Financing the Grid

Valuing Transmission and Storage Capacity

<u>FINAL PROJECT</u>

Group 4

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(Note: Please confer the submitted Python notebooks for further details on the code utilized, additional visualization, and in-depth commentary on dataset and statistical considerations)

Part 1 – The first facility

Data Wrangling and Simulation Parameters

We began by accessing the data for NSP.NWELOAD – a node located in the vicinity of Minneapolis – and then plotting the mean hourly prices in both the Day Ahead (DA) and Real-time (RT) markets, along with the corresponding standard deviations for each, to get a sense of the underlying movements for prices within the node. We then decided to fit a logistic distribution for the data for the preceding two years, for both DA and RT prices, to arrive at the parameters we would use for realistic simulations. We chose a logistic distribution because it is a natural distribution for power prices: close to a normal distribution but with heavier tails that allows negative values (also see the fitting_distribution.ipynb notebook where multiple distributions are fitted on historical data and logistic appears to fit it best). For this step, we grouped the prices by month and hour, as those two factors seem to be the primary drivers of variation with power markets.

Trading Strategies

With the fundamentals of the data and parameters in order, we ran 5,000 simulations to determine the profits associated with simply buying power in the DA market and the RT market. As a general rule, the prices in the DA market tend to exceed those in the RT, and our simulated profits reflected this intuition (called the DART premium) – the facility was more profitable buying power in the RT market, but this increased profitability came with higher variation, which also corroborates the general intuition of the purposes for the DA and RT markets.

In an effort to further refine our operating strategy for the facility, we simulated a more sophisticated approach, which entailed always buying power in the DA market but then deciding whether to mine Bitcoin with that power or sell it back in the RT market, based on which of those two options created more profit:

$$\text{Mine: Profit1} = P_{BTC} * Q_{BTC} - P_{DA} * Q_{elec}$$

$$\text{DART spread: Profit2} = (P_{RT} - P_{DA}) * Q_{elec}$$

Analysis of this approach revealed that 98.7% of the time, this strategy meant that we were electing for the first option. We also concluded that this strategy is very sensitive to assumptions surrounding the volatility of Bitcoin (the more volatile it is, the more the second option is chosen).

Our exploration of the data further suggested that, whenever mining is not profitable, it tends to be the case that selling power to the RT is also unprofitable. This insight allowed us to refine the strategy further and opt not to buy power in the DA (and therefore engage in neither Bitcoin mining nor RT power selling) whenever Bitcoin mining was not profitable – in essence, we curtailed the power we had purchased in the DA market.

Based on this refinement, we arrived at our optimal strategy: Purchase power in the DA market, curtail that power if Bitcoin mining yields profits below zero and otherwise each hour opt for either mining Bitcoin or selling power in the RT market based on whichever option is more profitable.

Results

	DA Only	**RT Only**	**Mine or Sell RT**	**Curtail, Mine, or Sell RT**
Average Annual Profit	$1,835,509	$1,918,178	$1,844,449.00	$1,846,673.00
Capital Charge (rF =4%)	$20,000	$20,000	$20,000	$20,000
Average Annual Excess Profit	$1,815,509	$1,898,178	$1,824,449	$1,826,673
Profit Volatility	$29,900.00	$30,270.00	$29,613.00	$29,500.00
Excess Profit to Volatility Ratio	60.72	62.71	61.61	61.92

As a general matter, these results conform with our expectations. The strategy of only purchasing power in the DA market yields the lowest profits; our optimal strategy improves both the profits and the volatility of this approach; and buying power in the RT market creates the largest profits but also entails the greatest risk.

Purchasing the Facility for $500,000

In light of the expected profits and the comparatively low volatility – captured by the quite high Sortino ratios for all of the trading approaches we employed – we would definitely purchase the facility from our uncle. Indeed, based on the return profile in our simulations, a reasonable breakeven expected value for the facility would be approximately $1.8m, so our uncle's offer price of $500,000 is highly advantageous to us.

