CHAPTER 20

Credit, Weather, Energy, and Insurance Derivatives

In this chapter we examine some recent innovations in derivative markets. We explain the products that have been developed to manage credit risk, weather risk, energy price risk, and the risks facing insurance companies. Some of the markets that we will talk about are in the early stages of their development. As they mature, we may well see significant changes in both the products that are offered and the ways they are used.

20.1 CREDIT DERIVATIVES

A credit derivative is a contract where the payoff depends on the credit worthiness of one or more commercial or sovereign entities. Its purpose is to allow credit risks to be traded and managed in much the same way as market risks.

Credit Default Swaps

The most popular credit derivative is a *credit default swap* (CDS). This is a contract that provides insurance against the risk of a default by particular company. The company is known as the *reference entity* and a default by the company is known as a *credit event*. The buyer of the insurance obtains the right to sell a particular bond issued by the company for its par value when a credit event occurs. The bond is known as the *reference obligation* and the total par value of the bond that can be sold is known as the swap's *notional principal*.

The buyer of the CDS makes periodic payments to the seller until the end of the life of the CDS or until a credit event occurs. A credit event usually requires a final accrual payment by the buyer. The swap is then settled either by physical delivery or in cash. If the terms of the swap require physical delivery, the swap buyer delivers the bonds to the seller in exchange for their par value. When there is cash settlement, the calculation agent polls dealers to determine the mid-market price, Q, of the reference obligation some specified number of days after the credit event. The cash settlement is then $(100 - Q)\%$ of the notional principal.

An example may help to illustrate how a typical deal is structured. Suppose that two parties enter into a five-year credit default swap on March 1, 2000. Assume that the notional principal is $100 million and the buyer agrees to pay 90 basis points annually for protection against default by the reference entity. If the reference entity does not default (that is, there is no credit event), the buyer receives no payoff and pays $900,000 on March 1 of each of the years 2001, 2002, 2003, 2004, and 2005. If there is a credit event, a substantial payoff is likely. Suppose that the buyer notifies the seller of a credit event on September 1, 2003 (halfway through the fourth year). If the contract specifies physical settlement, the buyer has the right to sell $100 million par value of the reference obligation for $100 million. If the contract requires cash settlement, the calculation agent would poll dealers to determine the mid-market value of the reference obligation a predesignated number of days after the credit event. If the value of the reference obligation proved to be $35 per $100 of par value, the cash payoff would be $65 million. In the case of either physical or cash settlement, the buyer would be required to pay to the seller the amount of the annual payment accrued between March 1, 2003, and September 1, 2003 (approximately $450,000), but no further payments would be required.

There are a number of variations on the standard credit default swap. In a *binary credit default swap*, the payoff in the event of a default is a specific dollar amount. In a *basket credit default swap*, a group of reference entities are specified, and there is a payoff when the first of these reference entities defaults. In a *contingent credit default swap*, the payoff requires both a credit event and an additional trigger. The additional trigger might be a credit event with respect to another reference entity or a specified movement in some market variable. In a *dynamic credit default swap*, the notional amount determining the payoff is linked to the mark-to-market value of a portfolio of swaps.

Total Return Swaps

In a total return swap, the return from one asset or group of assets is swapped for the return on another. The swap can be used to pass credit risks on to another party or to diversify credit risk by swapping one type of exposure for another. Consider two banks, TexBank and MicBank. TexBank is located in Texas and is primarily concerned with lending to the oil industry. MicBank is located in Michigan and is primarily concerned with lending to automotive manufacturers and their suppliers. To reduce its credit risk, TexBank could enter into a total return swap where the return on some of its loans are exchanged for a LIBOR-based return. MicBank could do the same. This would have the effect of passing the credit risks on to someone else. Alternatively, the two banks could enter into a total return swap where TexBank swaps the return on some of its oil loans for the return on some of MicBank's auto loans. This would achieve credit risk diversification for both sides.

Credit Spread Options

A credit spread option is an option on the spread between the yields earned on two assets. The option provides a payoff whenever the spread exceeds some level (the strike spread). Consider an investor with an investment in dollar-denominated bonds issued by Brazil. The investor could purchase an option that pays off whenever the yield on the bonds exceeds the yield on U.S. Treasuries by 500 basis points. The payoff could be calculated as the difference between the value of the bond with a 500 basis point spread and the market value of the bond. This option would limit the investor's exposure to the underlying sovereign credit.

