Financial Market Incompleteness and Implications on Capacity Investment

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Motivation

Is there a need to intervene by incentivizing investment in a competitive electricity market?

• No in functioning markets
• Yes in case of market failure

Are there market failures in electricity systems?
• The Missing Money Problem (extensively discussed)
• Lack of risk trading for the horizon relevant for investment

Questions for today’s talk
• How can we quantify the absence of risk trading/ lack of liquidity?
• Do capacity markets (as a remedy) transfer too much risk to the consumer?
• Do we need to discuss capacity markets in an environment of overcapacity?
Outline

- Introduction  Market failures in electricity: trading
- Two period example on the impact of trading on investment
- Capacity markets as a solution?
- Multi-period example for decommissioning of power plants
- Conclusion
Markets are incomplete

- Most restructured electricity markets are closed to be fully incomplete
- There exists no financial product to hedge the risk factors associated with investment decisions.
- For the relevant horizon, liquidity is simply not there
- This lack of hedging possibility disincentivizes investment
- Current uncertainties are just too wide (demand, regulation, fuel prices)
- The literature advocates trading products as a remedy
  - Not yet supported by a model to quantify the effects.
- This talk: a stochastic-endogeneous generation capacity expansion model where trading between market participant is explicitly represented
- Contract purely financial
A Model for the Power Industry

A simplified capacity expansion model that deals with uncertainty. The financial market is explicitly represented.

- **Two market players**, one producer and one consumer.

- **Two period model**:
  - The producer invests before knowing the realisation of the demand.
  - The producer/the consumer take financial positions to hedge the spot market.
  - The payoff of a financial contract is also uncertain (based on the spot market).
Two important benchmarks

- The complete market (Ralph and Smeers, 2013)
  - Assuming a complete set of financial product (e.g. Arrow-Debreu securities)
  - One can solve the equilibrium by minimizing the total risk of the system
  - Similar to risk averse planning.
  - The problem gives a welfare interpretation: the total risk of the system

- The fully incomplete market (Ehrenmann and Smeers, 2011)
  - Assemble the KKT conditions for the risk-averse producer and consumer
  - Together with the market clearing conditions
Two agents trading on a spot market

One producer and one consumer exchange electricity on a spot market. The outcomes depend on the marginal cost of the available capacity and on the consumer’s willingness-to-pay.

- Willing to pay up to \( \text{voll} \)
- Bid his inverse demand function
- Surplus = \((\text{voll} - p) (q - z)\)

\(\text{VOLL} = \) value of loss load

Consumers

- Profit-maximizing firm
- Bid his marginal cost function
- Surplus = \( p q - \text{COST}_{\text{tot}} (q) \)
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A simplified capacity expansion where market-players are risk-averse is used.

- Both players are **risk-averse**: They value their profit using a measure that prices traded risk at market quotation and asks a risk-premium for non tradable risk (CVaR).

**Consumers**
- Exposed to the risk of capacity shortage
- Risk hedging: avoid scenario with price spikes

**Electricity producers**
- Invest before knowing the realization of the demand
- Exposed to the risk of demand/price crash
- May not be able to recover their investment cost

Opportunity to trade!
How to Compare the Mechanisms?

We define the following four metrics to assess the efficiency of the mechanisms in terms of risk mitigation.

**A. Risk-adjusted Welfare – M€**

**What:** The risk-adjusted welfare is the sum of the risk-adjusted (E-CVaR) profits of the consumer and the producer. We show its variation with the risk aversion of the consumer and the producer.

**Why:** Measure the global efficiency of the mechanism.

**B. Profit distribution – M€**

**What:** The profit distribution shows the agent’s profit in each scenarios. The average \((E[\Pi])\) and the volatility \((\text{vol}[\Pi])\) of the distributions are also printed.

**Why:** Illustrate the risks behind the 15 scenarios.

**C. Installed Capacity - GW**

**What:** The installed capacity shows the investments in the two technologies (peak and base) and how they vary with the risk aversion of the producer.

**Why:** Measure the incentive for investments.

**D. Size of the Financial Market - TWh**

**What:** The financial market size indicates the volume exchanged in the financial market.

**Why:** Assess the feasibility of the mechanism studied – is the financial market liquid enough?

\(^{(1)}\) volatility: standard deviation divided by the average
The two Reference cases
Risk-Adjusted Welfare

The reference cases are extreme cases: However, the range does not cover all outcomes.

