Electricity and Weather Derivatives

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Electricity Derivatives
Electricity futures

- Electricity generators, grid operators and distributors use futures contracts to mitigate price risk. Besides regular players in the electricity market, speculators and arbitrageurs do trade in electricity futures.
- Exchanges offer futures contracts on base load and peak load ranging from daily, weekly, monthly, seasonal (summer and winter) and yearly contracts.
- Futures contracts on system prices as well as for different areas/regions are also offered.

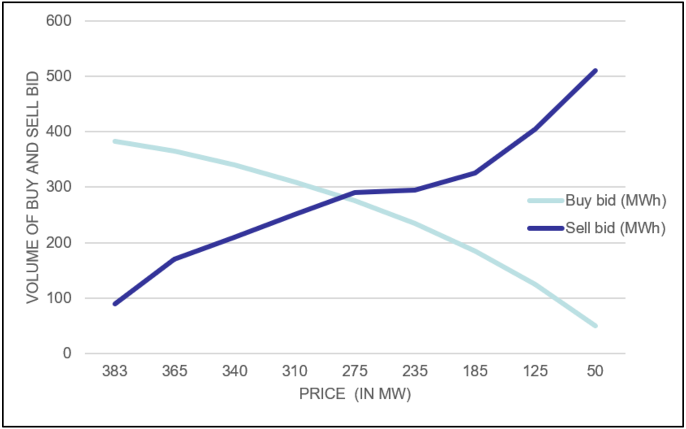
- There are three types of contracts
  - 1. **Day-ahead-market (DAM) / Day-Ahead-Spot (DAS)**:
    - ★ **Day-ahead-market** is also known as **Day-ahead-spot (DAS)** market.
    - ★ In a day-ahead market buyers and sellers can freeze the price of electricity on D-1 day, to be delivered on the following day, i.e., on day D.
    - ★ On day D-1, before a specific-cut-off time, buyers and sellers bid the volume of electricity they are willing to sell/buy and price.
- On exchange, a day is divided into 24 blocks of one hour each.
- Based on the demand and supply for each hour, a cut-off price and volume is determined.
- It means, on day D-1, 24 cut-off price and volume are determined.
- The cut-off price is known as **Market-Clearing Price (MCP)** or unconstrained MCP. The Cut-off volume is known as **Market volume (MCV)**.

- Example MCP and MCV:
- The hypothetical buy and sell bid at different prices for a given hour (9 a.m. to 10 a.m.) is given below. In real life buyers and sellers can bid a minimum volume of MWh and multiples of 0.01 MWh thereafter. Determine the unconstrained MCP and unconstrained MCV.

Buy and sell bids at different price for 9 am to 10 am

Price (INR/MW)	Buy bid (MWh)	Sell bid (MWh)
230	383	90
240	365	170
250	340	210
260	310	250
270	275	290
280	235	295
290	185	325
300	125	405
310	50	510

- Example MCP and MCV:



- At a certain price, the buy and sell bids should match.
- To do this, we can adopt the linear interpolation method.
- The thumb rule to these two price points in where the difference between buy and sell bid volume sign changes from positive to negative.
- At Rs. 260 difference between buy and sell is 60 MWh while at Rs. 270, the same is negative 15 MWh.

- Calculate the equilibrium points $\frac{x-x_a}{x_b-x_a} = \frac{y-y_a}{y_b-y_a}$
  $\frac{x-260}{270-260} = \frac{y-250}{290-250}$
  $y = 4x - 790$
- similarly, $\frac{x-260}{270-260} = \frac{y-310}{275-310}$
  $\frac{x-260}{270-260} = \frac{y-250}{290-250}$
  $y = 1220 - 3.5x$
- after solving
- x = 268 and y = 282
- Summary: the MCP (from 9 am to 10 am) is Rs. 268 and MCV is 282 Mwh.

- Buyers and sellers pay/receive a locational/regional marginal price for buying/selling electricity in the spot market.

- However, when these entities mitigate the locational/regional marginal price risk with futures contracts based on system price, locational basis risk arises. Locational basis risk is managed through **Contract for Differences (CFDs)**.

- CFDs are also known as basis contracts.

