Energy Imbalance Reserves: An Equilibrium Approach

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SIOPT26 – Celebrating ABP

How this talk witll appreciate ABP!

- It is concerned with a real problem.
- It contains equilibrium computation (shout out to Michael and Co.).
- We model risk aversion.
- We have theorems and proofs.
- We have numerical results.
- We even have some empirical results.

Problem motivation

- Federal Energy Regulatory Commission (FERC), directed ISO New England to submit "tariff revisions reflecting improvements to its market design to better address regional fuel security concerns".
- In response, ISO-NE proposed the creation of a formal reserve market that allows physical generators to sell additional energy not directly associated with a consumer. This is the day ahead ancillary services initiative (DASI) mechanism.
- We will lay out and investigate a new product called the Energy Imbalance Reserve (EIR) option in today's talk.

A stylized model of current operations

$$
\begin{array}{llll|lll}
 & \textbf{DA dispatch} & & & & \textbf{RT dispatch } (s) & \\
\text{min} & \sum_i C_i g_i^{DA} & & & \text{min} & \sum_i C_{i,s} g_{i,s}^{RT} & \\
 & \sum_i g_i^{DA} = D^{DA} & & [\lambda^{DA}] & & \sum_i g_{i,s}^{RT} = D_s^{RT} & [\lambda_s^{R} \\
 & g_i^{DA} \le Q_i^{DA} & (\forall i) & & & g_{i,s}^{RT} \le Q_i^{RT} & (\forall i) \\
 & g_i^{DA} \ge 0 & (\forall i) & & & g_{i,s}^{RT} \ge 0 & (\forall i)
\end{array}
$$

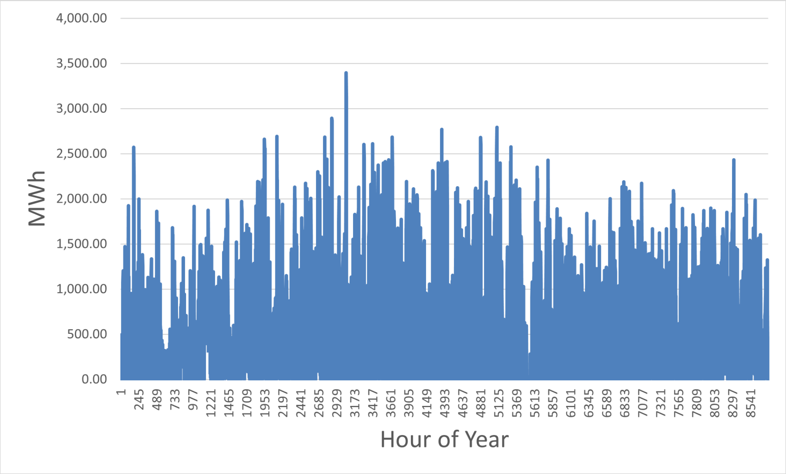
The generator profit is then:

$$\lambda^{DA} g_i^{DA} + \lambda_s^{RT} (g_{i,s}^{RT} - g_i^{DA}) - C_{i,s} g_{i,s}^{RT}$$

What's wrong with the current set up?

- D^{DA} is an estimate of D_s^{RT}.
- If $D_s^{RT} < D^{DA}$ then the generator(s) will likely not produce as much; this introduces a *risk* of losing money due to any *expensive* fuel procured for generation purposes.
- If on the other hand $D_s^{RT} > D^{DA}$ the generator incurs no risk, but the *system* risks outages and this can be detrimental.
- Try to align incentives.

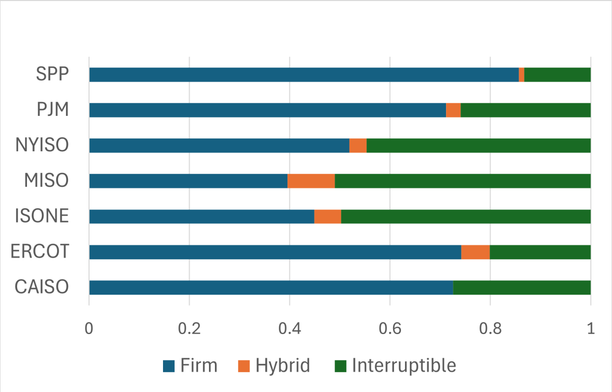
ISO-NE energy gap in 2024



Fuel procurement

- New England meets the bulk of its electricity needs through generation from natural gas (55% of electricity in 2024 was produced from NG).
- There is no "native" natural gas in the north east and what we use is taken from pipelines.
- In extreme cold situations, it becomes harder to extract gas from the pipeline, and there is more demand (heating demand as well as demand to generate electricity).
- This leads to the "fuel security concerns" of FERC and ISO-NE.