20.2 WEATHER DERIVATIVES

Many companies are in the position where their performance is liable to be adversely affected by the weather.[1] It makes sense for these companies to consider hedging their weather risk in much the same way as they hedge foreign exchange or interest rate risks.

The first over-the-counter weather derivatives were introduced in 1997. To understand how they work, we explain two variables:

HDD: Heating degree days

CDD: Cooling degree days

A day's HDD is defined as

$$\text{HDD} = \max(0,\ 65 - A)$$

and a day's CDD is defined as

$$\text{CDD} = \max(0,\ A - 65)$$

where A is the average of the highest and lowest temperature during the day at a specified weather station, measured in degrees Fahrenheit. For example, if the maximum temperature during a day (midnight to midnight) is 68° Fahrenheit and the minimum temperature is 44° Fahrenheit, $A = 56$. The daily HDD is then 9 and the daily CDD is 0.

A typical over-the-counter product is a forward or option contract providing a payoff dependent on the cumulative HDD or CDD during a period. For example, an investment dealer could in January 2000 sell a client a call option on the cumulative HDD during February 2001 at the Chicago O'Hare Airport weather station with a strike of 700 and a payment rate of $10,000 per degree day. If the actual cumulative HDD is 820, the payoff is $1.2 million. Often contracts include a payment cap. If the payment cap in our example is $1.5 million, the contract is the equivalent of a bull spread. The client has a long call option on cumulative HDD with a strike price of 700 and a short call option with a strike price of 850.

A day's HDD is a measure of the volume of energy required for heating during the day. A day's CDD is a measure of the volume of energy required for cooling during the day. At the time of writing, most weather derivative contracts are entered into by energy producers and consumers. But retailers, supermarket chains, food and drink manufacturers, health service companies, agriculture companies, and companies in the leisure industry are also potential users of weather derivatives. The Weather Risk Management Association (www.wrma.org) has been formed to serve the interests of the weather risk management industry.

[1] The U.S. Department of Energy has estimated that one-seventh of the U.S. economy is subject to weather risk.

In September 1999 the Chicago Mercantile Exchange began trading weather futures and European options on weather futures. The contracts are on the cumulative HDD and CDD for a month observed at a weather station.[2] The contracts are settled in cash just after the end of the month once the HDD and CDD are known. One futures contract is on \$100 times the cumulative HDD or CDD. The HDD and CDD are calculated by a company, Earth Satellite Corporation, using automated data collection equipment.

Weather derivatives are usually priced using historical data. Consider, for example, the call option on the February 2001 HDD at Chicago O'Hare airport mentioned earlier. We could collect 50 years of data and estimate a probability distribution for the HDD. This in turn could be used to provide a probability distribution for the option payoff. Our estimate of the value of the option would be the mean of this distribution discounted at the risk-free rate.[3] We might want to adjust the probability distribution for temperature trends. For example, a linear regression might show that the cumulative February HDD is decreasing at a rate of 15 per year on average. The output from the regression can then be used to estimate a trend-adjusted probability distribution for the HDD in February 2001.

20.3 ENERGY DERIVATIVES

Energy companies are among the most active and sophisticated users of derivatives. Many energy products trade in both the over-the-counter market and on exchanges. In this section we will examine the trading in crude oil, natural gas, and electricity derivatives.

Crude Oil

Crude oil is one of the most important commodities in the world with global demand amounting to about 65 million barrels (8.9 million tonnes) daily. Ten-year fixed-price supply contracts have been commonplace in the over-the-counter market for many years. These are swaps where oil at a fixed price is exchanged for oil at a floating price.

In the 1970s the price of oil was highly volatile. The 1973 war in the Middle East led to a tripling of oil prices. The fall of the Shah of Iran in the late 1970s again increased prices. These events led oil producers and users to a realization that they needed more sophisticated tools for managing oil price risk. In the 1980s both the over-the-counter market and the exchange-traded market developed products to meet this need.

In the over-the-counter market, virtually any derivative that is available on common stocks or stock indices is now available with oil as the underlying asset. Swaps, forward contracts, and options are popular. Contracts sometimes require settlement in cash and sometimes require settlement by physical delivery (that is, by delivery of the oil).

