CHAPTER 27
ENERGY AND WEATHER DERIVATIVES

AIMS

- To outline the main energy and weather derivatives.
- To show how energy derivatives are used for speculation and hedging ‘price risk’.
- To show how carbon permits are used to allocate greenhouse gas emissions.
- To show how weather derivatives are used to hedge ‘output risk’ of energy producers and users.
- Outline the use of catastrophe bonds by the insurance sector.

We are all aware that there are large oil reserves in a number of countries around the globe, most noticeably the Organisation of the Petroleum Exporting Countries (e.g. the Mid East, Venuzuela, Nigeria etc) and Russia, who together control about 60% of the world’s oil reserves. (Incidentally, the often much maligned Kazakhstan has the huge Kashagan oil field coming on stream in 2009 at a cost of $30bn – something Borat in the film Borat: Cultural Leanings of America for make Benefit Glorious Nation of Kazakhstan failed to mention). Russia also has huge natural gas reserves and under President Putin it is consolidating oil and gas holdings in the state controlled firm Gazprom – some fear this concentration of economic power may lead to more volatile price movements (and possible use of energy supplies as a political weapon – but that's another story).

Energy prices such as oil and natural gas are highly volatile and this causes large producers (e.g. oil producers, refiners) and users of energy (e.g. airlines, manufacturing companies) considerably uncertainty about the price they will receive or pay for energy in the future. To mitigate such price risk consumers and producers can use either over-the-counter OTC or exchange traded contracts such as forwards, futures, options and swaps.
These ‘commodity derivatives’ are widely used by the energy sector, some of which are cash settled and some involve physical delivery. Electricity is a little different to oil and natural gas since it cannot be stored but its price can also vary tremendously on an hourly basis and derivatives contracts on electricity are also available.

The weather in the form of abnormally high or low temperatures affects lots of industries. These include firms in the energy sector (for heating in winter and air conditioning in summer), the leisure sector (hotels, ski resorts) and agriculture (e.g. wine growers, orange growers). Abnormal variations in temperature can affect the output of these industries which in turn affects their profits – but derivative contracts on ‘temperature’ can be used to mitigate these effects. There are also weather derivatives based on the number of frost days in a month or the depth of snowfall at particular locations - this also affects the profits of various industries (not least, ski resorts).

In life there is always the possibility of an unusually large natural catastrophe even though this may have a relatively low probability of occurrence – for example, very severe hurricanes, floods and earthquakes. Insurance claims against such events could cause a particular insurance company to go bust, so there is a need to offset or spread such risks across many participants – so called CAT bonds are one way of doing this.

In this chapter we examine how derivatives are used to hedge (or insure) against price volatility found in spot energy markets and how weather derivatives are used to mitigate changes in profits caused by changes in the weather.

1. ENERGY CONTRACTS

We will not give an exhaustive account of energy derivatives but instead we concentrate on the main features of these contracts, so you get a flavour of what’s on offer. There has been an active OTC and exchange-traded market in oil products since the early 1980s. OTC forward contracts lock in a price today, for future delivery at specific delivery points. Futures and options contracts are traded on crude oil and its refined products, gasoline and heating oil, on both the New York Mercantile Exchange, (NYMEX), the Chicago Mercantile Exchange (CME) and the International Commodities Exchange (ICE) in London. (OTC options contracts are also available). Traded options contracts are actually written on the future price rather than the spot price and are therefore “futures options” – but we ignore this complication.
One **crude oil futures** contract is for delivery of 1,000 barrels while one gasoline or heating oil contract is for 42,000 gallons (equivalent to 1000 barrels) - so that's more than you need to fill the average petrol tank of a “4x4 gas guzzler” – known in London as a “Chelsea Tractor”). Some contracts (e.g. light sweet crude oil futures on NYMEX) require physical delivery while others are cash settled (e.g. Brent crude oil futures on ICE).

There is also the possibility of avoiding the delivery arrangements set by the exchange and instead, using "exchanging futures for physicals” (EFP) arrangements, prior to maturity. This is simply a bilateral agreement on location and price for delivery between the party with the long futures position and the party with an equal size short position. The exchange must be notified of the EFP arrangement and the futures positions for both parties are then terminated. EFP might be used when the long wants delivery at a specific location that is different from that stipulated in the futures contract – if it cost more (e.g. transportation costs) to deliver to the long’s desired location then she will pay an additional cash amount to the short.