Natural gas contracts



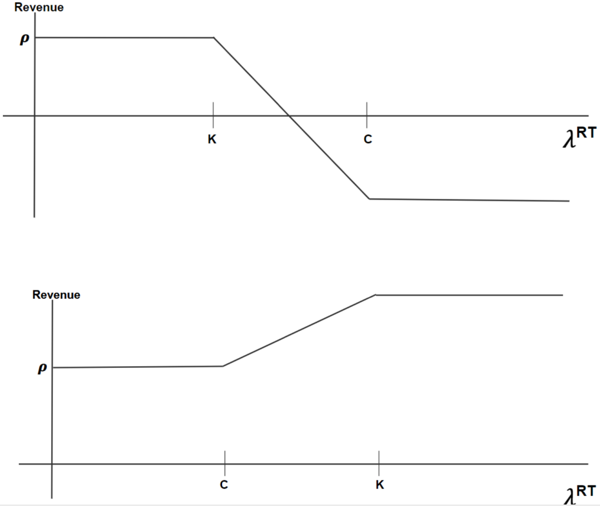
Introduction of EIR options

- The ISO has now introduced an option that it buys from generators through an auction.
- The strike price of the option is set (by ISO) at value K.
- The option is exercised by the system operator if $\lambda^{RT} > K$.
- So the *per unit profit* of the generator is given by

$$\rho - (\lambda^{RT} - K)^+ + (\lambda^{RT} - C_i)^+$$

Here, ρ is the per unit price of the option determined at the auction.

Illustration of payoff



Quick takeaway

Seems like the larger the strike price K, the less likely that a generator will be in the red, so, the better disposed they will be towards this option.

Moedlling to gain insight: risk averse agents

- We start with *competitive equilibrium* models with risk neutral and risk averse participants.
- We model our agents to have risk aversion.
- Their risk aversion is measured by Conditional Value at Risk.
- This is a nice, coherent risk measure that lends itself nicely to optimization.

Generator i's optimization problem in EMO

$$\max_{\Xi} \; \eta_i - \frac{1}{a_i}\sum_s \pi_s u_{i,s} \tag{1a}$$

$$\text{s/t } u_{i,s} \geq \eta_i - Z_{i,s} \qquad [q_{i,s}] \tag{1b}$$

$$g_i^{DA} \leq Q_i \qquad [\delta_i] \tag{1c}$$

$$g_{i,s}^{RT} \leq Q_i \qquad [\gamma_{i,s}] \tag{1d}$$

$$g_{i,s}^{RT,s} - I_{i,s} - A_i \leq 0 \qquad [\mu_{i,s}] \tag{1e}$$

$$g_{i,s}^{RT}, g_i^{DA}, I_{i,s}, A_i, u_{i,s} \geq 0 \qquad \forall s \tag{1f}$$

where

$$\Xi := (g_{i,s}^{RT}, g_i^{DA}, u_{i,s}, A_i, I_{i,s}, \eta_i, u_{i,s})$$

$$Z_{i,s} := \lambda^{DA} g_i^{DA} + \lambda_s^{RT}(g_{i,s}^{RT} - g_i^{DA}) - C_i g_{i,s}^{RT} - C_i^F A_i - C_{i,s}^I I_{i,s} \tag{2}$$

Generator i's optimization problem in EMIR

Minimize risk adjusted losses:

$$
\begin{array}{lll}
\max & \sum_s p^s[(1-\alpha)u_i^s + \alpha w_i^s] & \\
\text{s/t} & \eta + u_{i,s} - w_{i,s} = (\lambda^{DA} + \rho) * g_i^{DA} + \rho * e_i + & \\
 & \lambda_s^{RT} * (g_{i,s}^{RT} - g_i^{DA}) - [\lambda_s^{RT} - K]^+ * e_i - & \\
 & C_i * g_{i,s}^{RT} - C_{i,s}^I * I_{i,s} - C_i^A * A_i & \\
 & g_i^{DA} \leq Q_i^{DA} & [\delta_i] \\
 & g_{i,s}^{RT} \leq Q_i^{RT} & [\gamma_{i,s}] \\
 & e_i \leq Q_i^{EIR} & [\zeta_i] \\
 & g_{i,s}^{RT,s} - I_{i,s} - A_i \leq 0 & [\mu_{i,s}]
\end{array}
$$

Demand agent's problem in EMO

$$\max_{\eta^D, u_s^D, d^{DA}} \eta^D - \frac{1}{\alpha^D} \sum \pi_s u_s^D \tag{3}$$

$$\text{s/t} \, u_s^D \geq \eta^D - Z_s^D \qquad [q_s^D] \tag{4}$$

$$u_s^D, d^{DA} \geq 0 \qquad \forall s \tag{5}$$

where

$$Z_s^D := -\lambda^{DA} d^{DA} - \lambda_s^{RT} (D_s^{RT} - d^{DA}) \tag{6}$$

The demand agent maximizes its risk adjusted profit, similar to the generator's counterpart. When $\alpha^D = 1$, the demand agent is risk neutral.

