Risk aversion, input price risk and technology mix in an electricity market

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Introduction

- Electricity producers face many risks ;
  - Notably concerning the price of variable inputs : gas, coal, CO_2 emissions (tax, permits, allocations rules) ;
  - These risks are likely to influence their investment choices ; in particular if they are risk-averse.
  - Risk averse producers have an incentive to diversify their technology "portfolio".
- The existence of a technology mix is fundamentally justified by the variability of the demand for electricity ;
- The variability of the load is a known and anticipated phenomenon ;
- There are two motives for diversification :

load variation & risk management ;

Introduction

- The risk on input prices interact with the variability of the load because :
  - The prices of electricity are determined by short-term conditions : the load, the technology mix and the variable costs.
  - The variations of the prices of electricity are attributable to both the variability of the load and the input prices risks ;
  - Some of these variations are sure and some are uncertain.
- The risk associated to the variable cost of one technology induces a risk to other technologies via the electricity prices.
- The overall effect of risk on the technology mix is ambiguous.

Litterature review

General litterature

- Are firms risk averse ? Do they behave as if they were risk averse ?
- Many authors have considered the effect of firms risk aversion on market equilibrium.
    - Most of them have considered random demand under perfect competition (Dhrimes, 1964, Baron, 1970, Sandmo, 1971) monopoly (Baron, 1971) and oligopoly (Banal Estanol and Ottaviani 2006).
    - Some of them have considered production uncertainty (Newbery and Stiglitz 1981).
- Risk aversions has been used to justify the existence of forward markets (Mc Kinnon, 1967) and is a motives for vertical integration (Hirshleifer 1988) and conglomeration.
- The issue of the technology diversification has not received a considerable attention outside the litterature on electricity markets.

Litterature review

Electricity economics

- Bar-Lev and Katz (1976) initiated the use of financial technique (CAPM style) to evaluate generation mix of utilities.
- Roques et al. (2008) have a more positive perspective due to the liberalization process. They simulate efficiency frontier for technology portfolio.
- Neuhoff and de Vries (2004) analyze the effect of risk-aversion on investment in a single technology.
- Ehrenmann and Smeers (2011) provide simulations of an electricity market with numerous uncertainty.
- Fan et al (2010, 2011) provide numerical simulations and focuss on the effect of the CO_2 permit market design.
- Willems and Morbee (2010) consider the effect of the introduction of a financial market on welfare and the incentive to invest.

Results

- There are two technologies to serve a variable load, the baseload is sure, the peak has a risky variable costs.

1 The returns from the two technologies are negatively correlated.

2 Risk and risk aversion induce a distortion of the mix toward one the two technologies.

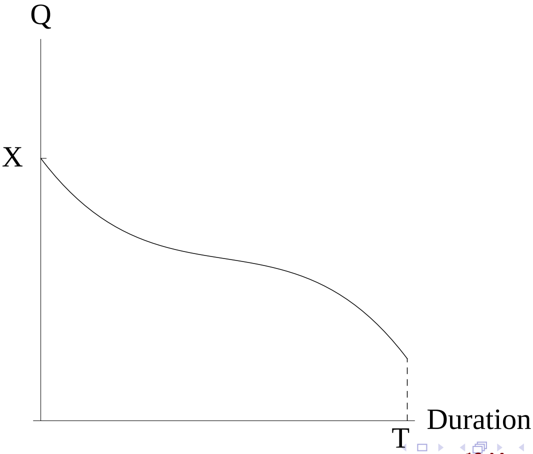
- There are two possible types of distortions :
  - the total capacity is decreased and the baseload capacity is increased ;
  - the total capacity is increased and the baselaod is decreased.

3 Whether the distortion is of one or the other type depends on the load duration curve and the technology characteritics.

4 Indeed, to complete markets can reduce if not cancel this distortion.

Model
Demand

- The demand side is represented by a load duration curve $\phi(t)$;
- The Voll is denoted v.



Model

Production

There are two technologies to produce electricity

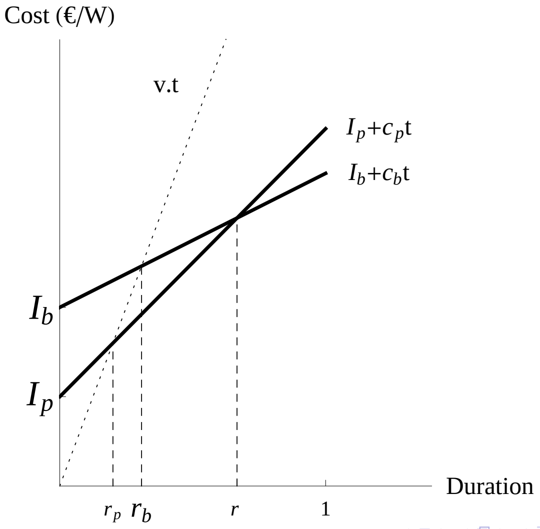
	Investment cost	variable cost
A baseload technology (e.g. nuclear)	I_b	c_b
A peak technology (e.g. CCGT)	I_p	c_p
Difference	$\Delta = I_b - I_p$	$\delta = c_p - c_b$

