r = 0.01$: \[ \Delta \text{NII} = +100 \times 0.01 = +1 \]

If interest rates decrease by 1%, the NII for bank 1 will increase by $3 million, and the NII for bank 2 will decrease by $1 million.

These changes in NII for banks 1 and 2 are displayed in a gap diagram in Figure 2-8. A gap diagram shows the changes in NII that will occur for particular changes in interest rates (e.g., up 1% or down 1%) for various asset-liability structures (e.g., a negative gap of $300 or a positive gap of $100). The risk profile illustrated earlier shows the changes in the value of the firm with respect to changes in interest rates for a given asset-liability structure. In essence, the risk profile is like a “slice” of the gap diagram. For example, if we “slice” Figure 2-8 at the - $350 million gap position, it is easy to see that an increase of 100 basis points in the interest rate will increase NII by $3 million, and a decrease of 100
basin points in the interest rate will decrease NII by $3 million. This "slice" of the gap diagram—the interest rate risk profile for bank 1—is displayed in Figure 2-9. Hence, for the special case of interest rate risk for a financial institution, the question of this chapter—"How is the change in the value of a firm determined for a specified change in the financial price?"—can be answered using the gap model.

Duration

Consider the bank balance sheet shown in Figure 2-10. We could examine this bank’s exposure to interest rates by using the gap model to estimate the impact on NII of changes in interest rates, that is, $\Delta \text{NII} \Delta \text{r}$. Alternatively, we could use duration analysis. In essence, the duration of a financial instrument provides a measure of when, on average,


Figure 2-9. Risk Profile for a Bank with a Gap of $-300.
the present value of the instrument is received. For illustration, we will look at the duration of two of the instruments on the bank’s balance sheet: the five-year CD and the business loan, the cash flows for which are sketched in Figure 2-11.

**The CD.** The CD is simple. It is a zero coupon instrument so all of the value is received at maturity. Hence, the duration of the five-year CD is five years.

**The Business Loan.** Suppose that the business loan has a maturity of 2.5 years and is amortizing (has a sinking fund). As the cash flows in
Figure 2-11 illustrate, value is received prior to maturity; thus, it follows that the duration of the instrument is less than 2.5 years. To find out how much less, we can refer to Table 2-1. Columns 1-4 indicate the value of the bond. Column 1 gives the times that the cash flows in column 2 are paid. Using the discount rates* in column 3, the present values are determined (column 4), and the sum of these present values yields the $400 value of this loan. To determine when, on average, the present value is received, we need to calculate the weighted average time of receipt. Column 5 provides the weights; for example, at time 0.5 years, $86.70/400 = 0.22$ of the total present value of the instrument is received. Multiplying these weights (column 5) by the times the cash flows are received (column 1) and summing gives the weighted average time of receipt—the duration of this business loan—as 1.45 years.

In algebraic form, the duration, $D_i$, is calculated above is

$$D = \sum_{i=1}^{n} \left( \frac{PV_i}{V} \right) t_i$$

(2-3)

where $PV_i$ is the present value of the cash flow received in time period $i$, and $V$ is the market value of the instrument.

Duration effectively converts a security to its zero-coupon equivalent. In addition, duration provides a means of relating changes in interest

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* These discount rates are zero-coupon rates that include the risk premium appropriate for this instrument.

Table 2-1. Calculation of the Value and Duration of the Business Loan.