- Electricity generators, grid operators, distributors, end users use futures contracts to mitigate price risk as outlined below:
  - As generators are naturally long on electricity, they take short positions to mitigate the price risk.
  - Similarly, end-users take long futures positions as they are short on spot electricity.
  - Transmission system operators/distributors/power trading companies buy electricity from generators and sell these to other distributors or end-users.
  - Hence, transmission operators can take either long or short position in futures contracts depending on whether they have net short or long position in spot electricity.

- Suppose a power trader has agreed to buy 100 MWh (per hour) electricity from an independent power producer during the next 3 months for 24 hours a day.
- The power trader has agreed to supply electricity to an industrial consumer for 50 MWh (per hour) for next 3 months, but only during 9 a.m. – 6 p.m.
- After netting off, the power trader is net long in electricity for 50 MWh for 24 hours for 3 months and 50 MWh for 6 p.m. – 9 a.m.

- To summarize, to hedge the price risk:
  - Generators take short positions
  - Transmission system operators/distributors may take long (short) futures depending on whether these entities are net short (long) on spot electricity.
  - End users take long futures positions.

- Contract for differences (CFDs):
  - CFDs contracts were first introduced by Nord Pool in the year 2000.
  - Forwards and futures contracts help in mitigating the price to be paid or received at a future date.
  - But we know that a buyer/seller may actually pay or receive the area/region price, which may differ substantially to system price if there is congestion in the transmission grid.
  - Hence, an entity which buys a derivatives contract based system prices.

- Contract for differences (CFDs):
  - CFDs = Area price (P) – System price (SP)
  - CFDs can trade in positive, negative or zero value depending on whether $AP > SP$, $AP < SP$ or $AP = SP$.
  - AP is higher than SP when an area is a net deficit region.
  - That is, when demand from that area is higher than the supply to that area. If the buyer of electricity is anticipating higher area prices, the buyer takes a long positon in CFDs.

- Contract for differences (CFDs):
  - If $AP > SP$ an anticipated, CFD has a positive value.
    In this case, the buyer pays higher price for electricity consumption in the spot market, but receives the differential from the CFD market.
  - Higher cash outflows in the spot market is compensated with the gain from the CFD market.
  - If $AP < SP$, then buyer pays less for electricity consumption, but pays the price differential to the CFD counterparty.

- Contract for differences (CFDs):
  - Similarly, if AP is expected to be less than SP, then the area is a surplus area.
  - Power supply companies/generators earn less revenue by supplying to this area.
  - To mitigate this risk, power supply utilities /generators take short position in CFDs.
  - If $AP < SP$, utilities receive less from selling electricity to spot market, but are compensated by the earnings from CFDs.

- Below table shows the traded prices of CFDs indicate the market's prediction of the price difference between the area price and system price during the delivery period.

Table 1

Product Series	Closing value (Rs in per MWh)	Hours
1. System region1 – Jan 2019	-12.75	743
2. System region2 – Feb. 2019	-14.05	720
3. System region 3 – March 2019	1.9	2184

- In the table, the product series System region 1 – Jan. 2019 indicates the price difference between and region 1 area price (AP) and system price (SP) for the month January 2019.

- This contract closes at Rs. 12.75 per MWh indicating that system price (SP) is expected to be higher than the area price for the January 2019.

- Similarly, for other contacts 2 and 3.

- Suppose an independent power producer (IPP) (injects electricity into the grid in region 2 area) took a short position on CFD of region 1 at a price of – Rs. 14.05 per MWh. On 20th January 2019, the system price and region 2 area price were either (a) Rs. 43 per MWh and Rs. 26.65 per MWh (b) Rs. 43 per MWh and Rs. 32 per MWh, respectively.

- Calculate the profit and loss due to CFD if the independent power producer (IPP) squares up short CFD on 20th February. Also find out the price it would receive per MWh of electricity it supplies including profit/loss from CFD.

