Deep Hedging for Commodities

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Abstract:
Deep hedging is an exciting new machine learning application in front office derivatives risk management, where a neural network replaces traditional risk neutral pricing and risk formulas. It has the advantage of reproducing traditional derivative pricing when the assumptions behind risk neutral pricing hold, but extends naturally to real-world cases where those assumptions are broken. I'll discuss the technique and look at an application of it to the problem of managing a heat rate option, which is a financial version of a gas-fired power plant.

Original Paper: https://arxiv.org/abs/1802.03042

Introduction to deep hedging

- Rethinks the core engine behind how to hedge a portfolio that generalizes beyond the assumptions behind traditional risk neutral pricing
- They focus on hedging vanilla options under a Heston stochastic volatility world

Risk Neutral Pricing (what deep hedging is trying to replace)

- Traditional approach to derivatives pricing and risk management but makes three important assumptions:
  - No transaction costs when hedging
  - Hedges are dynamically rebalanced continuously
  - There are no unhedgeable risks
- If those assumptions are valid, PNL distribution over life of a deal is a delta function
  - If they are violated, PNL distribution has some width
  - If that happens, what are hedging objectives?
- Risk neutral processes: when simulating market prices for the purpose of derivative pricing, need to use a modified process so that expected value of a price in the future matches its market forward price

Deep Hedging to go beyond Risk Neutral

- First, decide what you want to optimize
  - Convex risk measure of the post-hedges lifetime PNL distribution
  - For example, expected shortfall
- Assume that there's a nonlinear function which, given the market conditions and portfolio, tells you the new hedge trades to do
  - In risk neutral pricing, that comes the sensitivity of the risk neutral price to market inputs
  - In deep hedging, it's training a neural network that minimizes convex risk measure

Benefits of Deep Hedging

- No need for risk neutral processes - all real world measure
- Reproduces standard risk neutral results in the limit of continuous hedging, no transaction costs, and no unhedgeable risks
- Can use any realistic market model you want that violates those risk neutral assumptions
  - Transaction costs, infrequent hedging, unhedgeable risks
- Lots of real world applications, for example
  - Life insurers issuing variable annuities
  - Commodity traders managing physical assets
    - Managing physical assets, dynamic risks to the market to hedge, in combination with unhedgable risks

Neural Network Structure

- NN, two hidden layers, 50 nodes each
- Three inputs: current asset spot, current time, and current hedge notional
- One output: incremental notional of delta to trade on new hedge

Training

- Generate a subset of Monte Carlo paths (100 paths), each path has 20 time steps
  - Note this is exact same simulated data as risk neutral hedging series
- At each time step on each path, ask the neural network for incremental hedge notional and add to the portfolio
- Calculate the 70%-ile expected shortfall from the resulting PNL distribution
- Bump weights to minimize that expected shortfall
- Repeat 10K times until results are converged

Results

- As expected, reproduce the Black-Scholes delta

Extending to Transaction Costs

- Now we can move beyond risk neutral pricing using the same framework
  - Add transaction costs
  - Deep hedger tends to under-hedge compared to risk neutral pricing

Extending to Proxy Hedges

- High transaction costs on underlying asset, but add a new zero transaction cost asset that is correlated with the underlying asset
  - How much should you hedge with the liquid proxy?
  - Wider PNL distribution but smaller expected shortfall

Gas-Fired Power Plant Optimization

- Gas-fired power plant: buy and burn gas to generate and sell electricity
  - Run it when power-gas spread is high, don't run it when it's not
  - Acts like an option on the spread between power and gas prices
- If unhedged, revenue from the plant is volatile
  - Volatile earnings are bad for company valuation
- Hedging gas and power price risks smooths out revenue profile
  - In risk neutral limit, it makes revenue certain
  - Good for company valuation
- Good example of a problem where risk neutral assumptions are violated
  - Power and gas markets for delivery at the power plant are often illiquid and have high transaction costs
  - Un-hedgeable risks due to unexpected plant outages

Heat Rate Options

- Real world gas-fired power plants are complex and running them involves bespoke business risks
- Hedge a heat rate option where both gas and power prices have high transaction costs, but both also have liquid correlated proxies
- Deep hedger (green) does much better than traditional risk neutral hedging (blue)
  - Insert picture here
- Takes more risk but does better on upside and better on downside

Conclusions

- Deep hedging is a powerful new machine learning technique in derivatives pricing and risk management
- Deep hedging reproduces the results of risk neutral pricing when those assumptions are satisfied
- It thus let us extend quantitative hedging methods beyond the constraints of risk neutral pricing
- There are many problems of real option optimization in commodity markets where these techniques can perform better than previous state of the art

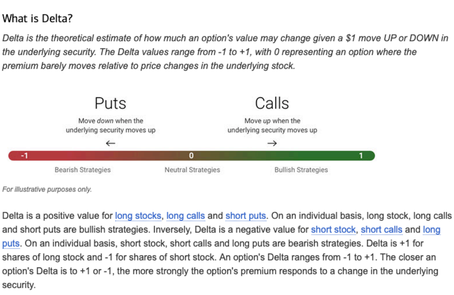
Extra learn:

What it shortfall -

A shortfall can refer to a current situation as well as one predicted for the future. A shortfall applies to any situation where the level of funds required to meet an obligation is not available. Shortfalls can occur in the business arena as well as for individuals. Temporary shortfalls often occur in response to an unexpected event, while long-term shortfalls may be related to overall business operations.

What is delta -

https://www.merrilledge.com/investment-products/options/learn-understand-delta-options



What is risk neutral pricing -

Risk-neutral probabilities are probabilities of potential future outcomes adjusted for risk, which are then used to compute expected asset values. In other words, assets and securities are bought and sold as if the hypothetical fair, single probability for an outcome were a reality, even though that is not, in fact, the actual scenario.
Risk-neutral pricing is the process of determining such risk-neutral scenario for asset pricing