

# **Real-Time Pricing for Managing a Steep Change of Electricity Demand**

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# 1. Background

- **A steep change** of electricity demand
  - especially on summer morning
- Generators must **ramp up** their units quickly
  - supply & demand must be balanced instantaneously

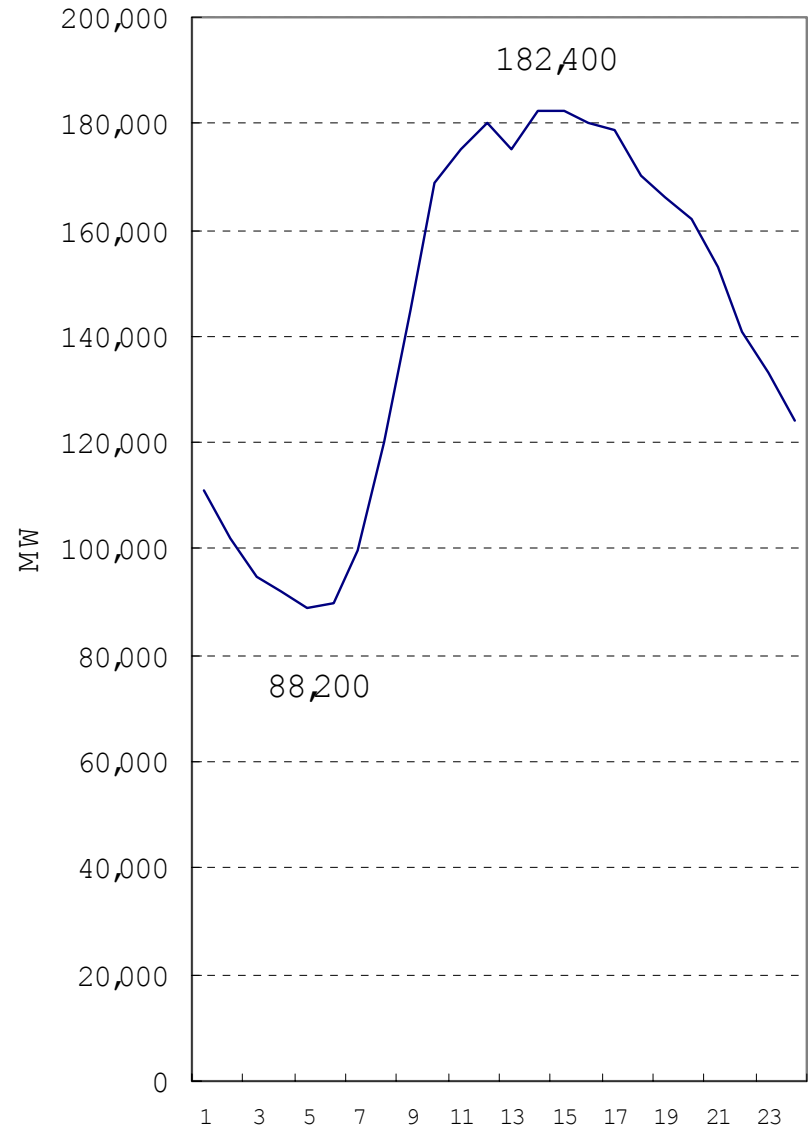


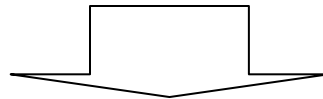
fig. load curve in Japan (2001.7.24)

- Supply-side measures

- the ramping capability of power supply equipment has been technologically improved



**The rate of a demand change is given**



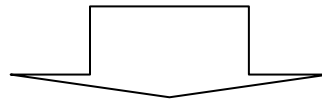
Allocative inefficiency

- **Demand-side** measures

- **price signals** induce **demand responses**
- peak-load pricing, real-time pricing (RTP)



A new approach to real-time pricing that explicitly incorporates **the ramping cost**