- **Solution**:
- Region area price = 26.65 per MWh
- On 20th February 2019, the IPP would receive Rs. 26.65 per MWh from spot delivery of electricity.
- System price = Rs. 43 per MWh

- Value of CFD = (26.65 – 43) per MWh = -16.35 per MWh all expressed in rupees.
- The IPP took a short position in CFD on 20th February 2019, the value of CFDs is -16.36 per MWh.
- The IPP squares up the short CFD position at a lesser value Rs. 16.35 per MWh, thus making a profit of Rs. 2.30.
- Hence, the IPP receives Rs. 28.95 per MWh of electricity from both spot market and profit from CFD.

- **Solution**:
- Case (b) Region 1 area price = Rs. 32 per MWh
- On 20th February 2019, the IPP would receive Rs. 32 per MWh from spot delivery of electricity.
- System price = Rs. 43 per MWh
- Value of CFD = (Rs 32 – Rs. 43) per MWh = - Rs 11 per MWh
- The IPP took a short position in CFD on 20th Feb. 2019 at Rs. -14.05 per MWh.
- On 20th February 2019, the value of CFD is -11 per MWh.
- The IPP squares up the short CFD position at a higher value – Rs. 11 per MWh, thus making a loss of Rs. 3.05.
- Hence, the IPP receives Rs. 28.95 per MWh of electricity from both spot market and adjustment of loss from CFD.

- **Spark spread futures**:
- Spark spread is defined as the difference between the price of electricity sold by a producer and the price of the fuel used to generate electricity.
- When natural gas is used to generate electricity, the spread is known as **spark spread** and when coal is used to generate electricity, the spread is known as **dark spread**.
- A fuel constitutes a significant portion of total costs incurred by power producers, these spread contracts help power producers mitigate price risk of both input and output.

- **Spark spread futures**:
- The spread is calculated based on the difference between price of electricity (in MWh) and the fuel cost associated with generating this power.
- Power plants convert fuel into heat and then to electricity.
- Heat rate measures the amount of fuel required to generate 1 unit of electricity.
- It is measured as mmbtu per MWh, i.e. number of units of natural gas (in mmbtu) is required to generate 1 MWh of electricity.

- **Spark spread futures**:
- Heat rate is the ratio of quantity of fuel consumed and quantity of electricity produced.
- Lesser the heat rate, higher is the efficiency of the power generation unit. If a unit requires 8 mmbtu to generate 1 MWh of electricity, the heat rate for this plant is 8 mmbtu/MWh.

- **Spark spread futures**:
- The futures price of electricity and the natural gas/coal also helps in determining market implied heat rate (MIHR).
- MIHR $= \frac{P_e}{P_g}$, where P_e is the futures/forward price of electricity. P_g Futures price of natural gas/coal.
- A power producer is considered efficient, when its own heat rate is lower than the market implied heat rate.

- **Spark spread futures**:
- An electricity producer heat rate is 10 mmbtu (MMBTU / MBTU, means One Million British Thermal Units (BTU)) / MWh . The 1 month futures price for electricity and natural gas are USD 27 per MWh and USD 2.8 per mmbtu, respectively. Find out the MIHR and comments on whether the electricity producer is efficient or not compared to other player's in the market.

- **Spark spread futures**:
- MIHR $= \frac{P_e}{P_g}$, where P_e is the futures/forward price of electricity. P_g Futures price of natural gas/coal.
- MIHR $= \frac{USD27}{USD2.8}$
- The MIHR is 9.64.

- As the producer's heat rate is 10, it is inefficient. This indicates that the producer will earn lesser margin in the coming month as compared to other players.

- **Spark spread Calculation**:
- As electricity producer's margin is governed by spark spread.
- Spark spread = price of electricity (per MWh) – (Heat rate * Natural gas price per mmbtu).

- **Spark spread Calculation**:
- A generator is currently selling electricity (per MWh) at USD 26.05. It is buying the natural gas for USD 2.50 per mmbtu. Calculate the spark spread, if the heat rate is 9.027 mmbtu.
- Spark spread = price of electricity (per MWh) – (Heat rate * Natural gas price per mmbtu).
- Spark spread = USD 26.05 - (9.05*USD 2.50) = USD 3.48.

- **Long and Short Positions for a Spark Spread Futures Contract**:
  - Electricity producers are exposed to both input and output price risk associated with both electricity and natural gas/coal price.
  - These spread futures help power producers to mitigate both input and output price risk in one single contract.
  - Futures contract on spark spread (short position) helps the electricity utility companies to fix their gross margin.
  - As the underlying units for electricity and natural gas are different, electricity producers have to take different number of units for electricity and natural gas contracts as part of the spread contract.

