

Restructuring Electricity Markets when Demand is Uncertain: Effects on Capacity Investments, Prices and Welfare

Anette Boom¹ and Stefan Buehler²

¹Department of Economics, Copenhagen Business School

²Research Institute for Empirical Economics and Economic Policy, University of St. Gallen

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Characteristics of the Liberalization of Electricity Markets around the World

- Legislators allowed competition into statutory vertically integrated monopolies.
- Often they complemented their reforms with regulations concerning the vertical structure of the market:
 - ⇒ Vertical unbundling,
 - ⇒ full vertical separation.

Examples for Regulations of the Vertical Market Structures

- UK:** Vertical separation into three generation firms, one firm which runs the grid, and 12 regional distribution firms in 1989. Later some distribution firms vertically integrated into generation.
- California:** Regulated utilities had to sell lots of their generation capacity due to the restructuring bill in 1996.
- EU:** Directive 2003/54/EC rules that electricity generating firms which are integrated into the transmission and/or distribution of electricity have to be functionally disintegrated.

Problem Concerning the Deregulation Process

- Introducing imperfect competition into statutory monopolies may undermine **infrastructure investments**.
⇒ Buehler et al. (2004)
- The interplay of the **vertical structure** and the introduction of **competition** is up to now not properly analyzed.
- Existing studies on the incentive to invest in capacity in electricity markets do not consider the vertical structure
 - ⇒ von der Fehr and Harbord (1997),
 - ⇒ Castro-Rodriguez et al. (2001),
 - ⇒ Borenstein and Holland (2005),
 - ⇒ Boom (2002),or focus on a single one
 - ⇒ Boom (2003).

Main Contribution of this Paper

- We compare the **capacity investments**, the **electricity prices** and the **social welfare** under
 - (i) integrated monopoly [Boom (2003)],
 - (ii) integrated duopoly with wholesale trade (2 integrated firms) [Boom (2003)],
 - (iii) separated duopoly with wholesale trade (2×2 firms).
- The **vertical structure** and the **market structure** in generation and retail is exogenous here.

Main Results of this Paper

- **Capacity investments** are highest under integrated duopoly and lowest under integrated monopoly.
- **Retail prices** are lowest under separated duopoly and highest under integrated duopoly.
- The separated duopoly yields the highest **social welfare**, whereas the integrated duopoly yields the lowest **social welfare**.

Outline

- 1 Introduction
- 2 Analytical Framework
- 3 Results for the Separated Duopoly
- 4 Comparing Market Configurations
- 5 Possible Extensions

The Demand Side

- The retail customers' preferences are such that their demand for electricity x can be represented by

$$x(r, \varepsilon) = \max\{1 + \varepsilon - r, 0\}.$$

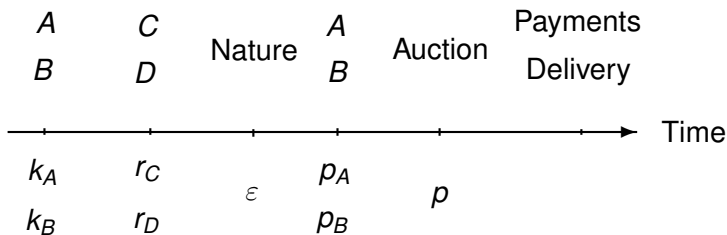
- Demand for electricity is linear in the retail price r and depends on the (negative) demand shock ε .
- The demand shock ε is uniformly distributed on $[0, 1]$.
- Retail customers subscribe to the retailer with the lowest retail price r or with probability $1/2$ to both if they offer identical retail prices.

The Supply Side

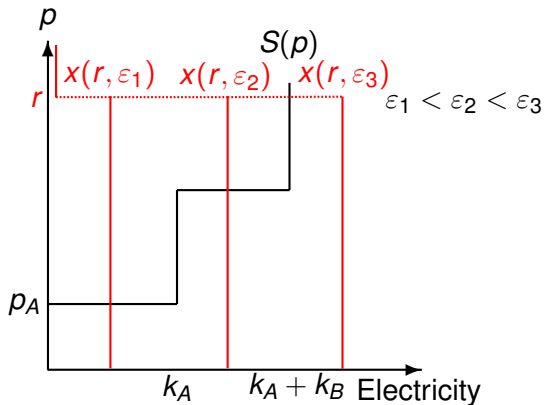
- Retailing is costless.
- The marginal costs of generating electricity is constant and normalized to zero.
- Electricity generator $i = A, B$ with the installed capacity k_i has the costs

$$C(k_i) = zk_i.$$

Timing in the Separated Duopoly



Determination of the Wholesale Market Price in a Unit Price Auction



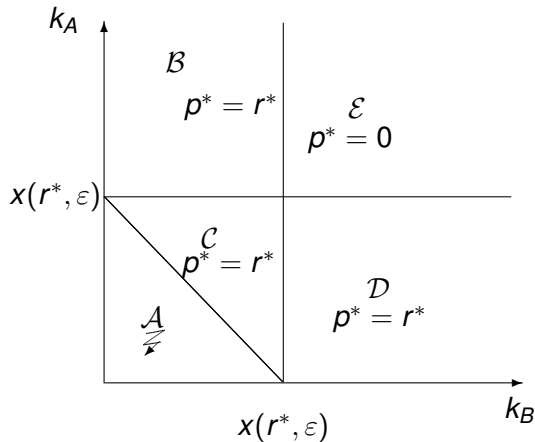
What Happens if Demand Exceeds Supply?