There are also OTC and exchange traded contracts on **natural gas**. Delivery is “through the pipe” at a specific geographical location, at a specific uniform rate through the month. The seller of gas (e.g. short futures position) is responsible for delivery at a specific delivery point, for example at the Henry Hub gas interconnector (in Louisiana) or at Zeebrugge (in Belgium), a key European hub. The supplier of gas might be a separate company to the producer of the gas – particularly in deregulated gas markets such and the USA and UK. NYMEX and ICE trade futures (and options) contracts which (if not closed out) require physical delivery of 10,000 million British Thermal Units (mbtu) of natural gas. Of course if you need your gas in Boston then you had better make sure you have purchased capacity in the pipe between the Louisiana delivery hub and Boston – because the pipe might be full! Options and swaps on natural gas are also available in the OTC market.

The **electricity market** is a bit different to oil and gas, as electricity cannot be stored. (Well technically you can store it in a battery, but it would require a very large battery). In the USA and UK electricity is produced primarily in coal fired, gas fired and nuclear plants. The latter provide the base load and extra demand is met by gas and coal stations. The transmission of electricity is costly and there are also transmission energy losses. So, electricity in the US is provided first to a specific region and any excess can then be sold in the wholesale market. (As everyone is becoming more “green” then in the future it may be possible for excess power from your home wind turbine to be sold to the “national grid”). Spikes in electricity consumption can be triggered by abnormally high temperatures in summer (particularly in the US where air conditioning is widely
used) or low temperatures in winter. So there is considerable volatility in electricity prices on a daily basis.

There are active markets in the US and UK in OTC forwards, options and swaps and NYMEX and ICE (check kc) trade a futures contract on the price of electricity. The contracts allow one party to receive a specified number of megawatt hours, at a specified price and location, during a particular month. For example this could be a 5 x 8 contract, for Monday to Friday only during offpeak hours (11pm to 7am) within a specified month. There is also a 5 x 16 contract for peak hours (7am to 11pm) or a 7 x 24 contract for delivery over 24 hours.

With an **option contract** on electricity you have precisely that, an option to take delivery at the strike price K or not. If the contract is for daily exercise, then with one days notice you can choose whether you want to take delivery at a price K, for the next day. For an option with monthly exercise, you make a decision at the beginning of the month whether you will take delivery each day at the strike price K.

In electricity and natural gas derivatives markets you can also be a “swinger”. You can purchase a **swing option** (also called a **take-and-pay option**). For an “electric swinger”, the option holder sets a maximum and minimum amount of power she will take each day during a specific month and a maximum and minimum for the whole month, with each megawatt taken at the strike price, K. You can then swing the amount of power you choose to take each day (within the bounds set) - although there is also usually a limit on the number days you can change your rate of consumption.

At this point it is also worth mentioning another market which is likely to expand rapidly in the future – carbon trading. This is a market where permits can be purchased by firms wanting to increase their output of greenhouse gases - the supply of permits is provided by firms who have been given an allocation of permits which exceeds their output of greenhouse gases (see the nearby box).

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**Box: Carbon Trading**

Going green seems to be catching on. On a small scale we have recycling of household rubbish, supermarkets charging for plastic bags or providing their customers with alternatives, houses with wind turbines and holidaymakers paying to offset the carbon emissions of air travel. On a bigger scale we have the Kyoto agreements to reduce greenhouse gas emissions. What methods are available for reducing greenhouse gas emissions from industry? One method is to tax emissions.
The problem here is that you have to set the tax rate at a level you think will achieve your emissions target but given the technological complexities involved, you could set the tax rate too high or too low, thus undershooting or overshooting your target.

The method which seems to have the most adherents is carbon trading. Currently this affects sectors such as power-generation, cement, ceramics, steel and paper industries. However, it is noticeable that the scheme does not cover air transport. The scheme works by setting allocations for emissions for each firm in the scheme. Firms which emit less than their allocation can sell the unused portion of their permits to the extreme polluters, via exchanges in London and Chicago. Although the US did not sign up to Kyoto it has a similar permit scheme limiting carbon dioxide, sulphur and nitrogen oxide emissions. In Europe it has been argued that the initial carbon permit allocation was too generous, so the price of carbon permits in the market was low and this provided little incentive for firms to curb their emissions. The European emissions trading scheme is due to be renegotiated by 2012 and it has been suggested that permits should not be allocated by government decree but should be auctioned. The higher the market price set when trading the permits, the higher the costs of pollution to firms and the greater incentive they have to innovate with clean technology or simply to reduce output. Total carbon dioxide emissions are therefore set by the scheme but their allocation across firms is set by the market. At the moment, trading environmental permits is solely a spot market activity, but should spot trading increase we can also expect us see the development of derivatives markets in this area.