- the variable cost c_p is risky, its variance is σ^2
- We denote by r, r_p and r_b the ratios :

$$r = \frac{\Delta}{\bar{\delta}}; \; r_p = \frac{I_p}{v - \bar{c}_p} \text{ and } r_b = \frac{I}{v - c_b}$$

Model

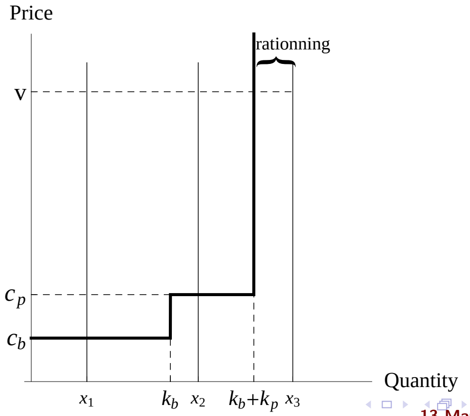
Production



Model

Prices

- In the short-term, capacities are fixed and the price of electricity is equal to the variable cost of the marginal technology or by v in case of rationing.



Model

Firms

- The firm $i \in I$ has a capacity $k^i = k^i_b + k^i_p$;
- The long-term profit of a firm is :

$$\pi^i = [T(v - c_p) - I_p]k^i_p + [T(v - c_b) + (T - T_b)(v - c_p) - I_b]k^i_b$$

in which, $T = \phi^{-1}(k)$ and $T_b = \phi^{-1}(k_b)$.

- It could be rewritten :

$$\pi^i = [T(v - c_p) - I_p]k^i + [T_b\delta - \Delta]k^i_b. \tag{1}$$

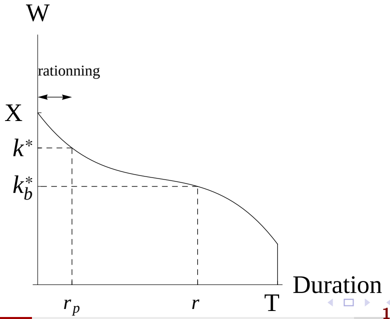
Results–Benchmark

- If firms are risk neutral :
- At the equilibirum, their long-term profits are null ;
  - The total capacity is such that (lolp.(vol-cp)=Ip) :

$$(v - \bar{c}_p)T = I_p \Leftrightarrow T = r_p;$$

  - and the technology mix is determined by

$$\bar{\delta} T_b = \Delta \Leftrightarrow T_b = r.$$



Results–Risk aversion

- Each firm maximizes the objective function :

$$U_i = E(\pi_i) - \frac{\lambda_i}{2} var\pi_i$$

- An increase of the variable cost c_p :
  - reduces by T the return from any unit ;
  - but increases by T_b the relative return from a baseload unit.
- The returns from the two types of technologies are negatively correlated ;
- The overall risk that a firm faces is

$$\text{var}(\pi^i) = \sigma^2 \left(Tk^i - T_b k_b^i\right)^2 = \sigma^2 \left[T^2 k^{i2} + T_b k_b^{i2} \underbrace{-2TT_b k^i k_b^i}_{covariance} \right]$$

Results–Risk Aversion

- At equilibrium the firm invest so that :

$$\frac{\partial \mathbb{E}\pi^i}{\partial k^i} = \frac{\lambda_i}{2}\frac{\partial}{\text{var}}\pi^i \partial k^i$$

- which turns into

$$(v - \bar{c}_p)T - I_p = \frac{\lambda^i}{2}k^i(Tk^i - T_b k_b^i) \quad (2)$$

$$\bar{\delta} T_b - \Delta = \frac{\lambda^i}{2}k_b^i(T_b k_b^i - Tk^i). \quad (3)$$

The two RHS are the effect of investment on risk, they are of opposite signs.

Results–Risk aversion

Proposition

Each equilibrium with risk aversion is of one of the following two types :

- ***Type I :*** *the total capacity is lower than* k^**,*
  the baseload capacity is larger than k_b^**,*
  and the peak capacity is lower than k_p^**.*
- ***Type II :*** *the total capacity is larger than* k^**,*
  the baseload capacity is lower than k_b^**,*
  and the peak capacity is larger than k_p^**.*

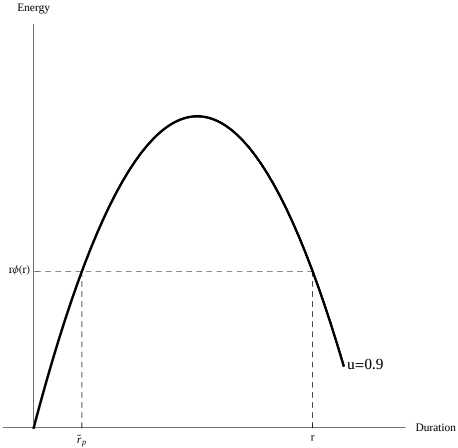
Results–Risk aversion

Proposition

If $r_p\Phi(r_p) - r\Phi(r) > 0$, *then there is one equilibrium of Type I;*
if $r_p\Phi(r_p) - r\Phi(r) < 0$, *then there is one equilibrium of Type II.*