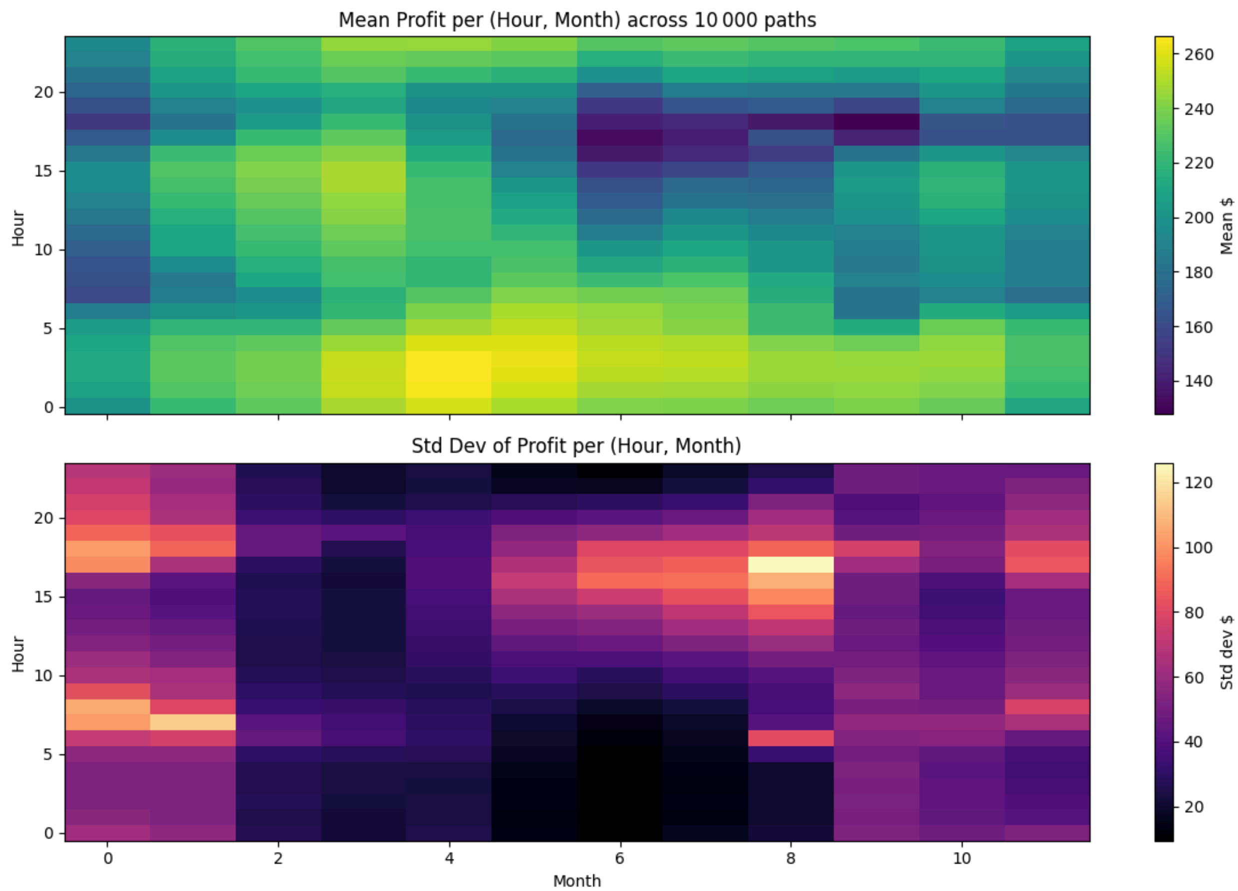
In an effort to account for the risk-return profile of the facility, we calculated the breakeven in the following manner:

$$Average\ Profit\ -\ Average\ STD\ -\ Asset\ Price\ =\ Asset\ Price \times Riskless\ Rate$$