2. HEDGING USING ENERGY FUTURES

Running an Airline

Suppose you own a medium size US airline and your marketing manager has told you what ticket prices you will be charging on all your routes, based on maintaining your competitive position in the market. If airline (jet) fuel remains at its current level it is estimated you will make a hansom profit over the next three years. But that is a big “if”, in today's volatile oil market. If you do nothing and jet fuel remains at its current level (or falls) you will be a happy CEO and your shareholders will be smiling too. But if jet fuel rises in price, then despite all your efforts on the technical side (reliability, maintenance and staff costs etc) you will end up looking pretty bad and may lose your job.

Consider hedging some or all of your projected fuel costs. There is no traded futures contract on jet fuel, the closest being a futures on heating oil HO (traded on NYMEX). Since you fear a rise in spot fuel costs in the future you should go long (buy) heating oil futures today. If spot prices do
rise over the next year, so will the futures price and you can close out on NYMEX at a profit - the latter offsets the higher cost of your spot jet fuel.

What are the practical complications involved? You have to decide what quantity \( Q \) of your fuel to hedge and then calculate the appropriate number of futures contracts for each month:

\[
N_f = \frac{\text{Monetary value to be hedged} \times \beta}{\text{Contract size} \times \beta} = \frac{Q}{\text{Contract size} \times \beta}
\]

Beta is the slope of the regression line for the change in the spot price of jet fuel on the futures price of heating oil (\( \Delta S = \alpha + \beta \Delta F \)). Since heating oil and jet fuel prices do not move perfectly together this is known as a “cross-hedge” and as you can only estimate the correlation between these two prices your hedge will be less than perfect – this is basis risk. However, over short horizons of say a month, the correlation coefficient (and ‘beta’) between heating oil and jet fuel is quite high (the beta is around 0.9) and both are reasonably stable over time – so, on average your hedge will work. But basis risk is also affected by changes in the convenience yield that is, the premium that holders of spot-heating oil place on having the heating oil available to satisfy their normal customers – this can cause a divergence between changes in the spot and futures prices at particular periods and could lead to larger hedging errors.

Suppose in January you decide to hedge 2 million gallons of jet fuel for each of the months of April, May and June. The contract size for heating oil futures is 42,000 gallons (equivalent to 1,000 barrels) hence the number of futures contracts for each month is 23.8 (24), that is you go long 24-April, 24-May and 24-June contracts – taken together these are often referred to as a strip hedge.

If you close out each contract just before its maturity date this will provide a reasonably good hedge - any gains/losses on your futures positions will closely offset any increased/lower costs of the spot fuel in the future. Effectively, you will ‘lock in’ a known average price of fuel approximately given by the average price of the futures contracts you enter into in January. You will not take delivery in the contracts because it is jet fuel you require (at various airports) and the futures contract delivers heating oil to New York Harbour. (Planes don’t fly well on heating oil).

**Caps and Floors**

The futures hedge ‘locks in’ a known price price but does not allow you to gain from lower fuel prices should they occur. To simplify the exposition, we assume spot heating oil and jet fuel prices do not differ and move dollar-for-dollar. What if you wanted to set a cap (upper limit) on
future fuel costs but also wanted to benefit from lower fuel prices should they occur? Suppose the current spot price of fuel is \( S_0 = \$1.9 \) per gallon. We know from our earlier discussions that what we need to do is to purchase a call option (on heating oil) at a specific strike price \( K_c = \$2.2 \) per gallon (say) - and for a maturity which matches the time we need to purchase the fuel in the spot market. If spot fuel prices turn out to be high \( (S_T > K_c) \) and the option is cash settled then we receive \( S_T - K_c \) at expiry of the option. Hence, even though the spot price of the oil we purchase is high, the net cost is \( S_T - (S_T - K_c) = K_c \) so we effectively end up paying a maximum price of \( K_c = \$2.2 \) (less the cost of the call option premium). On the other hand if the spot price of fuel turns out to be low (say \( \$1.7 \) per gallon) then we throw away the call option (i.e do not exercise) and just buy fuel at the low spot price of \( \$1.7 \). For the insurance that the option provides you have to pay the call premium at the outset. This use of the call is referred to as a caplet, since it caps your maximum payment for fuel at \( K_c \) for a specific month in the future. If you want to purchase fuel over several months ahead, then you need a series of calls - all with the same strike but with different maturity dates to match the dates of your future spot purchases of fuel. This requires a strip of caplets, which are collectively known as a cap and can be provided OTC by large financial institutions.