**The optimal rate of a demand change**

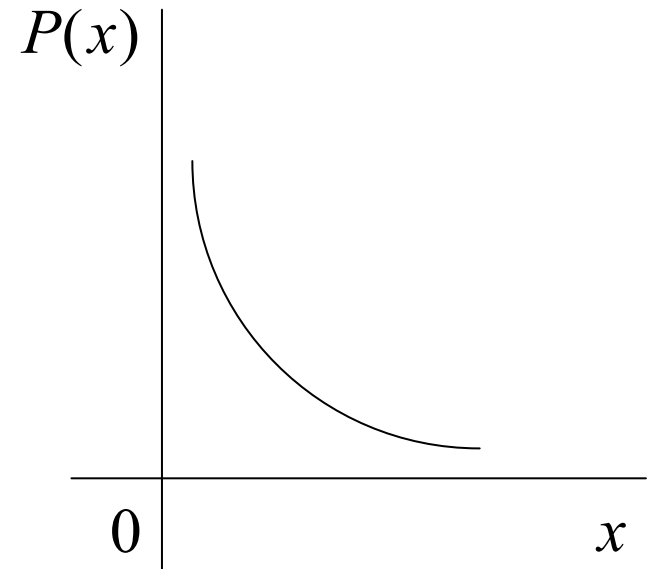
## 2. Model

### 2.1 Electricity demand

- Time-varying demand

$$p(t) = P(x(t), t)$$

$t$ : time,  $x(t)$ : quantity of power

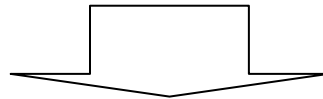


- The gross benefit of consumption

$$B(x(t), t) \equiv \int_0^{x(t)} P(q, t) dq$$

## 2.2 Electricity supply

- The ramping process
  - starting up, shutting down, loading, unloading, etc.



- **The ramping cost**
  - ramping process causes wear and tear on equipment and shortens the life of components  
cf. Wang and Shahidehpour (1995)
  - equipment needs special mechanical designs for fast ramping

- **The ramping cost**

- the outage cost

incurred by an electric power shortage

**Chao, H. P. (1983)**

“Peak Load Pricing and Capacity Planning with Demand and Supply Uncertainty”



A steep change of electricity demand raises the possibility of a power shortage



The expected social cost of an outage

- **The ramping cost: a general formula**

- a function of

- the rate of a demand change**  $\dot{x}(t) \equiv \frac{dx(t)}{dt}$

$$S(\dot{x}(t))$$

- assume that the marginal ramping cost  $S'(\dot{x}(t))$  is increasing

$$S''(\dot{x}(t)) > 0$$

- The variable cost

$$C(x(t))$$

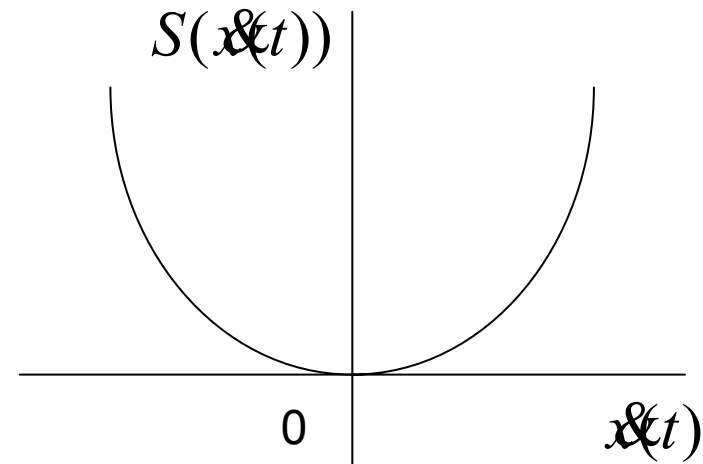


fig. example of the ramping cost func.

### 3. Optimal Pricing

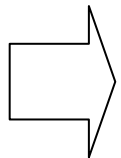
- Maximization of social welfare

$$\max_{x(t) \geq 0} : W^s \equiv \int_0^T \{B(x(t), t) - C(x(t)) - S(\dot{x}(t))\} dt$$