- **Long and short spark spread positions**:

Long position (buyer) of the spark spread	Buys the output (electricity) futures contract
futures	sells the input (natural gas) futures contract
Short position (seller) of the spark spread	Sells the output (electricity) futures contract
futures	Buys the input (natural gas) futures contract

- **Long and short spark spread positions: Example**:
- In February 2019, the futures price in electricity and natural gas in the month of March 2019 is USD 27 per MWh and USD 2.8 per mmbtu, respectively. An electricity utility company requires 8 mmbtu of natural gas to produce 1 MWh of electricity. It wants to take short futures position on 7 electricity contracts at Chicago Mercantile Exchange (CME) as it intends to generate 5000 MW of electricity in the coming month. At CME, each electricity futures (day-ahead monthly) futures contract has 736 MWh of electricity as underlying. Find out how many long futures contracts on natural gas, it should take as part of the short spark spread position. Each natural gas contract has 10,000 mmbtu as the underlying unit.

- **Long and short spark spread positions: Example**:
- Spread spread = USD 27 – (8*USD 2.8) = USD 4.6
- Underlying electricity (in MWh) for 7 contracts = 7*736 MWh = 5152 MWh
- Amount of natural gas required to generate 5152 MWh of electricity = 5152 * 8 = 42216 mmbtu of natural has
- Each natural gas contract at CME is for 10,000 mmbtu
- Number of natural gas contracts to be bought = 42216/10000 = 4.22.
- In other words, the generator can buy 4 or 5 futures contract on natural gas.
- Hence during February 2019, the utility company needs to take short position in 7 – 4 spark spread futures contract for the month of March 2019 and fix USD 4.6 per MWh as the margin.

Weather Derivatives
Origin

- Weather derivatives are of very recent origin. One of the first weather derivatives contracts to be transacted was between Consolidated Edision (ConEd) Corporation of New York and Aquila Energy (AE) of USA.
- The New York based power distribution company, ConEd used to purchase electricity from AE. Anticipating a cooler August (Cooler summer) in 1996, ConEd brought in a weather clause whereby AE would pay discount to ConEd if August is cooler than expected.
- To measure whether August is cooler or not both parties agreed to use the Cooling Degree Days (CDDs) measured in New York City's Central Park weather station. Both parties agreed that if actual CDD was 11-20% below the expected value of 320, ConEd would receive cash discount.

- This contract paved way for hedging weather related risk – many energy companies realized that a greater portion of energy demand governed by weather conditions. Not that the companies realized this all of a sudden, this contract made companies aware that weather related risk could be hedged.

- In another case, Koch Energy of USA was anticipating decline in power off-take due to El-Nino effect in 1997.
- It transacted weather option contract based on Heating Degree Days (HDD) index with Enron Corporation. From 1998 onwards, weather derivatives in Over the Counter (OTC) market started growing.
- In 1999, Chicago Mercantile Exchange (CME) started offering exchange traded futures and options contracts on weather derivatives. Since then, the weather derivatives contract market is growing robustly.

- Temperature based derivatives contracts
  - Contracts based on temperature have either **Heating Degree Days (HDDs)** or **Cooling Degree Days (CDDs)** as the underlying.
  - HDD is a quantitative measure to indicate whether a specific day's temperature at a specific location is cool enough so that buildings require heating. Similarly, CDD also indicates whether it is hot enough requiring air conditioning/cooling.
  - In a given day if the average temperature is less (higher) than base temperature, it is counted as one HDD (CDD).
  - Base temperatures are pre-specified for a geographical region based on climate condition. Weather contracts during winter months are related to HDD while these for summer months are related to CDD.

- Temperature based derivatives contracts
  - For HDD calculation, suppose the base temperature is 65^0F at a place X. On a given day the highest and lowest temperature at X is 50^0F and 30^0F, respectively.
  - Hence the average temperature is 40^0F. As the average temperature is less than the base temperature of 65^0F, then it would be considered as a heating degree day with the HDD value of 25 (65^0F - 40^0F).
  - The CDD is also calculated in a similar manner. If a given day's average temperature is 70^0F, with base temperature at 65^0F, then it would be counted as one CDD with CDD value of 5. On the other hand, if the average temperature is 60^0F, then the value of CDD is zero.