<table>
<thead>
<tr>
<th>Time to receive (years)</th>
<th>Cash flow</th>
<th>Discount rate</th>
<th>PV</th>
<th>Weight</th>
<th>Weight × Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>90</td>
<td>7.75%</td>
<td>86.70</td>
<td>0.22</td>
<td>0.11</td>
</tr>
<tr>
<td>1.0</td>
<td>90</td>
<td>8.00</td>
<td>83.33</td>
<td>0.21</td>
<td>0.21</td>
</tr>
<tr>
<td>1.5</td>
<td>90</td>
<td>8.25</td>
<td>79.91</td>
<td>0.20</td>
<td>0.31</td>
</tr>
<tr>
<td>2.0</td>
<td>90</td>
<td>8.35</td>
<td>76.66</td>
<td>0.19</td>
<td>0.38</td>
</tr>
<tr>
<td>2.5</td>
<td>90</td>
<td>8.50</td>
<td>73.40</td>
<td>0.18</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>400.00</td>
<td></td>
<td>1.45</td>
</tr>
</tbody>
</table>
rates to changes in the value of the security. Specifically,\(^\text{10}\)
\[
D = -\frac{\Delta V}{\Delta r} \times \frac{(1 + r)}{V} \tag{2-4}
\]
where \(D\) is the duration of the security as calculated above, \(V\) is the
market value of the security, and \(r\) is the interest rate. Rewriting
Equation (2-4), we can express the percentage change in the value of
the security in terms of the percentage change in the discount rate, \((1 + r)\),
and the duration of the security:
\[
\frac{\Delta V}{V} = -\frac{\Delta (1 + r)}{(1 + r)} \times D \tag{2-4'}
\]
For example, if the discount rate increases by 1\% (i.e., if \(\Delta (1 + r)\)\((1 + r)\) = 0.01), the market value of the five-year CD will decrease by 5\%:
\[
\frac{\Delta V}{V} = -(0.01) \times 5.0 = -0.05
\]
However, the same increase in the discount rate would decrease the
value of the 2.5-year business loan by only 1.45\%:
\[
\frac{\Delta V}{V} = -(0.01) \times 1.45 = -0.0145
\]
Hence, duration provides a method for relating the change in the value
of the security to changes in interest rates.

Since duration is additive, the duration technique can be expanded
deal with the impact of changes in interest rates on the value of
the entire firm. For a portfolio with \(n\) assets having market values \(V_i\) and
durations \(D_i\), the duration of the portfolio is
\[
D_{\text{portfolio}} = \frac{\sum V_i D_i}{\sum V_i} \tag{2-5}
\]
We can use Equation (2-5) to examine the duration of the assets of

\(^{10}\) Equation (2-4) holds only as an approximation. For true equality, we would have
to replace our simple duration measure with "modified duration"—a level of detail finer
than we wish here. For a development of this relation, the interested reader should see
George G. Kaufman, G. O. Horwag, and Alden Tervis, eds., Innovations in Bond
Portfolio Management: Duration Analysis and Immunization (Greenwich, Conn.: IAI
the bank in question. We already know that the duration of the business loan is 1.45 years. Suppose that the duration of the mortgage loans was calculated as 6.84 years. By definition, the duration of the cash is 0.0. Hence, the duration of the assets is

\[ D_a = \frac{(100 \times 0.0) + (400 \times 1.45) + (500 \times 6.84)}{1,900} = 4.0 \]

Likewise, we can examine the duration of the deposits. We have CDs with durations of one and five years so

\[ D_d = \frac{(600 \times 1.0) + (300 \times 5.0)}{900} = 2.33 \]

Combining the preceding results, we can calculate the duration of the equity: the elasticity of the value of the firm with respect to the discount rate, \((1 + r)\). Using Equation (2-5),

\[ D_{equity} = \frac{(V_e \times D_a) - (V_d \times D_d)}{V_e} \]

\[ = \frac{(1,006 \times 4.0) - (900 \times 2.33)}{100} = 19.03 \]

Therefore, if the discount rate increases by 1%, the value of the equity of this firm will decline by 19.03%.

Duration provides an relation between interest rates and the value of the firm. So in the context of our discussion so far, duration provides an alternative methodology for measuring the shape of the risk profile.

**Quantifying Financial Price Risk: The General Case**

Although gap and duration work well for financial institutions, these techniques break down in the examination of the interest rate sensitivity of a nonfinancial institution; and neither gap nor duration is of use in examining a firm’s sensitivity to movements in foreign exchange rates or commodity prices. What is needed is a more general method for quantifying financial price risk—a method that can handle firms other than financial institutions and financial prices other than interest rates.

To get a measure of the responsiveness of the value of the firm to changes in the financial prices, we must first define a measure of the value of the firm. As with interest rate risk for financial institutions,
this value measure could be a flow measure (gap analysis uses net interest income) or a stock measure (duration uses the market value of the portfolio).