It should be fairly obvious that if you are a supplier of jet fuel (and hold large reserves) then what you are worried about is a fall in the spot price. You can insure a floor value for your future fuel sales by buying a put option with strike \( K_p = \$1.6 \) say – this will guarantee you receive at least \$1.6 per gallon for your oil in the future. Of course if spot prices rise, you again throw away the put and simply sell your fuel at the high spot price. In these circumstances the put is (not surprisingly) known as a floorlet and a strip of puts is a floor. The advantage of the put is that it gives you the benefit of the “upside” when spot prices rise, whereas taking a short futures position, locks in the price you will pay.

Collar

Let’s get really clever now. Go back to the airline who capped its future fuel costs by buying a call at a strike, \( K_c = \$2.2 \) which sets the maximum cost for fuel purchases by the airline. But buying the call could be expensive. The airline could offset some of the cost of the call premium \( C \) by selling a put and hence receiving the put premium \( P \). If the airline who is going to purchase fuel in the future undertakes a buy call-sell put trade then this is known as a collar (and if the call and put premia exactly offset each other it is known as a zero cost collar). We know what happens if fuel prices rise, the call sets the maximum effective cost of the fuel purchase at \( K_c \). But what happens if fuel prices fall substantially?
If the airline had not sold the put, it would directly benefit from very low spot prices. But the airline has sold a put and if the put is now “in-the-money”, the airline will have to pay out \( (K_p - S_T) \) to the holder (buyer) of the put. If spot prices fall (and \( S_T < K \) ) the effective cost of fuel for the airline is equal to the spot price plus the payout on the put \( = S_T + (K_p - S_T) = K_p \). Hence if \( K_p = $1.6 \) the minimum price paid for the fuel by the airline will be $1.6 per gallon (even if spot fuel prices are below $1.6). So if you have to purchase airline fuel in the future but the airline also undertakes a collar trade, it will cap its effective cost at an upper level \( K_c = $2.2 \), but also limit the minimum effective price it will pay to \( K_p = $1.6 \). (Note that for the above to work as described, the put sold has to have a lower strike price than the strike in the call option, that is \( K_p < K_c \ ).

The effective cost (ignoring the cost of the call and the put) of the jet fuel to the airline which undertakes the collar trade is given in figure 1. If the spot price turns out to be between \( K_p = $1.6 \) and \( K_c = $2.2 \), say \( S_T = $1.8 \) then neither of the options is in-the-money and the airline merely purchases fuel at the spot price of $1.8. But if the spot price turns out to be above $2.2 the effective price paid is capped at $2.2, while spot prices below $1.6 cannot be taken advantage of by the airline, who pays an effective price of \( K_p = $1.6 \). A collar trade is therefore quite involved but the key thing is that it sets a maximum and minimum price paid for fuel by the airline – the maximum price paid is \( K_c = $2.2 \) and the minimum price paid is \( K_p = $1.6 \).

3. ENERGY SWAPS

We have already discussed interest rate and currency swaps in previous chapters. Now let us see how the energy sector might use swaps to offset any price risks they face. To get the ball rolling, suppose in January a company such as Centrica in the UK agrees to supply natural gas NG to a large industrial customer-Z (e.g. manufacturing firm) at a fixed price \( S(fix) \), over a 6 month period beginning in November. Centrica decides it will buy the gas in the spot market at
whatever price it has to pay at the time (i.e. it pays a “floating price”, \( S(\text{float}) \) to the gas producer who supplies the gas via the European hub at Zeebrugge (in Belgium) – see figure 2

(Figure 2- here ppt)

Figure 2: Natural Gas – Fixed for Floating Swap

Clearly, if the spot price rises in the coming years, the profit margin of Centrica will be squeezed (and it may even be committed to supplying the gas at a loss if the spot price in Zeebrugge \( S(\text{float}) \) rises dramatically. How can it offset this risk without re-negotiating any of its existing contracts with its customers? It can undertake a receive-fixed, pay-floating swap from a swap dealer (see the left hand side of figure 3 where \( S(\text{float}) \) is the floating price used and \( X \) is the agreed fixed price). If the spot price of NG in Zeebrugge increases in the future then Centrica receives more from the swap dealer, which it uses to purchase the NG from its supplier – it has hedged any rising costs of its gas purchase. The net result is that Centrica receives \( S(\text{fix}) \) from its industrial customers and pays the swap dealer \( X \). As long as \( S(\text{fix}) > X \), Centrica will have locked in a fixed profit margin of \( S(\text{fix}) - X \) on each unit of NG supplied.