- Temperature based derivatives contracts
  - HDD and CDD can be represented as:
  - HDD $=$ max(0, Base temperature - T_i)
  - CDD $=$ max(0, T_i - Base temperature), where $T_i = \frac{T_{max}+T_{min}}{2}$
  - CME weather derivatives based on temperature calculated over a week/ a month or over season.
  - A weekly HDD or CDD index value is simply the sum of all daily HDD or CDD in a week.

- Temperature based derivatives contracts: Example
  - Data given below shows the average temperature for 7 days at a given place. Calculate both HDD and CDD for a week with base temperature of $65^0 F$.

Day of the week	Mon.	Tues.	Wed.	Thu.	Fri.	Sat.	Sunday
Average temp(T_i)	69	66	60	59	61	58	56

Exchange traded weather derivative contract at CME

- Temperature based derivatives contracts: Solution

Day of the week	Mon.	Tues.	Wed.	Thu.	Fri.	Sat.	Sunday
Average temp(T_i)	69	66	60	59	61	58	56
HDD value	0	0	5	6	4	7	9

Cumulative HDD value for the week = 31

Now, CDD calculation:

Day of the week	Mon.	Tues.	Wed.	Thu.	Fri.	Sat.	Sunday
Average temp(T_i)	82	79	75	70	65	63	61
CDD value	17	14	10	5	0	0	0

Cumulative HDD value for the week = 46

- Temperature based derivatives contracts
  - Weather contracts is winter months are tied to HDD while weather contracts in summer months are CDD.
  - Some of the interesting features of CDD/HDD contract is as follows: At CME, USA-based CDD contracts are available for May, June, July, August and September.
  - The HDD contracts are available for November, December, January, February and March.
  - CDD/HDD futures contract specifications at CME are standardized. Contract size is USD 20 times the respective CME degree days (HDD/CDD) index.
  - It indicates that if a trader takes a position in contract with HDD/CDD value of 1000, the trader's contract value is USD 20,000.

- Temperature based derivatives contracts: Example
  - A wheat farmer from Minneapolis knows that a warmer winter is good for wheat production. The farmer is happy if there is less number of HDDs in the month of December 2018. Less number of HDDs indicates warmer winter, and hence, less HDD value. But the farmer fears that winter may be severe. Hence on 8th October 2018, the wheat farmer takes a long futures position in Minneapolis December 2018 HDD contract (100 units) with each unit trading at 625. The contract expired on 31st December 2018 with a settlement value of 690. Calculate whether the farmer has gained in the contract.

- Temperature based derivatives contracts: Example
  - Farmer's profit When HDD settlement value is 690
  - Farmer's profit = $USD20 \times (690 - 625) \times 100 contracts = USD130,000.$
  - Farmer will receive the cash of USD 130,000.
  - Farmer's profit When HDD settlement value is 603
  - Farmer's profit = $USD20 \times (625 - 603) \times 100 contracts = USD44,000.$
  - Farmer's pays the cash equivalent to USD 44,000.

- Temperature based derivatives contracts: Example
    - In April 2019, A major beachwear seller in Los Angles area fears that during May 2019, the peak tourist season, sales may not be high as the summer would not be hot enough. The company fears a cooler summer, i.e., less CDD. To mitigate the risk associated with loss of sales revenue, it takes short short futures contract. In 4th April 2019, the company takes a short futures position (250 contracts) in Los Angles may 2019 contracts at 1012. calculate the pay-off when the CDD settlement values are 1025 and 987.

- Temperature based derivatives contracts: Example
  - The beachwear company takes Short Futures (250 contracts) at 1012. Fears a colder summer i.e., lower CDD
  - Settlement (hotter summer): CDD settlement value 1025
  - company's loss = $USD20 \times (1025 - 1012) \times 250 contracts = USD65,000.$
  - Company will pay the cash of USD 65,000.
  - Company's profit When HDD settlement value is 987
  - Farmer's profit = $USD20 \times (1012 - 987) \times 250 contracts = USD125,000.$
  - Company receives the cash equivalent to USD 125,000.