Complete market
No trading

Comments

1 Welfare in the complete market is the highest possible.

2 In the no trading case, the producer and the consumer cannot share their risk. The risk-adjusted welfare is significantly destroyed as they become more and more risk averse.
The two Reference markets

Both the producer and the consumer benefit to trade in a complete market.

**Profit distribution/Welfare distributions – M€**

**Producer**
- $E[\Pi] = 4.23$
- $\text{vol}[\Pi] = 135\%$

**Consumer**
- $E[\Pi] = 43.9$
- $\text{vol}[\Pi] = 6.7\%$

**Comments**
1. When there is no trading possibilities, the profit of the producer is particularly volatile.
2. The consumer is exposed to large variation of welfare.
The two Reference cases
 Installed Capacity

In both cases, investment decreases with producer risk aversion.

**Comments**

1. In a complete market, the system tends to avoid overcapacity for low demand scenario.

2. In the no trading case, the decrease is exacerbated by producer's risk aversion.

3. Peak units are particularly at risk.
No intervention: forward contracts
Limited liquidity destroys the benefits of classical contracts

- The important risk reduction implied by classical contracts requires a level of trading far above today’s experience: YEARLY FUTURES the total volume exchange represents more than 150% of the expected power consumption.

- Financial markets for power do not have such liquidity.

- Producers cannot find counterparties to hedge fully their production.

- The liquidity limit on the futures contracts leads to a drastic reduction of the welfare.

- Assumption: the consumer only hedges 75% - 100% of its expected consumption.

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**Risk-adjusted Welfare**

![Graph showing risk-adjusted welfare with and without limited liquidity.](YEARLY_FUTURES_-_LIMITED LIQUIDITY)
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Capacity market
Beneficial if the targeted capacity is sufficiently high

We analyze two cases for the different capacity demand curve chosen by the regulator

- **CASE 1**: The targeted capacity is set below the maximal demand (on the complete market case). Creating scenarios where the consumer pays the capacity price and price spikes.

- **CASE 2**: targeted capacity above the maximum demand (the risk of price spikes is eliminated).

![Graph showing the capacity demand curve and supply curve with labeled axes: Capacity price [€/MW] on the y-axis, Capacity [MW] on the x-axis.](image-url)
Capacity market

Comments

• **CASE 1**: targeted capacity is set below the maximal demand (on the complete market case). Creating scenarios where the consumer pays the capacity price and the price spikes. In that case the forward capacity market does not perform well in term of risk mitigation (especially true for the consumer).

• **CASE 2**: targeted capacity above the maximum demand

• Significant welfare improvement risk reduction if the regulator fixes a capacity target that avoid spikes.
Capacity markets can serve as a proxy for (long term) forward contracting. Hence they reduce the risk of the consumer.

Consumer welfare in the 15 scenarios for all market cases discussed.
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Asset Management under uncertainty

- Deterministic asset management:

  Revenues <

  Fixed Costs + Variable Costs

  NO

  YES

  Do nothing

  Lifetime Extension

  Early Decommissioning

  Mothballing / Demothballing

  Reconversion

  Key focus in period of overcapacity

- Stochastic asset management

  Risk adjusted

  EXPECTED

  Revenues

  Fixed Costs + Variable Costs

  NO

  YES

  Do nothing

  Lifetime Extension

  Early Decommissioning

  Mothballing / Demothballing

  Reconversion
Capturing the dynamics of mid-term uncertainties
The Fishbone tree

- We construct the following decision tree for Italy where each year you have a chance

  Stay temporarily in an average

  Go and stay in
  - a Growth or
  - in a continued recession scenario

- We focus on the central scenario where the producer should manage his assets knowing that there is some chance:
  - The economy steady recover
  - We face a sluggish recovery
Calculation for the example of a European country
We model the entire production park. Differences in prices are explained by asset management decisions.

Runs settings:
- Good-deal measure calibrated with
  - Sharpe ratio $= 0.52$
- Recourse option
  - demand curtailment $= 3000 \ [\text{€/MWh}]$

Range $\approx 5 \ [\text{€/MWh}]$

(1) **Sharpe ratio**: measure of the excess return per unit of risk
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Conclusion

- The energy markets have become very risky to invest in. Contracts could help but we don’t observe much trade in the horizon that matters for investment.