Demand agent's problem in EMIR

$$\max_{\eta^D, u_s^D, d^{DA}} \eta^D - \frac{1}{\alpha^D} \sum \pi_s u_s^D \quad (7)$$

$$\text{s/t} \; u_s^D \geq \eta^D - Z_s^D \qquad [q_s^D] \quad (8)$$

$$u_s^D, d^{DA} \geq 0 \qquad \forall s \quad (9)$$

where

$$Z_s^D := -\lambda^{DA} d^{DA} - \lambda_s^{RT}(D_s^{RT} - d^{DA}) - \rho(FER) + [\lambda_s^{RT} - K]^+ \sum_i e_i \quad (10)$$

Market clearing conditions

- We model arbitrageurs that trade between day ahead and real time markets to maximize profit.
- The market clearing constraints require demand and supply balance, in particular RT demand to equal real time supply.
- The ISO requires also that EIR and day ahead procurement to equal to the forecast demand plus a cushion.
- Additionally, we model lost-load in real time if λ_{RT} exceeds a price cap.

Market clearing again

$$\sum_i g_i^{DA} + a = d^{DA} + b \perp \lambda^{DA} \text{ free}, nb \qquad (11)$$

$$\sum_i g_{i,s}^{RT} = D_s^{RT} \perp \lambda_s^{RT} \text{ free}, \qquad (12)$$

$$0 \leq \sum_i g_i^{DA} + \sum_i e_i - FER \perp \rho \geq 0 \qquad (13)$$

The experiment

- We can stack the optimality conditions for the generators, demand and arbitrageurs with the market clearing conditions.
- This will give us a mixed complementarity problem (MCP).
- The solution to this MCP will constitue an equilibrium.
- We can compute an equilibrium with and without the EIR options available for trade and vary a range of parameters.

Risk neutral agents

- It is interesting to analyze the equilibrium when participating agents are all risk neutral and maximize expected profits/minimize expected cost.
- One question to answer is: "Now that the demand will have to pay for the provision of energy imbalance (i.e. ρ from the EIR auction), will it be incentivized to provide an accurate estimate of real time demand, in the day ahead?

Equivalence of equilibria in risk neutral case

Proposition

Suppose that total available capacity is greater than FER (i.e. $\sum_i Q_i > FER$). Then any valid solution to the model with energy imbalance reserve and virtual traders, satisfies $\rho = 0$. Furthermore, when the close out cost is not identically zero across all scenarios, $e_i = 0$ in equilibrium.

Intuition for the proposition

- Essentially the arbitrageurs equiliberate the day ahead and the expected real time price.
- Since the agents are risk neutral, the day ahead demand plus the so called "INCs" minus "DECs" is the demand estimate that would correspond to the expected real time price.
- Note that this is not necessarily the same as the expectation of real time demands.
- Existence of arbitrageurs, more or less makes the EIR options redundant under the assumptions above, in particular *risk neutrality* and *competitive behavior* of agents.

What about risk aversion

- We will present some results of what *can* happen under risk aversion.
- We set up and solve the MCPs using GAMS Path solver.
- The equilibria here are not necessarily unique (we have experimental instances where we have found multiple equilibria).

The set up

Table: Two Generator Inputs

Scenario	1	2	3	4	5
D_s^{RT}	50	75	100	125	150
$C_{i,s}^I$	15	20	30	50	100
$R_{i,s}$	10	10	10	10	10
π_s	0.2	0.2	0.2	0.2	0.2

Table: Two Generator Inputs

	Q_i	C_i	C_i^F
Gen 1	100	0	50
Gen 2	100	5	50

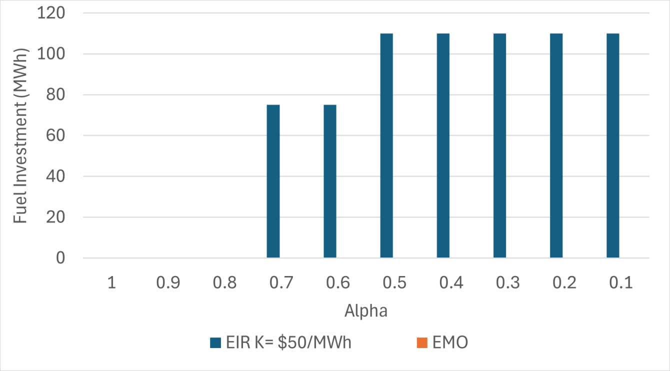


Figure: Advanced Fuel Investment vs Alpha when K = $50/MWh

As risk aversion increases, more advanced fuel is procured in the EIR market.