Exchange-traded contracts are also popular. New York Mercantile Exchange (NYMEX) and the International Petroleum Exchange (IPE) trade a number of oil futures and futures options contracts. Some of the futures contracts are settled in cash; others

[2] The CME has introduced contracts for 10 different weather stations (Atlanta, Chicago, Cincinnati, Dallas, Des Moines, Las Vegas, New York, Philadelphia, Portland, and Tucson).

[3] This approach is theoretically correct because weather can reasonably be assumed to have no systematic risk.

are settled by physical delivery. For example the Brent crude oil futures traded on the IPE has cash settlement based on the Brent index price; the light sweet crude oil futures traded on NYMEX requires physical delivery. In both cases the amount of oil underlying one contract is 1,000 barrels. NYMEX also trades popular contracts on two refined products: heating oil and gasoline. In both cases one contract is for the delivery of 42,000 gallons.

Natural Gas

The natural gas industry throughout the world has been going through a period of deregulation and the elimination of state monopolies. The supplier of natural gas is now not necessarily the same company as the producer of the gas. Suppliers are faced with the problem of meeting daily demand.

A typical over-the-counter contract is for the delivery of a specified amount of natural gas at a roughly uniform rate over a one-month period. Forward contracts, options, and swaps are available in the over-the-counter market. The seller of gas is usually responsible for moving the gas through pipelines to the specified location. NYMEX trades a contract for the delivery of 10,000 million British thermal units of natural gas. The contract, if not closed out, requires physical delivery to be made during the delivery month at a roughly uniform rate to a particular hub in Louisiana. The IPE trades a similar contract in London.

Electricity

Electricity is an unusual commodity because it cannot easily be stored.[4] The maximum supply of electricity in a region at any moment is determined by the maximum capacity of all the electricity-producing plants in the region. In the United States there are 140 regions known as *control areas*. Demand and supply are first matched within a control area, and any excess power is sold to other control areas. It is this excess power that constitutes the wholesale market for electricity. The ability of one control area to sell power to another control area depends on the transmission capacity of the lines between the two areas. Transmission from one area to another involves a transmission cost, charged by the owner of the line, and there are generally some transmission or energy losses.

A major use of electricity is for air-conditioning systems. As a result the demand for electricity, and therefore its price, is much greater in the summer months than in the winter months. The nonstorability of electricity causes occasional very large movements in the spot price. Heat waves have been known to increase the spot price by as much as 1000% for short periods of time.

Like natural gas, electricity has been going through a period of deregulation and the elimination of state monopolies. This has been accompanied by the development of an electricity derivatives market. NYMEX now trades a futures contract on the price of electricity, and there is an active over-the-counter market in forward contracts, options, and swaps. A typical contract (exchange-traded or over-the-counter) allows one side to receive a specified number of megawatt hours for a specified price at a specified location during a particular month. In a 5×8 contract, power is received for

[4] Electricity producers with spare capacity often use it to pump water to the top of their hydroelectric plants so that it can be used to produce electricity at a later time. This is the closest they can get to storing this commodity.

five days a week (Monday to Friday) during the off-peak period (11 p.m. to 7 a.m.) for the specified month. In a 5×16 contract, power is received five days a week during the on-peak period (7 a.m. to 11 p.m.) for the specified month. In a 7×24 contract, it is received around the clock every day during the month. Option contracts have either daily exercise or monthly exercise. In the case of daily exercise, the option holder can choose on each day of the month (by giving one day's notice) to receive the specified amount of power at the specified strike price. When there is monthly exercise a single decision on whether to receive power for the whole month at the specified strike price is made at the beginning of the month.

An interesting contract in electricity and natural gas markets is what is known as a *swing option* or *take-and-pay option*. In this a minimum and maximum for the amount of power that must be purchased at a certain price by the option holder is specified for each day during a month and for the month in total. The option holder can change (or swing) the rate at which the power is purchased during the month, but usually there is a limit on the total number of changes that can be made.

Characteristics of Energy Prices

Energy prices, like stock prices, exhibit volatility. Unlike stock prices they also exhibit seasonality and mean reversion. (See Section 18.7 for a discussion of mean reversion.) The seasonality is created by the seasonal demand for energy and the difficulties in storing it. The mean reversion arises because short-term supply and demand imbalances cause prices to move away from their seasonal average, but once normal market conditions are restored they tend to be "pulled back" toward the seasonal average. For crude oil, volatility, seasonality, and mean reversion are all relatively low. For natural gas they are somewhat higher and for electricity they are very much greater. A typical volatility for oil is 20% per annum; for natural gas, it is 40% per annum; for electricity, volatility is often in the 100 to 200% per annum range.

