Time of Use Pricing and Electricity Demand Transfer: A Long Run Analysis of Capacity and Prices

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Plan

1. Introduction & Model
2. Analytical Results
3. Numerical Application: Ontario (Canada)
   - Capacity reduction
   - Prices
   - Energy consumption & Technologies
1. Introduction & Model

![Diagram showing peak and off-peak demand with associated costs and shifting peak]

- Peak demand
- Off-peak demand

\[ P (\$) \]
\[ Q (\text{MW}) \]
1. Introduction & Model

1. When do we get a firm or a shifting peak?
2. What are the capacity, price and energy consumption changes?
3. How do different price elasticities influence the results?
4. What about cross-price elasticities? (transfer of demand from peak to off-peak periods)
1. Introduction & Model

- 2 time periods: peak ($\omega$) and off-peak
- 1 technology: $c = \text{variable cost}$
  
  \[ r = \text{fixed cost} \]

- Demand functions:
  
  \[
  \text{Off-peak (Low) period} \quad Q_L = aP_L^b \\
  \text{Peak (High) period} \quad Q_H = aZP_H^{\alpha b}
  \]

  $a$ and $Z$: parameters scaling demand
  $b$: price elasticity
  $0 < \alpha < 1$: parameter adjusting elasticity (peak)
2. Analytical Results

• ACP conditions

Revenue constraint

\[(P-c)[(1-\omega)Q_L+\omega Q_H]=rQ_H\]

\[Q_H=K\]

• TOU conditions: Firm peak

\[P_L=c; P_H=c+r/\omega; Q_H=K\]

Revenue constraint

\[(P_L-c)(1-\omega)Q_L+(P_H-c)\omega Q_H=rQ_H\]

• TOU conditions: Shifting peak

\[Q_L=Q_H=K\]

Revenue constraint

\[(P_L-c)(1-\omega)+(P_H-c)\omega=r\]
2. Analytical Results

• ACP solution

\[(P-c)[P^{b(1-\alpha)}(1-\omega)+\omega Z]=rZ\]

• TOU solution: Firm peak

\[P_L=c\]
\[P_H=c+r/\omega\]

• TOU conditions: Shifting peak

\[P_L=Z^{1/b}P_H^\alpha\]
\[(1-\omega)Z^{1/b}P_H^\alpha+\omega P_H=c+r\]
2. Analytical Results

Firm peak or Shifting peak?

Firm peak means $Q_H > Q_L$. This is true when

$$r < \omega \left[ \left( \frac{c}{Z^b} \right)^{\frac{1}{\alpha}} - c \right]$$

Or alternatively

$$Z > \left( \frac{c}{\left( c + \frac{r}{\omega} \right)^{\alpha}} \right)^b$$
2. Analytical Results

Transfer of demand

- Demand functions:

  **Peak (High) period**
  \[ Q'_H = aZP_H^{ab} - \gamma aZP_H^{ab} = (1-\gamma)aZP_H^{ab} \]

  **Off-peak (Low) period**
  \[ Q'_L = aP_L^{b} + \gamma aZP_H^{ab} \]

  \(0 < \gamma < 1\): exogenous parameter representing the percentage of demand transferred from the peak to the off-peak period
2. Analytical Results

Firm peak or Shifting peak?

Firm peak means $Q'_H > Q'_L$. This is true when

$$r < \frac{c^b}{Z(1 - 2\gamma)} \left( \frac{1}{\alpha} \right) - c$$

or

$$Z > \frac{c^b}{\left( c + \frac{r}{\omega} \right)^{\alpha}} \left( 1 - 2\gamma \right)$$

or

$$\frac{Z}{\left( c + \frac{r}{\omega} \right)^{\alpha}} - c^b$$

or

$$\gamma < \frac{Z}{2Z \left( c + \frac{r}{\omega} \right)^{\alpha}} - c^b$$
2. Analytical Results

• **Result 2.** It can be shown that a Firm peak is *less likely* when there is transfer of demand.

• **Result 3.** $P_H = P_L = c + r$ when

$$\gamma = \frac{Z - (c + r)^{b(1-\alpha)}}{2Z}$$
3. Numerical Results: Ontario

**High demand (peak) period** - Average of 13,035 MW
- 7h-23h in January, February, July and August

**Low demand (off-peak) period** - Average of 11,198 MW
- All day from March to May and September to December
- 23h-7h in January, February, July and August
3. Numerical Results: Ontario

- Nuclear: $c = 22.80 + 37 = 59.80/\text{MWh}$
  \[ r = 31.56/\text{MW} \text{ (per hour)} \]
- Na.Gas: $c = 53.59 + 37 = 90.59/\text{MWh}$
  \[ r = 9.15/\text{MW} \text{ (per hour)} \]
- $b = -1.29$, $\alpha = 0.667$
- $Z = 0.17$, $a = 3,192,468$, $\omega = 0.22$
- $\gamma = 0.05$ equal prices for $\gamma = 0.094$ (nuclear) and $\gamma = 0.109$ (natural gas)
3. Numerical Results: Ontario

\[ Q_H = 0.1768 \times 3,192,468 \times P_H^{0.667(-1.29)} \]

\[ Q_L = 3,192,468 \times P_L^{1.29} \]

TOU_H = 107.56

ACP = 97.51

P_2003 = 80

Low Demand Period

High Demand Period

2003 Ontario Data

TOU Price No transfer

ACP
## 3. Numerical Results: Ontario

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<th>Average Cost Pricing</th>
<th>TOU Pricing % of change</th>
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<th><strong>Average Cost Pricing</strong></th>
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Pierre-Olivier Pineau & Stephan Schott
Summary

Analytical results

• **Result 2.** With transfer of demand, full capacity is used in all periods under less stringent conditions.

• **Result 3.** There is a specific level of transfer for which prices will be equal with TOU pricing.

Numerical results

• With transfer of demand, the **reduction in capacity** is limited.

• With transfer of demand, the **increase in consumption** is even greater.

• **Technology** has a tremendous impact on capacity, prices and energy consumption.

• **Elasticity** and **transfer of demand** are very important factors.
Conclusion

TOU pricing (and real time pricing) have perverse effects, that create other problems:

higher prices in some periods & overall increase in consumption

The dilemmas that electricity policy creates are far from being easily solved.