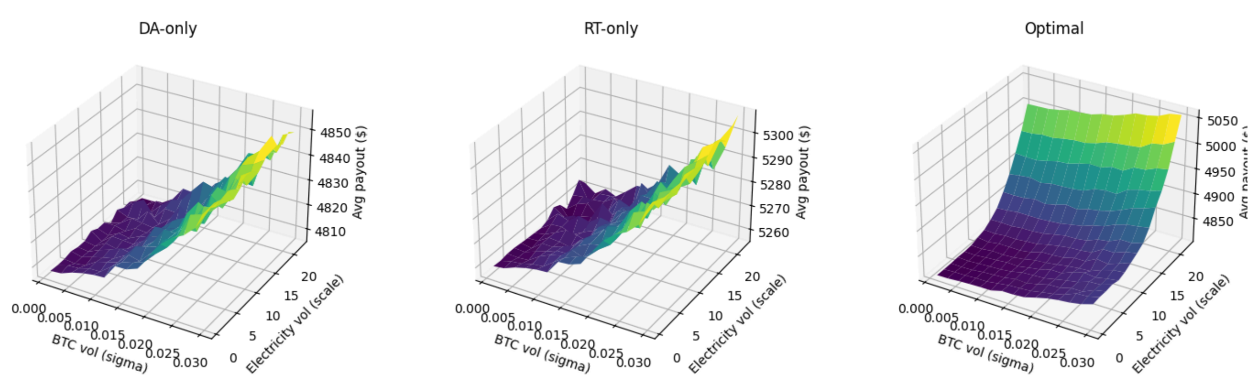
The idea of this calculus is to say that we are risk averse and therefore, we invest only if the asset is profitable with probability 85%.

Intraday Analysis

A visualization of the profits and volatility for intraday periods across simulations makes clear that value of operating the facility, the risk profile of doing so, and the net payout are all subject to substantial variation – as we would expect, given the underlying characteristics of Bitcoin prices and electricity pricing within MISO. Peak hours and month lead to more volatile profits.



Bitcoin and Electricity Volatilities



Among our three strategies – DA, RT, and Optimal – the volatility of both Bitcoin and electricity prices have a pronounced impact on the profitability of the facility. Across strategies, we benefit from the increased volatility of Bitcoin, as our asset morphs into a real option: we do not have to mine Bitcoin unless it is profitable for us.

The effects of the increased electricity scale (note: not sigma, as we employ logistic distributions) are far more noticeable in the Optimal Strategy than the two basic strategies.

Once again, this result aligns well with intuition: the more flexible approach of selling power in the RT if doing so is more profitable than mining only becomes more advantageous as the volatility of electricity prices increases.

Part 2 – A second facility

Given the attractive risk-return profile of our simulations for the first facility, we would certainly invest an additional $500,000 in a second facility.

Node Analysis: Generation Type
In considering where to place this facility, we thought a useful first step in the analysis would be to determine if, within MISO, there is a particularly advantageous type of power generation for our facility to be supplied by. With this in mind, we found five nodes which are each almost entirely supplied by a single type of power, and tried to select for nodes that are geographically well-suited to the individual power supply – i.e., a gas-powered node in Southern Louisiana, a solar farm in Texas, and wind in Iowa.

Fuel	Name	State	LMP Node
Coal	Prairie State Generating Company	Illinois	AMIL.PSGC1.AMP
Gas	Nine Mile Point Combined Cycle	Louisiana	EES.NINEMILE4
Nuclear	Prairie Island Nuclear Station	Minnesota	NSP.PRISL1
Solar	Umbriel Solar Farm	Texas	EES.SAN_JC1_CT
Wind	Storm Lake Wind	Iowa	MEC.PPWIND

After making the appropriate efforts to access relevant datasets and create simulation parameters, we repeated the three main strategies from Part 1 – DA only, RT only, and Optimal – on each of these nodes to see whether any power source was markedly better in its return-risk profile for our purposes in setting up a second facility.

COAL (AMIL.PSGC1.AMP)	**DA Only**	**RT Only**	**Curtail, Mine, or Sell RT**
Average Annual Profit	$1,879,309	$1,947,369	$1,885,932
Capital Charge (rF =4%)	$20,000	$20,000	$20,000
Average Annual Excess Profit	$1,859,309	$1,927,369	$1,865,932
Profit Volatility	$29,961	$30,073	$29,676
Excess Profit to Volatility Ratio	62.06	64.09	62.88