There are other important elements to the swap deal. There will be a notional quantity \( Q \) of NG in the swap, for example this might be \( Q = 1 \text{ million mbtu per day} \) and the ‘tenor’ of the swap could be every month from November to March. The swap payments to Centrica would then be

\[
\text{Swap payments each month to Centrica} = (1 \text{ million}) \times \text{days} \times [ S(\text{float}) - X ]
\]
where “days” = number of days in the month. The swap contract may be cash settled each month and it is then a “contract for differences” - as only the net cash payment is made by one of the parties to the swap contract. If, in any month:

\[ S(\text{float}) > X \], then Centrica receives cash from the swap dealer.

\[ S(\text{float}) < X \], then Centrica pays cash to the swap dealer.

The floating index \( S(\text{float}) \) will have to be decided upon and this spot price often goes under rather strange names, for example for the Centrica deal it might be the “front of month inside FERC” index. In fact, the floating payment \( S(\text{float}) \) you receive from the swap dealer is based on the “front of month” (FOM) price but you actually buy your NG at spot prices throughout the month – so there is some residual price risk remaining.

The fixed price \( X \) quoted in the swap is the “swap rate” and will vary depending on the maturity of the swap deal – so different swap rates will be quoted for 1-year, 2-year, … etc swaps. Broadly speaking the swap rate \( X \) is an average of the forward/futures prices for NG over the life of the swap – in terms of jargon, “the swap is priced off the forward curve” (ie. Forward prices of NG at different maturities).

An OTC swap of the above type can be tailor made by the swap dealer to suit Centrica. It can begin immediately or can have a delayed start (“a forward swap”) or it can be made to apply only to specific months when Centrica feels the spot price for NG is likely to be abnormally high. The notional quantity in the swap, which above is 1-million (mbtu) per day, can be pre-set at different levels on particular days within a month. Alternatively, the notional quantity can be a fixed daily amount within any one month, with different daily levels applying to for each separate month. These would then be referred to as “roller coaster swaps”. With the swap, Centrica effectively locks in the effective price it pays for NG, regardless of whether the spot price turns out to be high or low in the future.

Suppose Centrica is happy to receive \( S(\text{float}) - X \) from the swap dealer when spot prices turn out to be high (and hence has an effective cost of buying NG of \( X \)). But when the floating price of NG is less than the fixed price \( X \) in the swap, Centrica only wants to pay the swap dealer 60% of \( S(\text{float}) - X \). For example, if \( S(\text{float}) = 80 \) and \( X=100 \) then the effective cost of buying NG is \( 80 + 60\% \times 20 = 92 \), whereas with a plain vanilla swap the effective cost would have been \( X = 100 \). So the “60% swap deal” allows Centrica to pay less when prices are low and hence
participate in some of the benefit of low prices – not surprisingly this is known as a **participation swap**.

You may have noticed in figure 3 that the swap dealer has taken on risk, since she is paying $S\text{(float)}$ to Centrica each month and receiving $X\text{-fixed}$ from Centrica - so if NG prices rise in the future the swap dealer will experience losses. How does the swap dealer deal with this problem? Well, she may be lucky and find an offsetting deal with another party who wants to pay the swap dealer a floating price (with the same maturity as the original swap with Centrica). This may happen automatically or the swap dealer can shade her price quotes to encourage such swaps. But let us assume (realistically) that even after these offsetting swaps she still ends up as a net payer at a floating price.

We know that the swap dealer fears a rise in $S\text{(float)}$. But if there is a futures contract where the underlying asset is the spot price of NG, she can go long (an appropriate number of) futures contracts. Then if $S\text{(float)}$ does rise in the future she can close out the futures at a profit and use this cash inflow to offset the higher floating payment in her swap deal. So in actual fact what derivatives markets are very good at providing is risk spreading across a wide array of participants in these markets. The price risk is still there but each party only holds “a bit” of it – it is an efficient “risk sharing” mechanism. In short, without derivatives markets your gas bill might be even higher. The nearby box shows how electricity producers can “lock in” a profit margin on their power generation.

**BOX: SPARK SPREAD SWAP**

We all know that electricity can produce a spark and in the UK an electrician is called a “sparky”. What can a “spark” have to do with derivatives and swaps? Well suppose you run a gas fired power plant which produces electricity. Your profit margin (per unit of electricity) is

$$\text{Profit margin of electric power plant} = S\text{(electric)} - S\text{(NG)}$$

where both prices are measured in say “pounds per megawatt hour”, £/MWh. (This simplified presentation avoids complications like the “heat rate” which is the rate at which NG can be converted into electricity). In fact, Centrica owns gas fired power plants in the UK so it provides a good example here. The power plant manager may be willing to take on some “price risk” due to the spot price of NG rising more than the price of electricity in the future, hence squeezing profit.
margins. Indeed, if in any future periods $S(NG) > S(electric)$ the manager may actually temporarily shut down the plant and cease to provide electricity to the “grid” during these periods. (Of course many other factors may enter into the decision to temporarily close down the plant, not least the ease with which the plant can be up and running again).

