Demand Response for Industrial-Scale Energy Users in Midwest ISO: A Dynamic Programming Approach for Curtailing Energy Use

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Motivation

• Demand Response (DR): Users adjust consumption to electricity price changes

• Demand Response with Interruptible Load:
  – Curtail energy consumption during peak hours
  – Incentive: $6-$8/kWh payment with Interruptible Load

• Industrial Customers and Demand Response
  – They consume large amount of energy
  – Some industries are flexible to interrupt production
Cement Production and Interruptible DR

- Largest energy using industry in the US
- Electricity use is interruptible during production
- Electricity is about 8% of the energy mix
  - Energy Mix: Coal, Fuel, Electricity, Natural Gas
- Up to 50% of electricity consumption reduction is possible (Olsen 2010)
Energy Mix in Cement Production

**Electricity:** 160kWh/ton

**Coal:** 220kg/ton

**Fuel:** 19,100 Btu/ton

**Natural Gas:** 4.21mmBtu/ton

16kWh

[Flowchart showing the energy mix and production process]

1.5 tons raw material:
- 1275kg limestone
- 187.5kg clay/clay-like material
- 37.5kg other

**Raw Mill**  →  1.5 tons raw mix  →  **Kiln Feed Prep**  →  **Clinker Production (Kiln)**  →  0.95 tons clinker  →  **Cement Mill**

1 ton cement

0.05 tons gypsum

56kWh
Stochastic Electricity Prices

Simulated Electricity Prices

- Mean Reverting Process

\[ dq(t) = \alpha(\bar{q} - q(t)) + \sigma d\varepsilon(t) \]

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Jul</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha)</td>
<td>3.08</td>
<td>1.2</td>
</tr>
<tr>
<td>(q)</td>
<td>26</td>
<td>35</td>
</tr>
<tr>
<td>(\sigma)</td>
<td>10.6</td>
<td>17.7</td>
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Analytical Framework I

Real-options theory: Value of future information

- Decision to adopt DR: $k(t)$
- Stochastic Electricity Prices: $q(t)$
- DR incentive: $r$

$$\max_{k(t)} \pi_t(k(t), q(t)) = p \cdot (X - \gamma \cdot k(t) \cdot X(t)^e) + k(t) \cdot (X(t)^{max} - X(t)^e \cdot r - C(X(t))$$

s.t.

$$\pi_{T+1}(k(T), q(T)) = 0$$

$$X(t)^{max} \geq X(t)^e \geq 0$$

$$C(X(t)) = q(t)X(t)^e + p^{ng}X^{ng} + p^cX^c + p^fX^f$$

$$k(t) \in (0,1)$$

$$\gamma = \frac{X(t)^e}{X(t)^{max}}$$
Analytical Framework II

Solving with backwards recursion using Bellman’s Rule of Optimality

Value Function

\[ V(\pi(k(t), q(t))) = \max_{k(t)} [\pi(k(t), q(t)) + \beta \cdot V(\pi(k(t + 1), q(t + 1))] \]

Terminal Value

\[ V(\pi_{T+1}(k(T + 1), q(T + 1)) = 0 \]
Results

• The solution of the problem involves finding profitability threshold for adopting DR

• This threshold represents the lowest electricity price that will spur DR adoption at any given time (t) in a day

• Decision to adopt DR depends on the stochastic electricity prices
DR Adoption Boundary

Peak Summer (Jul)  Peak Winter (Jan)

Critical Boundary for no DR

Critical Boundary for DR

ADOPT DR

Electricity Price

Time

Electricity Price

Time
Higher DR Incentive (r)

Higher DR payment decreases DR Boundary

<table>
<thead>
<tr>
<th>r</th>
<th>Min DR Boundary</th>
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<tbody>
<tr>
<td>$6/MWh</td>
<td>$24/MWh</td>
</tr>
<tr>
<td>$8/MWh</td>
<td>$16.4/MWh</td>
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<tr>
<td>$12/MWh</td>
<td>$12/MWh</td>
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On-going Work

• Industry Model for Hourly Production in Cement

• Choice as different types of demand response (e.g. Direct Load Program)

• Fuel switching

• Emissions implications of demand response

• Spatial market differences
Future Research
Thanks for your attention

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