GAS (EES.NINEMILE4)	**DA Only**	**RT Only**	**Curtail, Mine, or Sell RT**
Average Annual Profit	$1,877,082	$1,939,706	$1,880,569
Capital Charge (rF =4%)	$20,000	$20,000	$20,000
Average Annual Excess Profit	$1,857,082	$1,919,706	$1,860,569
Profit Volatility	$29,828	$29,932	$29,650
Excess Profit to Volatility Ratio	62.26	64.14	62.75
NUCLEAR (NSP.PRISL1)	**DA Only**	**RT Only**	**Curtail, Mine, or Sell RT**
Average Annual Profit	$1,978,217	$2,039,817	$1,983,643
Capital Charge (rF =4%)	$20,000	$20,000	$20,000
Average Annual Excess Profit	$1,958,217	$2,019,817	$1,963,643
Profit Volatility	$29,828	$30,151	$29,600
Excess Profit to Volatility Ratio	65.65	66.99	66.34
SOLAR (EES.SAN_JC1_CT)	**DA Only**	**RT Only**	**Curtail, Mine, or Sell RT**
Average Annual Profit	$1,893,177	$1,955,701	$1,898,321
Capital Charge (rF =4%)	$20,000	$20,000	$20,000
Average Annual Excess Profit	$1,873,177	$1,935,701	$1,878,321
Profit Volatility	$29,874	$30,065	$29,604
Excess Profit to Volatility Ratio	62.70	64.38	63.45
WIND (MEC.PPWIND)	**DA Only**	**RT Only**	**Curtail, Mine, or Sell RT**
Average Annual Profit	$2,165,346	$2,221,185	$2,250,529
Capital Charge (rF =4%)	$20,000	$20,000	$20,000
Average Annual Excess Profit	$2,145,346	$2,201,185	$2,230,529
Profit Volatility	$30,198	$49,441	$37,177
Excess Profit to Volatility Ratio	71.04	44.52	60.00

Commentary

Our analysis of the varying power generation sources broadly aligns with expectations. Wind power offers the highest profitability but also has the highest volatility, so it offers the best profit potential but the lowest Sortino ratio among the optimal strategies. We were slightly surprised to find that the best Sortino ratio came with nuclear power, though retrospectively it makes sense that the stability of nuclear power pricing would lend itself well to our mining facility.

It is also worth observing that our optimal strategy provides broadly consistent metrics across the types of power generation. This is not the case for the naive strategies and lends credence to the idea that our optimal strategy is aimed at consistency – as with all investments, there is much to recommend a strategy that is consistent even if it is not maximally profitable. This is where it is illuminating to draw a distinction between corporate finance and planning for investments in real assets, relative to simply maximizing the Sortino ratio of a strategy.

Although being located near wind power brings with it the greatest profit potential, we could site our second facility near a nuclear power plant; in keeping with the spirit of the exercise, we would opt for the highest Sortino ratio. The relatively low volatility of nuclear prices, and the more consistent cash flows, would also enable us to consider employing leverage in our second facility, and as a result, concentrating the results to equity holders. The stability of nuclear power might also empower us to consider a third facility with a risk profile that would otherwise be unappealing, perhaps combined with some intelligent hedging – for instance, a mining facility near a large wind farm along with a portfolio of weather derivatives.

Doubling Current Facility vs. Building New Facility

As a matter of first principles, it must be the case that building a new facility is a more attractive option than doubling our current one, so long as the new facility is far enough removed from the original that there is less than perfect correlation between the electricity prices at the two facilities. This allows us to earn the benefits of diversification and an improved risk-return profile.

To confirm this understanding of the theory, we ran a final set of simulations, which considered six scenarios.

	Combination	Optimal Profit	Optimal Sortino Ratio
Scenario 1	Original Node + Coal Node	$3,732,808	62.68
Scenario 2	Original Node + Gas	$3,727,446	62.58
Scenario 3	Original Node + Nuclear	$3,830,520	64.42
Scenario 4	Original Node + Solar	$3,745,198	62.95
Scenario 5	Original Node + Wind	$4,097,406	64.47
Scenario 6	2 × Original Node	$3,693,726	62.26

The results confirm that each of the five diversification scenarios yields a higher Sortino ratio than simply doubling our current facility. This final set of results is intriguing because of the combination scenarios, adding a wind-heavy facility to our current one yields the highest Sortino ratio, which is perhaps indicative of the fact that our current facility is either already exposed to nuclear power (which is plausible given its location in Minnesota) or under-exposed to wind power (also plausible for Minnesota).

Appendix

There are 3 notebooks (python code):

- Part1: We work on the node given in part 1 and evaluate the profits of the mining factory. Mainly used to answer the part 1 of the problem, but also provides elements for answering part 3
- Part2: Work on other nodes to answer mainly the part 2 of the problem, while also providing elements for answers in part 3
- Fitting_distribution: In this file we want to know how to simulate realistic prices for LMPs. To do so we fitted historical prices to several distributions and asset the fit of each one.