We can view the power plant as earning net receipts of $S(electric) - S(NG)$ which will fluctuate as these two spot prices move up and down over time. Suppose the plant manager thinks that over the next few months either electricity or NG prices or both are likely to be more volatile than normal (e.g. due to highly variable weather conditions which affect electricity prices or risks on the supply of NG “through the pipe” which affect spot NG prices). The power plant manager could agree to pay a swap dealer an amount $S(electric) - S(NG)$, in return for receiving a fixed payment $X$, from the swap dealer over the next few months. She will then have fixed the profit margin at $X$ (per unit of electricity sold). The agreed fixed payment $X$ is the spark spread swap rate. Once again swaps allow one party to offset risks from price fluctuations and to ‘lock in’ known cash receipts over a specific time period.

CRACK SPREAD

The “crack” you have probably heard of is the white powder celebs allegedly snort to add zing to their lives (or if you have been to Ireland “craic” refers to good times, usually over a Guinness or Murphy’s alcoholic beverage). Well “crack” appears in energy markets too, in the form of the “crack spread”. An oil refiner can convert crude oil CO into heating oil HO and her profit margin (per barrel) depends on the difference between these two prices. (I hope you can see the analogy with the spark spread). Clearly, the oil refiner is worried that in the future either heating oil prices fall or crude oil prices rise, or both - since this will hit her profit margins. She could offset this risk by hedging using separate futures contracts on crude oil and heating oil – here she would go long crude oil futures and would short heating oil futures. However, to save you the trouble of doing these two transactions, the futures market bundles them together and provides a futures contract on the crack spread that is, on $S_{CO} - S_{HO}$. Since the oil refiner is worried about a fall in the spot crack spread then she will short crack spread futures, to hedge this possibility. If the spot crack spread rises she makes higher profit margins but loses an equal amount on the short futures position. On the other hand if the spot crack spread falls her profit margins are squeezed but she makes an equal amount when she closes out the short futures position.

There is a 1:1 crack spread futures contract which takes account of the fact that 1 barrel of crude oil can (physically) be refined to produce 1 barrel of heating oil – as outlined above. But it is also
possible to take 3 barrels of crude oil and convert this into 2 barrels of gasoline (petrol) and 1 barrel of heating oil. This refiner faces price risk in the ratio 3:2:1 and it may not surprise you that there is a 3:2:1 crack spread futures contract to hedge price risks for this type of refinery. Crack spread contracts are traded on CME and ICE.

4. WEATHER DERIVATIVES

Weather derivatives can be used by anyone whose output and hence profits are affected by abnormal movements in “the weather”. Whereas most futures are used in hedging price movements, broadly speaking weather futures are used to hedge uncertainty about future “output” (e.g. the number of gallons of heating oil you might sell to consumers). For the moment let’s consider “temperature” as the only “weather variable” influencing profits (that is we ignore such weather factors as the number of days of frost or depth of snowfalls, which clearly affect some firms’ output). Energy producers and consumers are affected by temperature since this influences the amount of energy (heating oil, natural gas, electricity) used for heating in the winter months and (in the USA) the amount used for air conditioning. But the volume of agricultural production is also influenced by temperature (e.g. orange production in Florida), as are leisure industries (e.g. holiday companies) and some manufacturers (e.g. of cold drinks or ice cream).

To keep things simple at this point, assume there are traded futures and options contracts, whose payoff depends on the temperature (at a particular point in time and at particular geographical location), relative to the average daily temperature which we take to be 65 degrees Fahrenheit. Let us also assume these derivatives contracts apply to a particular month (and we assume all months have 30 days). Hence on January 15th, if the market believes that the average daily temperature in June will be 70°F then the current value of the June-futures contract is 5°F x 30 days = 150 degree-days. In the jargon, we say that the average cooling degree day CDD is 5 and the expected cumulative CDDs in June are 150 – this is because a higher temperature than 65 degrees is likely to lead to more energy use for ‘cooling’, using air conditioning. Traders would say that the June contract is currently trading at 150 CDD. If the contract multiple is $20, the value of the June futures (on January 15th) is $20 x 150 days = $3000.