Considering **the ramping cost** explicitly

$$p^s(t) = C'(x^s(t)) - S''(\dot{x}(t)) \dot{x}(t)$$

**RTP-S: Real-Time Pricing for Managing  
a Steep Change of Demand**

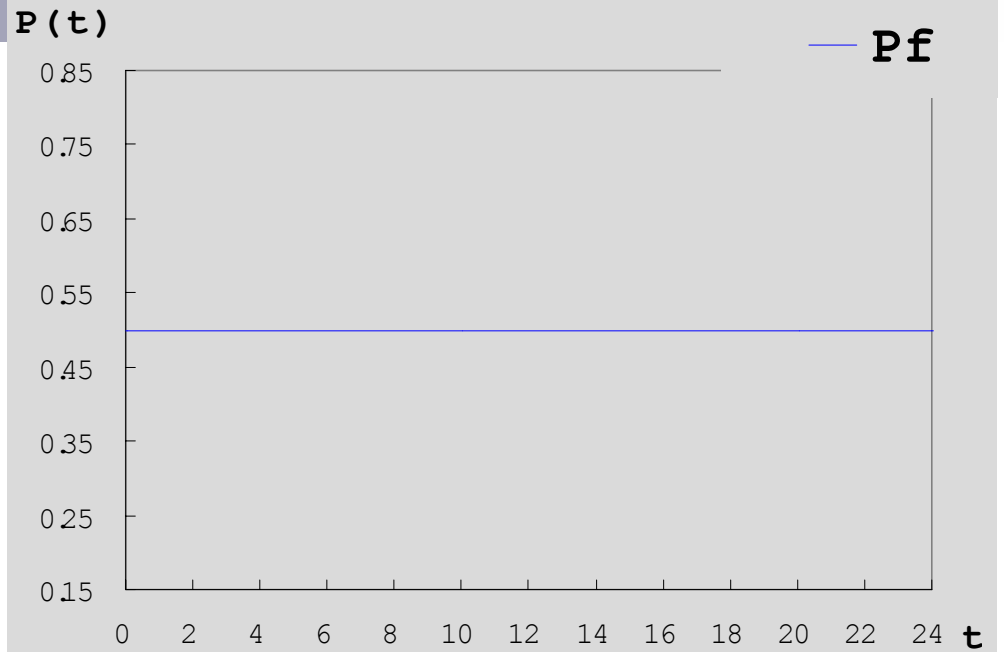


**The optimal rate of a demand change**

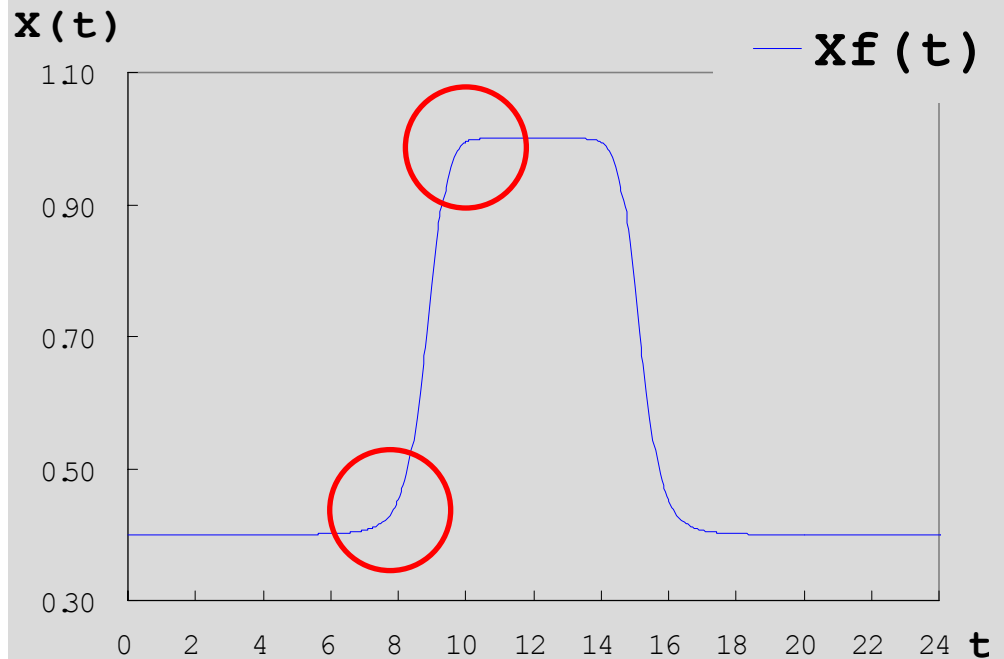
# 4. Numerical Example

**Flat rate :  
The base case**

The price path

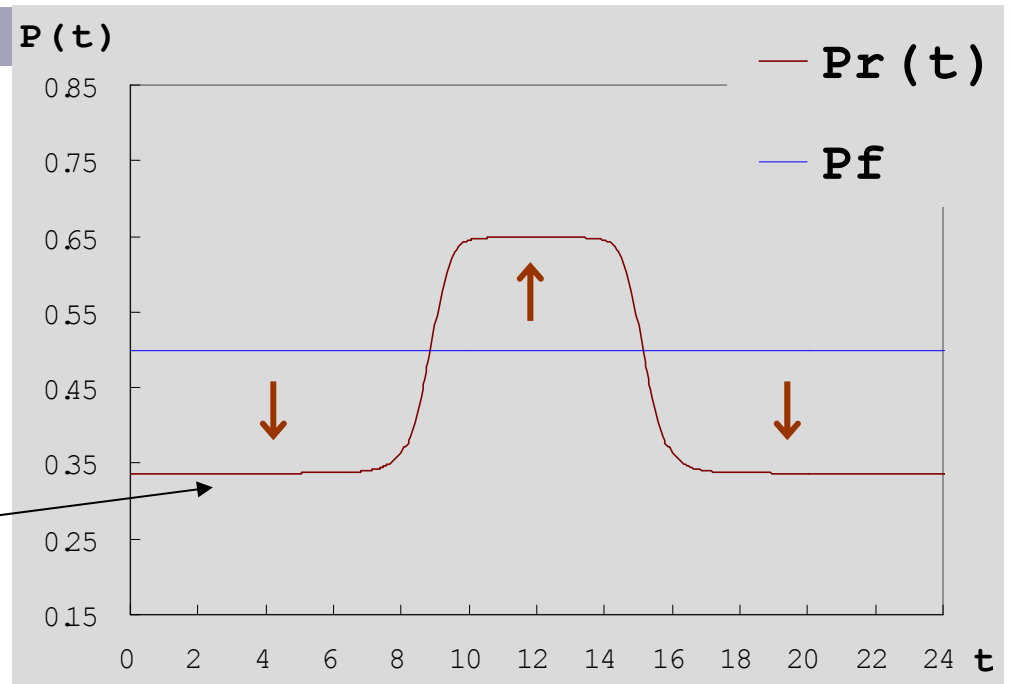


The demand path



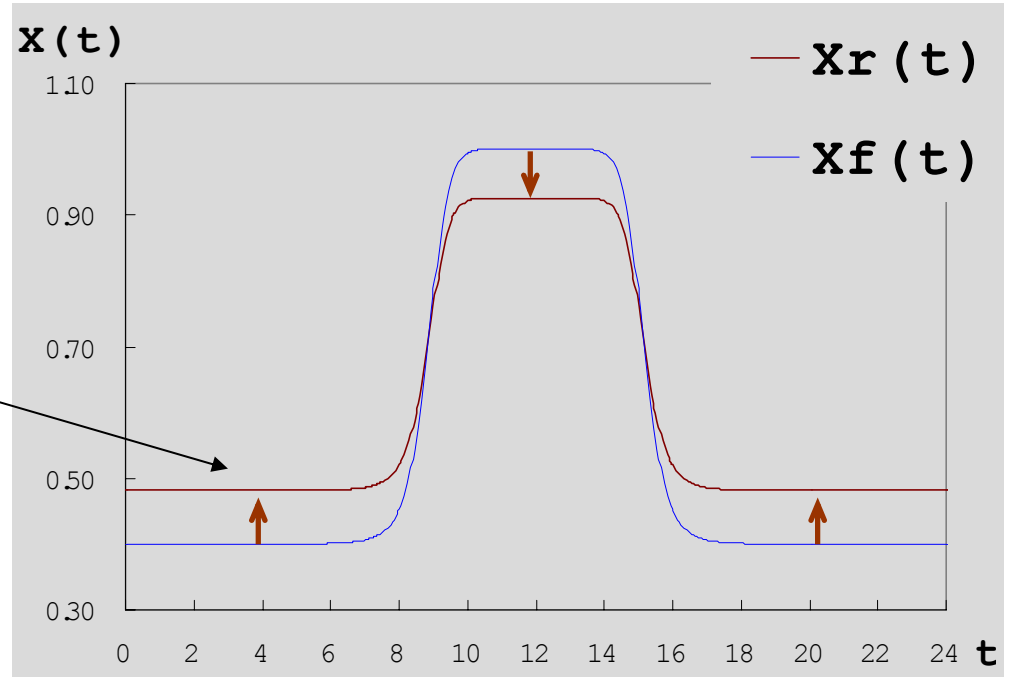