How an Energy Producer Can Hedge Risks

There are two components to the risks facing an energy producer. One is the price risk; the other is the volume risk. Although prices do adjust to reflect volumes, there is a less-than-perfect relationship between the two, and energy producers have to take both into account when developing a hedging strategy. The price risk can be hedged using the energy derivative contracts discussed in this section. The volume risks can be hedged using the weather derivatives discussed in the previous section.

Define

Y: Profit for a month

P: Average energy prices for the month

T: Relevant temperature variable (HDD or CDD) for the month

An energy producer can use historical data to obtain a best fit linear regression relationship of the form

$$Y = a + bP + cT + \epsilon$$

where ϵ is the error term. The energy producer can then hedge risks for the month by taking a position of $-b$ in energy forwards or futures and a position of $-c$ in weather forwards or futures. The relationship can also be used to analyze the effectiveness of alternative option strategies.

20.4 INSURANCE DERIVATIVES

When derivative contracts are used for hedging purposes, they have many of the same characteristics as insurance contracts. Both types of contracts are designed to provide protection against adverse events. It is not surprising that many insurance companies have subsidiaries that trade derivatives and that many of the activities of insurance companies are becoming very similar to those of investment banks.

Traditionally the insurance industry has hedged its exposure to catastrophic (CAT) risks such as hurricanes and earthquakes using a practice known as reinsurance. Reinsurance contracts can take a number of forms. Suppose that an insurance company has an exposure of $100 million to earthquakes in California and wants to limit this to $30 million. One alternative is to enter into annual reinsurance contracts that cover on a pro rata basis 70% of its exposure. If California earthquake claims in a particular year total $50 million, the costs to the company would then be only $15 million. Another more popular alternative, involving lower reinsurance premiums, is to buy a series of reinsurance contracts covering what are known as *excess cost layers*. The first layer might provide indemnification for losses between $30 million and $40 million; the next layer might cover losses between $40 million and $50 million; and so on. Each reinsurance contract is known as an *excess-of-loss* reinsurance contract. The reinsurer has written a bull spread on the total losses. It is long a call option with a strike price equal to the lower end of the layer and short a call option with a strike price equal to the upper end of the layer.[5]

The principal providers of CAT reinsurance have traditionally been reinsurance companies and Lloyds syndicates (which are unlimited liability syndicates of wealthy individuals). In recent years the industry has come to the conclusion that its reinsurance needs have outstripped what can be provided from these traditional sources. It has searched for new ways in which capital markets can provide reinsurance. One of the events that caused the industry to rethink its practices was Hurricane Andrew in 1992, which caused about $15 billion of insurance costs in Florida. This exceeded the total of relevant insurance premiums received in Florida during the previous seven years. If Hurricane Andrew had hit Miami, it is estimated that insured losses would have exceeded $40 billion. Hurricane Andrew and other catastrophes have led to increases in insurance/reinsurance premiums.

Exchange-traded insurance futures contracts have been developed by the CBOT, but have not been highly successful. The over-the-counter market has come up with a number of products that are alternatives to traditional reinsurance. The most popular is a CAT bond. This is a bond issued by a subsidiary of an insurance company that pays a higher-than-normal interest rate. In exchange for the extra interest the holder of the bond agrees to provide an excess-of-cost reinsurance contract. Depending on the terms of the CAT bond, the interest or principal (or both) can be used to meet claims. In the example considered above where an insurance company wants protection for California earthquake losses between $30 million and $40 million, the insurance company could issue CAT bonds with a total principal of $10 million. In the event that the insurance company's California earthquake losses exceeded $30 million, bond holders would lose some or all of their principal. As an alternative the insurance company could cover this

[5] Reinsurance is also sometimes offered in the form of a lump sum if a certain loss level is reached. The reinsurer is then writing a cash-or-nothing binary call option on the losses.

excess cost layer by making a much bigger bond issue where only the bondholders' interest is at risk.