As you are probably aware one of the main topics of conversation of the average citizen is what the weather is likely to be over the coming months. So, one can only assume they might like to gamble on the weather. Clearly this is possible using traded weather futures. On January 15th assume the June weather futures is trading at 70°F, equivalent to a price of $3,000. If you think the daily temperature in June will be 80 degrees (and your guess turns out to be correct), then the January-futures contract in June will be priced at around (80-65) x 30 days x $20 = $9,000 and
your profit on closing out will be $6,000. The latter figure is simply the increase in the average daily temperature of 10°F (= 80-70), scaled up by the 30 days and the $20 per index point.

\[
\text{Profit} = \text{Increase in temperature} \times 30 \text{ days} \times 20
\]

The January price of the futures assumes 150 CDDs in June (i.e. an average daily temperature of 70 degrees). Hence if you thought the average temperature in June would be less than 70 degrees then as a speculator you would sell June-futures in January (and hope to close out at a lower price in June).

What would an option ‘on the weather’ look like? Assume the average June temperature at a particular location (e.g. Portland Oregon) is 70 degrees, so the cumulative CDDs for June are \((70 - 65) \times 30 = 150\). A strike ‘price’ of \(K=150\) CDDs for June therefore corresponds to an average temperature of 70 degrees. Speculation is easy. If in January, you think the average temperature in Portland in June will be higher than 70 degrees then you might buy an option on CDD with a strike equal to 150. If the average temperature in June turns out to be greater than 70, the option will be in-the-money and can be exercised at a profit. If it is less than 70 you simply lose your option premium.

**Hedging and Insurance**

Now let’s consider hedging with weather derivatives. Suppose you run a number of large retail outlets in California, which use air conditioning. In January you may be worried that the temperature in July will be abnormally high (due to global warming) so your heating costs will rise, cutting into your profits. To offset some or all of this extra energy cost you could buy July-weather futures in January. If the temperature turns out to be abnormally high in June, you can close out your futures position at a profit - which can be used to offset your higher air conditioning costs. If the temperature turns out to be lower than average in July, you close out your futures at a loss, but this is offset by lower energy costs. Here the aim of the hedge is to keep overall energy costs in June constant (i.e. so that spot energy costs plus profits/loss on the futures remain constant).

Of course you have to work out how much profit you will lose for each one degree Fahrenheit rise in temperature. Only then can you decide *how many* weather futures to purchase in order to offset your expected increase in energy costs (and loss in profits). So you need someone to provide you with a business scenario model, which shows how overall profits (in July) vary with temperature.

How would options work? A call option ‘on the weather’ provides insurance against rising energy costs. If the July temperature turns out to be above its strike level (set in the option contract), then the money you make on exercising the option will just offset the higher air conditioning costs, so
your profits remain at their normal level. However, as the temperature falls (below the strike) your call option is worthless but your energy costs continue to fall as you use less and less air conditioning. You buy the call option in January and in July you have an asymmetric pay-off. You obtain higher than average profits if temperatures are low and normal profits if the temperature is abnormally high – for this you have to pay an insurance premium ‘up front’ in January, and that is the price of the call option.

So, when hedging with a weather futures contract you make average profits, regardless of whether the temperature is high or low. But a call option gives you the ‘option’ of earning high profits if the temperature is low and normal profits if your temperature in July is abnormally high.

**Contract Details**

Now you have sorted out the general principles of speculation and hedging with weather derivatives, let us look at a few of the contractual and institutional details. The first OTC weather derivatives were introduced around 1997 and are based on heating degree days HDD and cooling degree days CDD, defined as:

\[
\text{Daily HDD} = \max\{0, 65 - T\} \\
\text{Daily CDD} = \max\{0, T - 65\}
\]

where T is the average of the highest and lowest temperature (degrees Fahrenheit) during the day at a specific location (e.g. at the Chicago O’Hare Airport weather station calculated by the Earth Satellite Corporation). For example if T=70 then the daily CDD = 5 and the HDD = 0. The monthly HDD and CDD are simply the sum of the daily values. For example if the value of the daily HDD in Chicago in November are 25, 10, 20, 15, 19, 27, 26 (and the rest are 0) then the HDD for November is 142. (Also note that settlement on CME for weather derivatives is in 0.5 increments). Note that when temperatures are low (i.e. well below 65), then HDD is high – a negative correlation. However, CDD increases with temperature (above 65 degrees) – a positive correlation.