# Flat rate vs. RTP

RTP  
The price path



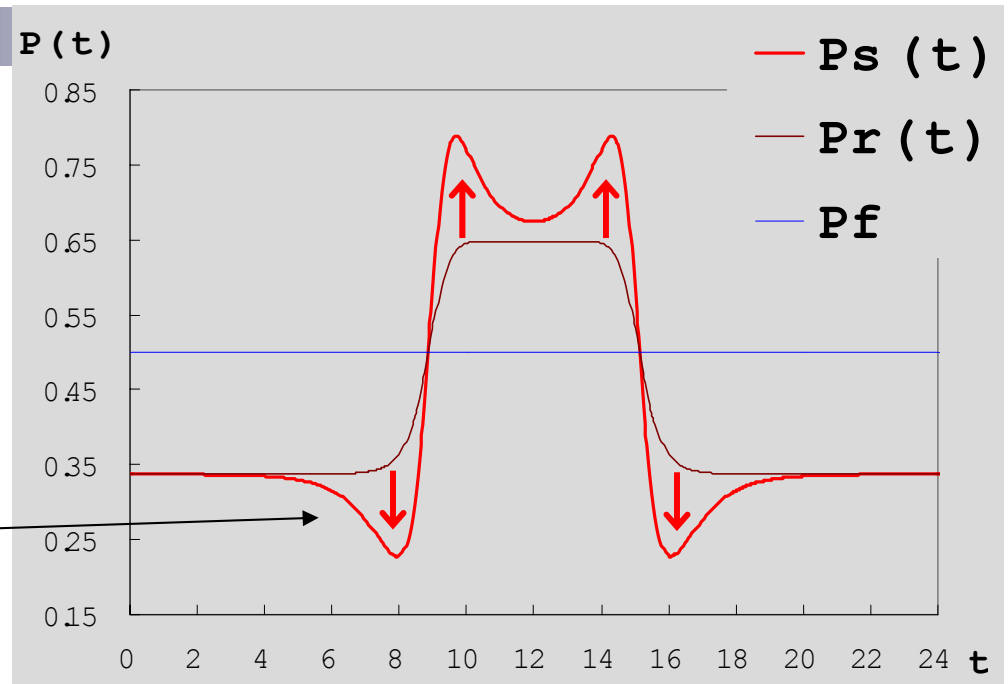
The demand path  
under RTP

The demand path



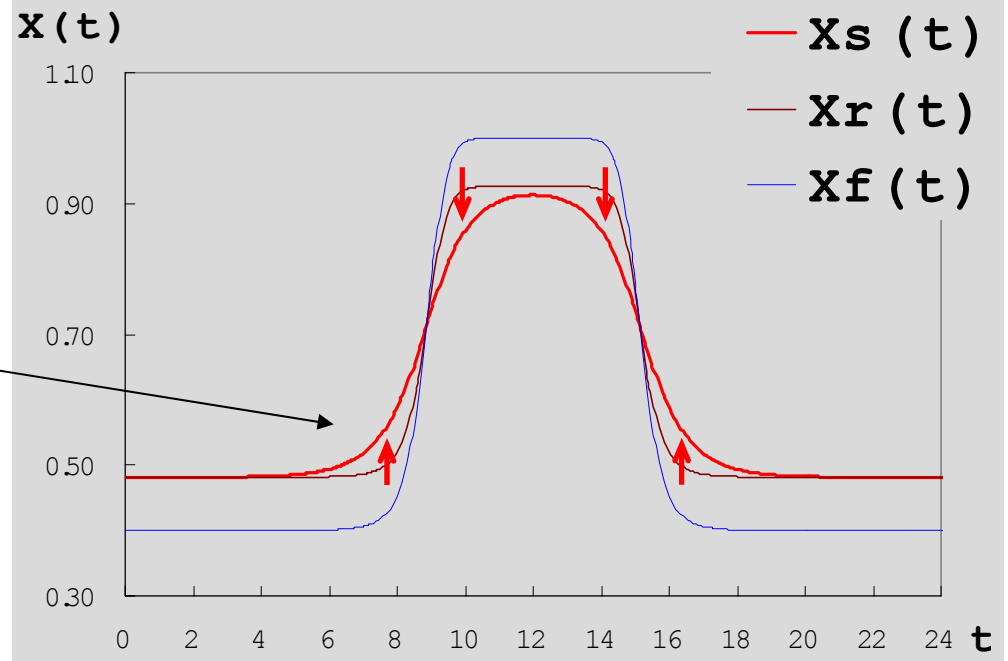
# Flat rate vs. RTP vs. RTP-S

**RTP-S**  
The price path



The demand path  
under **RTP-S**

The demand path



## 5. Practical Applications

- RTP-S in a competitive electricity market

A day-ahead market:

- generators offer supply schedules
- consumers submit demand schedules
- the market operator sets the price schedules

**Generators incorporate their ramping cost  
into their offers**



**RTP-S in a day-ahead market**

## 6. Conclusions

- ✓ **RTP-S: Real-Time Pricing for Managing a Steep Change of Demand**
  - **Optimal rate of a demand change**
  - **Ramping cost considered explicitly**
- ✓ Long-run effect
- ✓ RTP-S in competitive electricity markets
- ✓ Further theoretical and empirical research on the ramping cost