Increasing K

As K increases, while the generators do sell EIR options, they do **not** procure fuel!

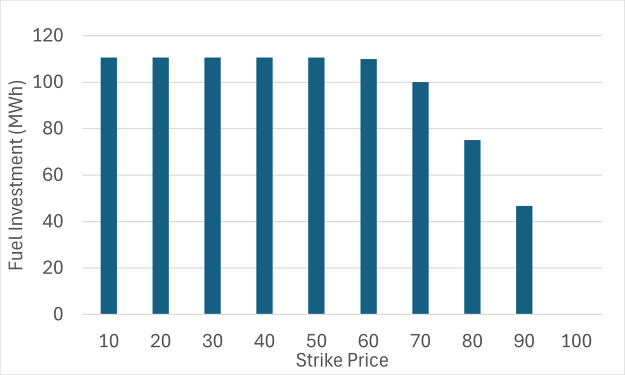


Figure: Advanced Fuel Investment vs Strike Price When $\alpha_1 = \alpha_2 = 0.6$ in EMIR Model

Why is this?

- If a generator does **not buy advanced fuel** but does sell EIRs, their fuel procurement **costs** in higher demand scenarios **is higher**.
- The **real time price** will becomes higher as a result of this.
- However, $[\lambda_s^{RT} - K]^+$ will **decrease** as a function of K, so the amount and probability of having to pay out decreases.
- On the other hand, purchase of advanced fuel will result in a "sunk cost" across all scenarios, and it is particularly bad for low demand scenarios.
- Models that entail multiple agents and risk are complex and many different aspects need to be studied.

Risk averse demand agent

Table: d^{DA} with Risk Averse Demand Agent

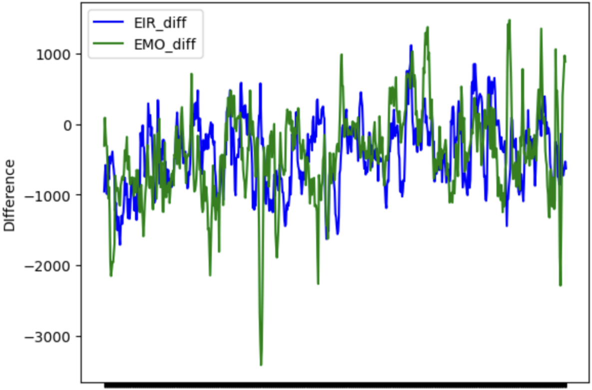
	EIR	EMO
1	61.4305	3.00217
.9	166.541	166.665
.7	166.541	166.665
.6	175.818	175.861
.5	172.222	172.222
.2	172.059	172.059
.1	172.059	172.059

When the demand agent becomes risk-averse, it increases its day-ahead demand purchases above and beyond the load forecast in both the EMIR and EMO models irrespective of K value.

Further steps

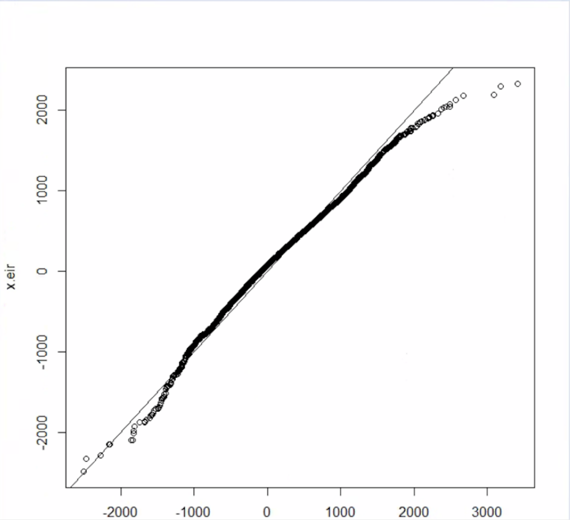
- We have preliminary models for exercise of market power.
- Thus far we have found that EIR can be a vehicle for further exercise of market power.
- DASI has been in action for a bit over a year so we can do some empirical analysis.
- We do not have information on the fuel contract positions, but we can look at the gap between day ahead estimate of and real time realization of demand.

Difference in gaps seem to shrink?



The horizontal axis is the hours in the month of February (EMO for 2024, EIR for 2025).

Look at the full year of data, QQ plots



Is the gap shrinking really? statistical inference

- There is a strong positive correlation between the hourly gaps.
- We fit an AR1 model to both the EMO and EMIR data; the regression coefficient is the same for both to 5 significant digits.
- We can look at the residuals and compare. The variances are statistically significantly different. The EMIR variance is smaller.
- Statistically significant, but is this "important"? Don't really know, we'll have a better idea with more data.

Thank you and questions??

- Thank you Andy for all the lessons.
- We're grateful to ISO-NE for their generous support of this research.
- Any questions and comments most welcomed.