- The methodology to price the incompleteness is available. We find that incompleteness leads to underinvestment. Capacity markets can act as a proxy for contracts and hence improve the situation for consumers.

- Today’s decisions are not about investment but about decommissioning and mothballing but the same impact can be observed on a realistic case study.
Stochastic generation capacity expansion models

- Straightforward adaptation of the deterministic models

- Need to invest before the realization of some key market drivers

\[
\begin{align*}
\text{Min} & \quad \sum_k I_k v_k + \mathbb{E} \left[ \sum_\ell \tau_\ell \left( \text{VOLL} z_\ell(\omega) + \sum_k C_k(\omega) y_{k,\ell}(\omega) \right) \right] \\
\text{s.t.} & \quad 0 \leq v_k - y_{k,\ell}(\omega) \\
& \quad 0 \leq \sum_k y_{k,\ell}(\omega) + z_\ell(\omega) - d_\ell(\omega) \\
\end{align*}
\]

\textbf{Primal Variables}

- \( v_k \): Investment in technology \( k \)
- \( y_{k,\ell}(\omega) \): Production
- \( z_\ell(\omega) \): Curtailment

\textbf{Parameters}

- \((\tau_\ell, d_\ell(\omega))\): Load duration curve
- \(I_k\): Overnight cost of technology \( k\)
- \(C_k(\omega)\): Operating cost of technology \( k\)
- \text{VOLL}: Value of loss load

- Demand is price insensitive up to VOLL (the model is directly transposable to price elastic)

- Multistage, grid constraints easily handled
Stochastic generation capacity expansion models
Equilibrium interpretation

- Interpretable as a competitive equilibrium model where market participants are risk-neutral/shares the same WACC.

- The second stage KKT conditions describe the functioning of an energy only market.

\[
\begin{align*}
0 & \leq v_k - y_{k,\ell}(\omega) \quad \perp \quad \mu_{k,\ell}(\omega) \geq 0 \\
0 & \leq \sum_k y_{k,\ell}(\omega) + z_\ell(\omega) - d_\ell(\omega) \quad \perp \quad \pi_\ell(\omega) \geq 0 \\
0 & \leq c_k(\omega) + \mu_{k,\ell}(\omega) - \pi_\ell(\omega) \quad \perp \quad y_{k,\ell}(\omega) \geq 0 \\
0 & \leq v_{\text{OLL}} - \pi_\ell(\omega) \quad \perp \quad z_\ell(\omega) \geq 0
\end{align*}
\]

- Dual Variables
  - \(\pi_\ell(\omega)\): Electricity price
  - \(\mu_{k,\ell}(\omega)\): Gross margin of technology \(k\)

- The first stage KKT conditions gives a investment rules (NPV)

\[
0 \leq I_k - \mathbb{E} \left[ \sum_\ell \tau_\ell \mu_{k,\ell}(\omega) \right] \quad \perp \quad v_k \geq 0
\]
Modelling risk aversion

- Models where market participants are risk averse $\rho(\Pi) = \min_{Q \in Q} \mathbb{E}_Q [\Pi]$
- Risk-aversion is modelled through coherent risk measure (Artzner et al. 1997)
- The measures $Q$ are endogeneous to the problem.

The model for the risk-averse producer

$$\mathcal{P}^{\text{prod}}(\pi_\ell(\omega)) \equiv \max \quad \rho^{\text{prod}} \left\{ \sum_{\ell} \sum_{k} \tau_\ell (\pi_\ell(\omega) - C_k(\omega)) y_{k,\ell}(\omega) - \sum_{k} l_k v_k \right\}$$

$$0 \leq v_k - y_{k,\ell}(\omega)$$

The model for the risk-averse consumer

$$\mathcal{P}^{\text{cons}}(\pi_\ell(\omega)) \equiv \max \quad \rho^{\text{cons}} \left\{ \sum_{\ell} \tau_\ell (VOLL - \pi_\ell(\omega)) (d_\ell(\omega) - z_\ell(\omega)) \right\}$$

- The consumer of the problem does not involve any first stage decision.

$$0 \leq VOLL - \pi_\ell(\omega) \perp z_\ell(\omega) \geq 0$$