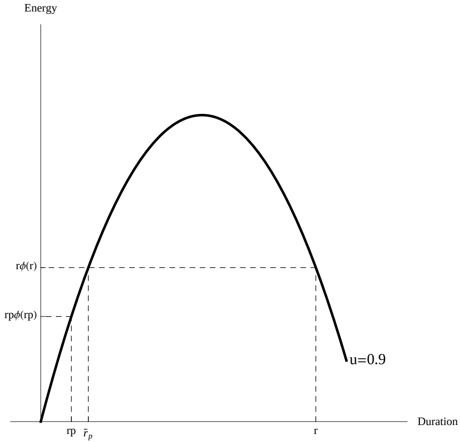
- $r_p\phi(r_p) = T^*k^*$ is the quantity of electricity sold at a price v;
- $r\phi(r) = T_b^*k_b^*$ is the quantity of baseload electricity sold at a price larger than c_b.

Results–Cost structure



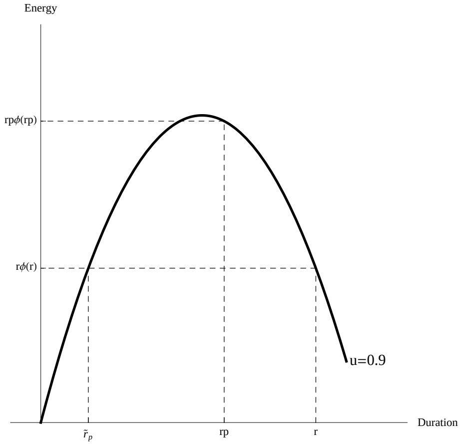
The function $t\phi(t)$ and the ratio r.

Results–Cost structure



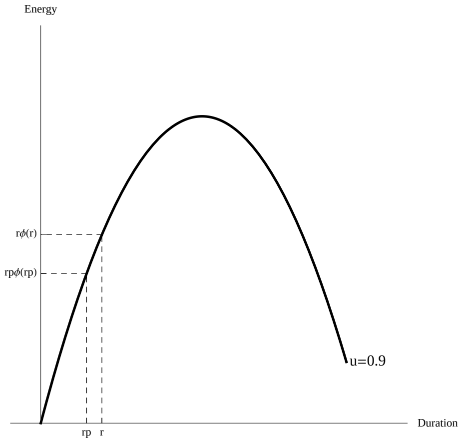
With two differentiated technologies the equilibrium is of either Type.

Results–Cost structure



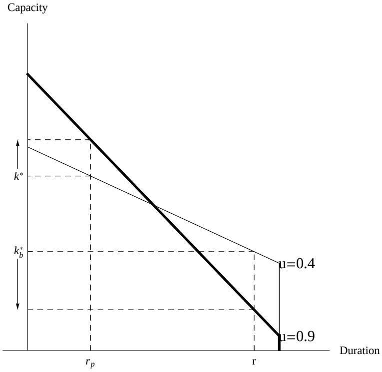
With a baseload and midload technology the equilibrium is of Type I.

Results–Cost structure



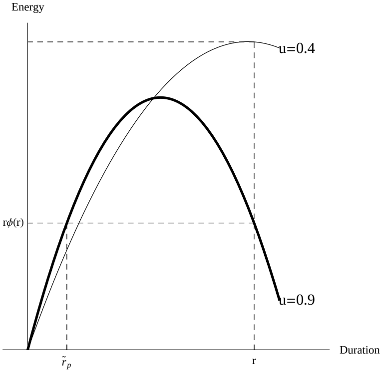
With two peak technologies, the equilibrium is of Type II.

Results–Load variability



Two load duration curves and the corresponding technological mixes
With a more variable load there are more peakers and less baseload units.

Results–Load variability



The marginal risk with two loads.
With a less variable load the equilibrium is more likely to be of Type I.

Normative issues

- It is not straighforward to define a wellfare function without identifying the roots of firm's (apparent) risk aversion ;
- A priori, to complete markets is a good idea (Diamond, 1967 ; Hart, 1975).
- Within our framework :
  - The quantity of electricity sold in a single year is deterministic,
  - The durations of the year with prices at v and c_p are also deterministic,

→ One (long-term) forward market is sufficient to fully stabilize the revenue of a firm !

→ If consumers are risk-neutral, the implementation of one forward market restore the risk-neutral benchmark by completely transferring risk to consumers.

NB The forward market can be either related to input or to electricity.

Conclusions

- When the variable cost is random, so is the output price and the returns from all technologies is affected.
- The returns from the two technologies are negatively correlated ;
- It implies that risk aversion has opposite effects on the investment in both technologies.
- The total capacity could increase with risk and risk-aversion.
- The non-risky technology could be negatively affected and the more so the less variable the load is.
- The uncertainty surrounding the CO_2 price could have a negative effect on investment in a clean technology and a positive one on a dirty technology.
- The more so if the load variability is reduced (e.g. with RTP).