Lots of “bespoke” weather futures are sold in the OTC market but some plain vanilla contracts are also available with 24 hour electronic trading (e.g. on the CME Globex trading platform) - both weather futures and European options (on weather futures) are based on monthly HDD or CDD. These products are also available as seasonal products. The winter season is November to March and the summer season May to September - although April can be added to the summer and October to the winter season, so all months can be covered). You can choose from two to six months in a seasonal strip contract, so you might choose say three months (December,
January, and March) from the winter season strip, as these may be the months which for your (energy) needs are most volatile and hence need to be hedged. The CME Clearing House guarantees trading on Globex by requiring performance bond (collateral) deposits (i.e. margin payments) at each level in the clearing process – customer to broker, broker to clearing firm and clearing firm to clearing house.

There are also weather derivatives based on the number of frost days in the month and on the depth of snowfall at particular geographical locations and these work along the same broad principles as weather derivatives based on temperature described above. Forwards and futures contracts allow you to protect your profits because of volume changes in your business if there are severe frosts in particular months (e.g. wine growers in Napa and Sonoma Valley in California who suffer if grapes are harmed by severe frosts) or if there is less or more snowfall than average - the most obvious case here is a lack of snow at a ski resort but excessive snowfalls can also severely disrupt transport companies such as road haulage (the trucking business). Options contracts allow you to purchase insurance. For example, a wine grower in November might buy a call option on “frost days” in March, then the option pays out depending on the number of frost days (above the strike) and this compensates the wine grower for any deterioration in the grape harvest. On the other hand if there are no frost days in March then there is no loss of grapes to the wine grower but the call expires out-of-the-money. The cost of the insurance is the call premium.

5. REINSURANCE AND CAT BONDS

We have seen how weather derivatives can be used to hedge and provide insurance when there are abnormal weather conditions. In general OTC and exchange traded weather derivatives are used to hedge changes in temperature (or frost or snowfall) which are slightly different from ‘average’. These products are provided in the OTC market by large banks, specialist energy firms and insurance companies. On the other hand, extreme weather conditions such as hurricanes, earthquakes and floods are generally dealt with via some form of explicit insurance contract with an insurance company.

Any single insurance company might hold a large number of catastrophe insurance contracts and may therefore hold lots of risk, from these low probability but highly costly events. To mitigate some of this risk an insurance company may reinsure say 70% of its risks with other companies leaving it liable to only 30% of any claim (Lloyds of London is probably the oldest organisation providing reinsurance). Alternatively the insurance company can purchase a series of
reinsurance contracts for *excess cost layers*. If the insurance company has $100m exposure to hurricane damage in Florida then it may issue (separate) *excess-of-loss* reinsurance contracts to cover losses between $40m and $50m, $50m and $60m etc. Between $40m and $50m of losses, the insurance company receives a $-for-$ payoff from the reinsurer but receives nothing from this (first) reinsurance contract if losses are outside this range. Hence, for the first reinsurance contract the insurance company has the equivalent of a long bull spread - namely, a long call at a strike of $40m and a short call at a strike of $50m.

Reinsurance contracts are very useful but the insurance company can also issue bonds to cover catastrophic (CAT) risks. These have a liquid secondary market and can be sold to many investors thus “spreading” the catastrophic risk widely. CAT bonds pay a higher than average interest (coupon) but the holders agree to cover the excess-of-loss insurance. For example, by issuing $10m principal of CAT bonds an insurance company could cover any losses between $40 and $50 million by not repaying some or all of the principal on the CAT bonds. Alternatively it can make a much larger bond issue, with the covenant that any losses between $40 and $50m will be covered by a reduction in interest payments.

The demand for CAT bonds by investors arises from the fact that they pay higher coupons (or yield to maturity) and the returns on CAT bonds have an almost zero correlation with stock market returns and hence have no systematic risk. In a diversified portfolio specific risk will be small so CAT bonds improve the (mean-variance) risk-return trade off.

6. SUMMARY

- Forwards, futures, options and swap contracts on the price of energy (oil products, natural gas, electricity) are available OTC and as exchange traded products.

- Energy derivatives can be used to hedge (forwards, futures and swaps) and to provide insurance (options) against future changes in spot energy prices.

- Some contracts are cash settled and others involve delivery – although alternative delivery arrangements from those stipulated in the contract can be separately negotiated and this is known as “exchanging futures for physicals”, EFP.

- Weather derivatives can be used to hedge (or provide insurance) against changes in output of energy and other industries whose profits depend on the weather.
The value/price of the most actively traded weather derivatives are based on temperature at particular locations at specific times but others depend on the number of frost days or the depth of snowfalls.

The key exchanges are the New York Mercantile Exchange NYMEX and the International Commodities Exchange ICE in London, while the Chicago Mercantile Exchange CME trades weather derivatives.