- In 1992, 194 formed the United Nations Framework Conventions on Climate Change (UNFCCC) to work towards reducing global warming.
- In 1997, **Kyoto Protocol** came into existence to reduce the carbon emission. Industrialized countries were blamed for carbon emission due to heavy industrialization.
- According to **Article 3 of Kyoto Protocol**, the member countries, individually or jointly, ensure that their carbon emissions do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments, with a view to reducing their overall emissions of such gases by at-least 5% below 1990 levels in the commitment period 2008-2012.

- Kyoto Protocol allowed the market mechanism to meet the carbon emission reduction targets.
  - Emission trading
  - The Clean Development Mechanism
  - Joint Implementation

- Under Kyoto Protocol, different countries have accepted the target of reducing greenhouse emission. These targets are expressed as percentage of emission limit or reduction commitment.
- These emission reduction percentages also set the allowable level of emission for a given country.
- The allowable level of emission is also known as **Assigned Amount Units (AAUs)**.
- The AAUs are defined as allowance to emit one tonne of carbon dioxide (CO2) equivalent.
- The UNFCCC decides the emission reduction target which in turn is used to calculate the assigned units for a given country.

Tabel 1 Emission Limitation or Reduction Commitment (EL/RC)

Country	EL/RC (in %)
Australia	108
Austria	92
Belgium	92
Bulgaria	92
Canada	94
Croatia	95
Germany	92
Iceland	110
New Zealand	100
UK	92
USA	93

- The percentage calculation is based on the GHG emission by the country in the base yeaar 1990.
- 108% of Australia implies that its emission needs to be just 8% more than 1990 level
- Similarly for Austria, 92% implies that its emission level should be 8% less than 1990 level.

Tabel 2 Total Aggregate GHG Emission (Co2, Ch4, N2O,HFCs,PFCs and SF6) in Gigagrams of CO2

Country	1990	2000	2005	2009	% change 1990-2009
Australia	4,18,372	4,96,185	5,27,743	5,99,829	29.90%
Germany	12,31,753	10,24,672	9,77,585	9,37,262	-23%
UK	7,74,680	6,75,981	6,58,088	5,65,987	-27.70%
USA	61,11,815	70,08,191	71,04,615	56,18,165	5.60%

- Suppose Australia's emission reduction target is 108% of the volume of GHG gas it emitted during 1990 given in table 1.
- Assigned amount for Australia = Level of emission in the base year (i.e. 1990) $\times$ Emission limit (108% of Australia) $\times$ number of years in the commitment period (5 years during 2008-2012).
- $418{,}372 \times 108\% \times 5 = 2{,}259{,}209$ units of CO2 equivalent.

- Assigned amount or allowances forms a cap (know as emission cap) on the maximum amount of GHG a country can emit.
- If a country's actual GHG emission (in units) is less than assigned amount, the country can trade these surplus units with another country which has a deficit.
- A country will be a deficit country, if its actual emission is higher than the assigned units.
- The deficit country has to buy these units from the surplus countries.
- Buying and selling of these units are either done in OTC market or through organized exchange.
- Trading on AAUs is known as cap-and-trade programmes.

Carbon Trading
cap-and-trade mechanism

- A country's total emission cap is distributed among the industrial operators from that country.
- Let's assume that, a country has only two industrial operators A and B.
- The total emission cap for the country is 100 units.
- Depending on the volume of activity undertaken by A and B, sanctioning authority of the country allocates 60 and 40 units to A and B, respectively.
- Suppose A actually emits 45 units and B emits 50 units.
- A has surplus carbon units of 15 while B has a deficit of 10 units from A.
- The purchase consideration paid by B is the penalty for polluting more than the desired level.

Carbon Trading
cap-and-trade mechanism

- Different countries assign these AAUs to their industrial operators/installations.
- A country decides which sectors are covered sectors.
- Normally, industries which contribute maximum GHG come under the purview of covered sectors.
- These AAUs are either freely allocated to these industries based on historical emission level or sold through auction.

Thanking You