CAT bonds typically give a high probability of an above-normal rate of interest and a low probability of a high loss. Why would investors be interested in such instruments? The answer is that there are no statistically significant correlations between CAT risks and market returns.[6] CAT bonds are therefore an attractive addition to an investor's portfolio. They have no systematic risk so that their total risk can be completely diversified away in a large portfolio. If a CAT bond's expected return is greater than the risk-free interest rate (and typically it is), it has the potential to improve risk-return trade-offs.

20.5 SUMMARY

This chapter has shown that when there are risks to be managed, derivative markets have been very innovative in developing products to meet the needs of market participants.

The purpose of credit derivatives is to enable credit risks to be traded and managed in much the same way as market risks. A credit default swap provides insurance against the risk of a particular company defaulting. A total return swap allows a portfolio of credit risks to be managed. A credit spread option provides a payoff dependent on the spread between two rates.

The market for weather derivatives is relatively new, but is already attracting a lot of attention. Two measures, HDD and CDD, have been developed to describe the temperature during a month. These are used to define the payoffs on both exchange-traded and over-the-counter derivatives. No doubt as the weather derivatives market develops we will see contracts on rainfall, snow, and similar variables become more commonplace.

In energy markets, oil derivatives have been important for some time and play a key role in helping oil producers and oil consumers manage their price risk. Natural gas and electricity derivatives are relatively new. They became important for risk management when these markets were deregulated and state monopolies discontinued.

Insurance derivatives are now beginning to be an alternative traditional reinsurance as a way for insurance companies to manage the risks of a catastrophic event such as a hurricane or an earthquake. No doubt we will see other sorts of insurance (for example, life insurance and automobile insurance) being securitized in a similar way as this market develops.

Suggestions for Further Reading

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Quiz (Answers at End of Book)

20.1. Explain the difference between a credit default swap and a total return swap.

20.2. A credit default swap requires a premium of 60 basis points per year paid semiannually. The principal is $300 million and the credit default swap is settled in cash. A default occurs after four years and two months, and the calculation agent estimates that the price of the reference bond is 40% of its face value shortly after the default. List the cash flows and their timing for the seller of the credit default swap.

20.3. A contract provides a payoff in dollars equal to the HDD observed on a day. Characterize this as an option.

20.4. Suppose that each day during July the minimum temperature is 68° Fahrenheit and the maximum temperature is 82° Fahrenheit. What is the payoff from a call option on the cumulative CDD during July with a strike of 250 and a payment rate of $5,000 per degree day?

20.5. What are the characteristics of an energy source where the price has a very high volatility and a very high rate of mean reversion? Give an example of such an energy source.

20.6. How can a gas producer user derivative markets to hedge risks?

20.7. Explain how CAT bonds work.

Questions and Problems (Answers in Solutions Manual)

20.8. "The position of a buyer of a credit default swap is similar to the position of someone who is long a Treasury bond and short a corporate bond." Explain this statement.

20.9. Suppose that you have 50 years of temperature data at your disposal. Explain the analysis you would you carry out to calculate the forward cumulative CDD for next July.

20.10. Would you expect mean reversion to cause the volatility of the three-month forward price of an energy source to be greater than or less than the volatility of the spot price? Explain.

20.11. Explain how a 5 × 8 option contract for May 2001 on electricity with daily exercise works. Explain how a 5 × 8 option contract for May 2001 on electricity with monthly exercise works. Which is worth more?

20.12. Consider two bonds that have the same coupon, time to maturity, and price. One is a B-rated corporate bond. The other is a CAT bond. An analysis based on historical data shows that the expected losses on the two bonds in each year of their life is the same. Which bond would you advise a portfolio manager to buy and why?

20.13. In a basket credit default swap, does the cost of the insurance increase or decrease as the correlations between the defaults of the reference entities in the basket increase?

Assignment Questions

20.14. An insurance company's losses of a particular type are to a reasonable approximation normally distributed with a mean of $150 million and a standard deviation of $50 million. (Assume no difference between losses in a risk-neutral world and losses in the real world.) The one-year risk-free rate is 5%. Estimate the cost of the following:

a. A contract that will pay in one-year's time 60% of the insurance company's costs on a pro rata basis

b. A contract that pays $100 in one-year's time if losses exceed $200 million.

20.15. Suppose that

a. The yield on a five-year Treasury bond is 7%

b. The yield on a five-year corporate bond issued by company X is 9.5%

c. A five-year credit default swap providing insurance against company X defaulting costs 150 basis points per year.

What trading strategy would you recommend and why?