- No rationing of demand.
⇒ **Black-out.**
- No firm can sell and deliver electricity.
- All the firms realize zero profits

Similarities and Differences to Standard Models of Vertically Related Markets

- The equilibrium concept is the subgame perfect Nash equilibrium.
- The retail price is determined **before** the wholesale price.
 - ⇒ The wholesale price is a function of the retail price.
 - ⇒ The retail price cannot react to changes in the wholesale price.
- The wholesale price is not determined by the competing *take it or leave it offers* of upstream firms but by a **unit price auction**.

Equilibria in the wholesale market



Characterization of the Nash-Equilibria

◀ Return

Table: Nash Equilibria

(k_A, k_B)	Nash Equilibria	p^*
A	any (p_A, p_B)	none
B	(r^*, p_B) with $p_B < \bar{p} < r^*$	r^*
C	(p_i, r^*) with $p_i < \bar{p} < r^*$ and $i = A, B$	r^*
D	(p_A, r^*) with $p_A < \bar{p} < r^*$	r^*
E	$(0, 0)$	0

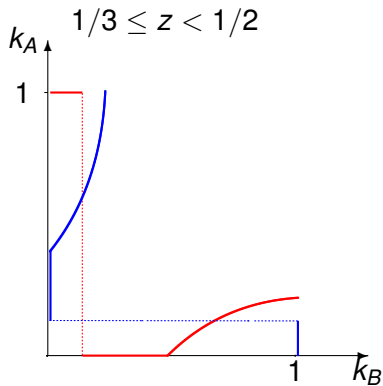
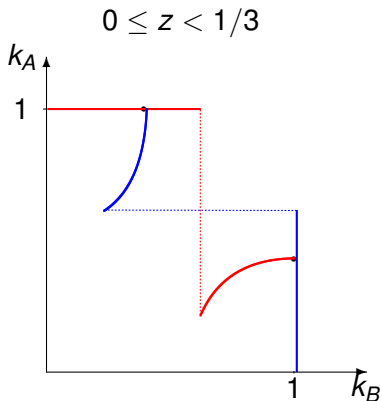
Characterization of the Nash Equilibrium in Retail Prices

Proposition

Depending on the capacity levels (k_A, k_B) , there are the following subgame perfect Nash equilibria in retail prices.

- (i) If $\min\{k_A, k_B\} \geq 1$ there is a unique Nash equilibrium in pure strategies with $r_C = r_D = 0$.*
- (ii) If $\min\{k_A, k_B\} < 1$ all Nash equilibria in pure strategies are characterised by $r_C \leq 1 - \min\{k_A, k_B\}$ and $r_D \leq 1 - \min\{k_A, k_B\}$.*

The Best Responses in Capacities



Simultaneous Capacity Choice

Proposition

The level of capacity costs determines whether a subgame perfect Nash equilibrium in pure strategies exists with simultaneous capacity choices.

- (i) If $0 \leq z < 1/3$, there are two asymmetric subgame perfect Nash equilibria in pure strategies, with capacities $k_i^* = 1$ and $k_j^* = (1 - z)/2$, $i, j = A, B$ and $i \neq j$.*
- (ii) If $1/3 \leq z < 1/2$, there is no subgame perfect Nash equilibria in pure strategies.*
- (iii) If $1/2 \leq z$, there is a unique subgame perfect Nash equilibrium where generators install no capacity.*

Sequential Capacity Choice

Proposition

With sequential capacity choices, the game always has a unique equilibrium.

- (i) If $0 \leq z < 1/3$, there is a unique subgame perfect Nash equilibrium in pure strategies where firm A chooses $k_A^* = (1 - z)/2$ and firm B chooses $k_B^* = 1$.*
- (ii) If $1/3 \leq z < 1/2$, there is a unique subgame perfect Nash equilibrium in pure strategies where firm A chooses $k_A^* = 1 - 2z$ and firm B chooses $k_B^* = 1$.*
- (iii) If $1/2 \leq z$ holds, there is a unique subgame perfect Nash equilibrium in pure strategies where generators install no capacity.*

Intuition for the Capacity Ranking $k^d \geq k^* \geq k^m$

Integrated Duopoly: If a generator is unable to serve its own retail demand he has to give up all rents from selling electricity. To avoid such an outcome, each generator will invest more than it would be willing to invest as a monopolist ($k^d > k^m$).

Separated Duopoly: The generators no longer face the risk of having to give up all rents from selling electricity, and thus install smaller capacities than integrated duopoly generators ($k^d > k^*$). Introducing competition has a positive effect on capacity investments because separated duopoly generators install a higher aggregate capacity than the integrated monopoly ($k^* > k^m$).

The Ranking of the Retail Prices $r^d \geq r^m \geq r^*$

- High retail prices ensure again a low risk of being not able to supply one's own subscribers in the integrated duopoly.
- The competition in the separated duopoly yields a lower price than in the integrated monopoly.

Intuition for the Social Welfare Ranking

$$W^* \geq W^m \geq W^d$$

- Irrespective of the market configuration, total installed capacity is always large enough to satisfy retail demand at the relevant retail price.
- Higher capacities do not mean a higher security of the electricity supply but larger costs.
- Higher capacities and higher prices in the integrated duopoly induces a lower social welfare than in the other market configurations.
- In the separated duopoly the effect of the lower retail price dominates the higher capacity costs compared to the integrated monopoly.

Interesting Extensions

- Endogenizing the vertical structure.
- Analyzing whether integrated suppliers discriminate against non-integrated retailers.
- Increasing the number of upstream competitors.
- Introducing rationing.