Flow Measures
Within a specific firm, estimation of the sensitivity of income flows is an analysis that can be performed as part of the budgeting/planning process. The trade press notes that firms have begun using simulation models to examine the responsiveness of pretax income to changes in interest rates, exchange rates, and commodity prices. Beginning with base-case assumptions about the financial prices, the firm obtains a forecast for revenues, costs, and the resulting pretax income. Then the firm considers alternative values for an interest rate, an exchange rate, or a commodity price and obtains a new forecast for revenues, costs, and pretax income. By observing how the firm’s forecast sales, costs, and income move in response to changes in these financial prices, the managers of the firm are able to trace a risk profile similar to those illustrated in Figures 2-1 through 2-6.

In the accomplishment of such an estimation, two interrelated problems confront the analyst: (1) This approach requires substantial data, and (2) it relies on the ability of the researcher to make accurate, explicit forecasts for sales and costs under alternative scenarios about the financial prices. Hence, such an approach is generally possible only for analysts within a specific firm.

Stock Measures
Given the data requirements just noted, analysts outside the firm generally rely on market valuations, the most widely used of which is the market value of the equity. Using a technique similar to that by which analysts obtain the firm’s "beta," it is possible to measure the historical sensitivity of the equity value to changes in interest rates, foreign exchange rates, and commodity prices.

In Part (a) of Figure 2-12, we have drawn a general risk profile, relating deviations in the value of the firm from its expected value ($V - V_0$) to deviations in the financial price from its expected value. In Part

11. See, for instance, Paul Dirks. op. cit.
12. In the context of the financial prices we are examining, this expected price is the forward price.
Figure 2-12. (a) A Risk Profile in \((\Delta V, \Delta P)\) Space. (b) A Risk Profile in \((V, P)\) Space.

(b), we have transferred this risk profile from \((\Delta V, \Delta P)\) space to \((V, P)\) space; that is, the point \((\Delta V = 0, \Delta P = 0)\) in part (a) is at \((V = V^*, P = P^*)\) in (b).

Figure 2-12(c) suggests a simple methodology for estimating the slope of the risk profile for any firm: Use the firm’s share price as the measure of the value of the firm (i.e., define \(S_t = V_t\)). Using time series data on the firm’s share price and on the financial price, estimate via linear regression the equation:

\[
S_t = \alpha_0 + \alpha_1 P_t
\]  

(2-6)
In Equation (2-6) the parameter $c_1$ is the slope term, $\Delta V / \Delta P$; thus, it appears that the estimate of $c_1$ would provide the slope estimate we seek. There are, however, two problems with this simple methodology. First, models of corporate finance have shown that share price follows a random walk. Empirically, this problem can be dealt with by using rates of return in place of prices. That is, we could change Equation (2-6) to

$$R_t = a + b(\Delta P/P)_t$$

where $R_t$ is the rate of return in period $t$ for holding the share of stock, and $\Delta P/P$ is the percentage change in the value of the financial asset; for example, if we wished to estimate the sensitivity of the value of the firm to six-month LIBOR, $\Delta P/P$ would be the percentage change in the value of a six-month Eurodollar deposit. The parameter $b$ measures the responsiveness of firm value to the financial price, that is, the elasticity of share price with respect to the financial price.

Second, financial price risk is only one part of the total risk a shareholder faces. In the jargon of corporate finance, total risk can be divided into market risk and diversifiable risk. And, as we will discuss in depth in Chapter 18, financial price risk is a diversifiable risk: the risk to the shareholder that arises from interest rate changes, or from changes in foreign exchange rates, or from changes in commodity prices is one that can be eliminated by holding a well-diversified portfolio of securities. Equation (2-6) is in effect attributed total risk (the variance in $R_t$) only to diversifiable risk (the variance in $\Delta P/P$). Market risk must be added to this equation; that is, we must decompose the total variance in $R_t$ into the variance attributable to the variance in $\Delta P/P$ as well as the variance attributable to variance in the market returns.

The market risk of a security is measured by the responsiveness of share returns to the returns on the market portfolio. The so-called market model is $R_t = a + bR_m$, where $R_m$ is the return on the market portfolio and $b$ measures market risk. Consequently, expanding Equation (2-6) to reflect market risk gives

$$R_t = a + bR_m + b(\Delta F/P)_t$$

13. This share price follows a random walk derives from efficient financial markets. A review of the efficient markets proposition and of the empirical evidence is contained in any corporate finance text; see, for example, Chapter 17 Richard Brealey and Stewart Myers, Principles of Corporate Finance, 2nd ed (New York: McGraw-Hill, 1984).
where $\beta$ reflects the market risk of security $j$, and $b$ reflects the responsiveness of the return on share $j$ to changes in the financial price. Using a more concrete illustration, suppose we wish to determine the sensitivity of a firm to:

- the one-year T-bill interest rate
- the deutsche mark/dollar exchange rate
- the pound sterling/dollar exchange rate
- the yen/dollar exchange rate
- the price of oil

Using Equation (2-7), this can be done by estimating the regression equation:

$$R_i = \alpha + \beta R_{MK} + b_1(\Delta P_{TB}/P_{TB}) + b_2(\Delta P_{DM}/P_{DM}) + b_3(\Delta P_{PL}/P_{PL}) + b_4(\Delta P_{YD}/P_{YD}) + b_5(\Delta P_{PO}/P_{PO}),$$

where $R_i$ is the rate of return for holding a share of the firm's stock; $R_{MK}$ is the rate of return for holding the market portfolio; $\Delta P_{TB}/P_{TB}$ is the percentage change in the price of a one-year T-bill; $\Delta P_{DM}/P_{DM}, \Delta P_{PL}/P_{PL}, \Delta P_{YD}/P_{YD}$ are the percentage changes in the dollar prices of the three foreign currencies; and $\Delta P_{PO}/P_{PO}$ is the percentage change in the price of crude oil. The estimate of $b_i$ provides a measure of the sensitivity.

of the value of the firm to changes in the one-year T-bill rate; \( b_1 \), \( b_2 \), and \( b_3 \) estimate the sensitivity to the exchange rates; and \( b_4 \) estimates the sensitivity to the oil price.\(^{15}\)

**Example**

**Estimation of financial price risk**

To illustrate the kind of results the preceding technique would yield, we looked at three examples: an industrial, Caterpillar; an oil company, Exxon; and a bank, Manufacturers Hanover. For the period January 6, 1964, to December 2, 1988, we calculated weekly (Friday close to Friday close) share returns and the corresponding weekly percentage changes in the price of a one-year T-bill; the dollar prices of a deutsche mark, a pound sterling, and a yen; and the price of West Texas Intermediate crude. Using these data, we estimated the regression equation, Equation (2-8). The resulting estimates of the firm’s beta and the sensitivities to the price of the T-bill, the foreign exchange rates, and the oil price are displayed in Table 2-2. Caterpillar appears to have a positive exposure to the one-year T-bill rate; the negative parameter estimate indicates that increases in the one-year T-bill rate

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15. These coefficients actually measure elasticities. Furthermore, had we used the percentage change \( (1 + \text{one-year T-bill rate}) \) instead of the percentage change in the price of the one-year T-bill, the coefficient \( b_4 \) could be interpreted as a “duration” measure (specifically, a measure of “the duration of equity”).

**Table 2-2. Betas and Exposure to Interest Rate, Foreign Exchange Rates, and Oil Prices**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>t value</th>
<th>Parameter</th>
<th>Estimate</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caterpillar</td>
<td>Exxon</td>
<td>Manufacturers Hanover</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta</td>
<td>1.25**</td>
<td>13.02</td>
<td>0.60**</td>
<td>9.51</td>
<td>0.54**</td>
</tr>
<tr>
<td>Price of 1 yr T-bill</td>
<td>-4.45**</td>
<td>3.14</td>
<td>0.76</td>
<td>0.81</td>
<td>2.27*</td>
</tr>
<tr>
<td>Price of DM</td>
<td>0.228</td>
<td>0.92</td>
<td>-0.122</td>
<td>0.75</td>
<td>-0.48*</td>
</tr>
<tr>
<td>Price of sterling</td>
<td>-0.126</td>
<td>0.61</td>
<td>0.235*</td>
<td>1.65</td>
<td>0.365*</td>
</tr>
<tr>
<td>Price of yen</td>
<td>0.227</td>
<td>1.06</td>
<td>-0.180</td>
<td>1.34</td>
<td>-0.086</td>
</tr>
<tr>
<td>Price of WTI crude</td>
<td>-0.010</td>
<td>0.23</td>
<td>0.059**</td>
<td>3.28</td>
<td>0.125**</td>
</tr>
</tbody>
</table>

* Significant at 90%
** Significant at 95%
(decreases in the price of the T-bill) lead to increases in the value of the firm. Somewhat more surprising, in the context of much that has been written about Caterpillar, is the lack of any significant exposure to the yen. This result is more understandable if we decompose this five-year span and look at Caterpillar’s sensitivity to the price of the yen year-by-year:

<table>
<thead>
<tr>
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<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% change in yen</td>
<td>1.14</td>
<td>0.77</td>
<td>-0.23</td>
<td>-0.42</td>
<td>-0.49</td>
</tr>
<tr>
<td>% change in yen/price</td>
<td>1.23</td>
<td>0.62</td>
<td>-0.51</td>
<td>0.58</td>
<td>1.11</td>
</tr>
</tbody>
</table>

The data reflects the fact that as Caterpillar has moved its production facilities, the firm changed from being positively exposed to the yen (an increase in the value of the dollar) to being negatively exposed to the yen (an increase in the value of the dollar helps Caterpillar).

Exxon does not appear to have a significant exposure to the interest rate (at least to the one-year T-bill rate). Exxon does exhibit the anticipated exposure to the price of oil: increases in the price of crude oil are linked to increases in the value of Exxon. Also, as has been reported in the trade press, if we look at the sensitivity to oil price over time, our estimates suggest that Exxon’s exposure to the price of oil has been declining—in magnitude and, generally, in significance:

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% change in oil</td>
<td>0.82</td>
<td>0.17</td>
<td>0.09</td>
<td>0.12</td>
<td>0.05</td>
</tr>
<tr>
<td>% change in oil/price</td>
<td>4.05</td>
<td>0.97</td>
<td>3.44</td>
<td>1.13</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Given its international production and distribution, as well as its international portfolio of assets, Exxon also exhibits exposure to foreign exchange rates. Our estimates suggest that Exxon benefits from an increase in the value of the pound (and there is some indication that this may be undermined by an increase in the value of the yen).

Given the tendency for a bank to accept short-term deposits to fund longer-dated assets (loans), it is not surprising that our estimates for Manufacturers汉over indicate a marginally significant inverse exposure to interest rates, the positive parameter estimate indicates that an increase in the one-year T-bill rate (a decrease in the price of the T-bill) will lead to a decrease in the value of the bank. Although this is interesting in and of itself, more information may be gleaned if the analyst compares this parameter estimate with those of other firms in the same industry. In the following table, we can compare the
An overview

The estimated sensitivity of Manufacturers Hanover to the one-year T-bill rate is compared to that of other banks:

<table>
<thead>
<tr>
<th>Bank</th>
<th>Estimated sensitivity</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank of America</td>
<td>2.2</td>
<td>1.13</td>
</tr>
<tr>
<td>Bankers Trust</td>
<td>1.1</td>
<td>0.88</td>
</tr>
<tr>
<td>Chase</td>
<td>1.6</td>
<td>1.15</td>
</tr>
<tr>
<td>First Chicago</td>
<td>2.0</td>
<td>1.22</td>
</tr>
<tr>
<td>Manufacturers Hanover</td>
<td>2.3</td>
<td>1.62</td>
</tr>
</tbody>
</table>

In addition to the anticipated interest rate exposure, our estimates suggest that Manufacturers Hanover also is exposed to other financial price risks. Our estimates indicate significant foreign exchange risk, due perhaps to foreign lending or foreign operations. It appears this bank is also exposed to oil price risk; a rising oil price is linked to an increase in the value of Manufacturers Hanover.

16. Our estimates suggest that Manufacturers Hanover is benefited by increases in the value of the pound and harmed by increases in the value of the deutsche mark. We obtained generally the same estimates for Chase Manhattan Bank.
17. We obtained similar results for Chase Manhattan and Bank of America.