



ENGIE

Investment under uncertainty

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July 2015

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Motivation & Approach

- Investment in Energy-Only Markets is jeopardized for mainly 2 reasons:
 - **Inefficient price caps/ Missing Money:** Price spikes, which are needed to recover investment costs in EOM, are not always accepted. Price caps in the energy market are too low.
 - **Increasing risk:** The occurrence of price spikes can become very volatile in a system characterized by an increasing share of intermittent renewable electricity generation.



Uncertainty concerning the climate policies and the RES deployment may magnify the risk such that markets alone are unlikely to deliver appropriate investment responses.

Regulations that restrict efficient price formation (e.g. price cap) undermine the market signal for investment

IEA – “Securing Power during the Transition” - 2012

- EOM 2.0 discussion focus largely at fixing the short term markets including the price caps (see German White paper, earlier talks today).
- Less agreement on the need to fix the problem of uncertainty. Why? In most reports (Frontier Economics, Consentec..) risk is mentioned but the impact is never properly quantified.

The Missing Money

Are instruments designed for deterministic models effective in a risky world?

- ***On the short run marginal cost***

- The equality between long and short run marginal costs is a property of an optimal generation system in a deterministic world (it can be expanded to a stochastic setting with risk neutral agents).
- There is no property that states the equality between short and long run marginal cost in a incomplete market when agents are risk averse.

- ***On the long run marginal cost***

- Risk also plays a role in the long run marginal cost through the cost of capital of plants.
- The CAPM is the standard instrument to compute capital costs. It is usually implemented by estimating “betas” on past data. But the CAPM requires referring to risk exposure in the future.
- Moreover because this risk depends on the generation system, it is endogenous to the investment process



Assessing the impact of risk

We will not discuss the origin of the risk but the way it should be valued.

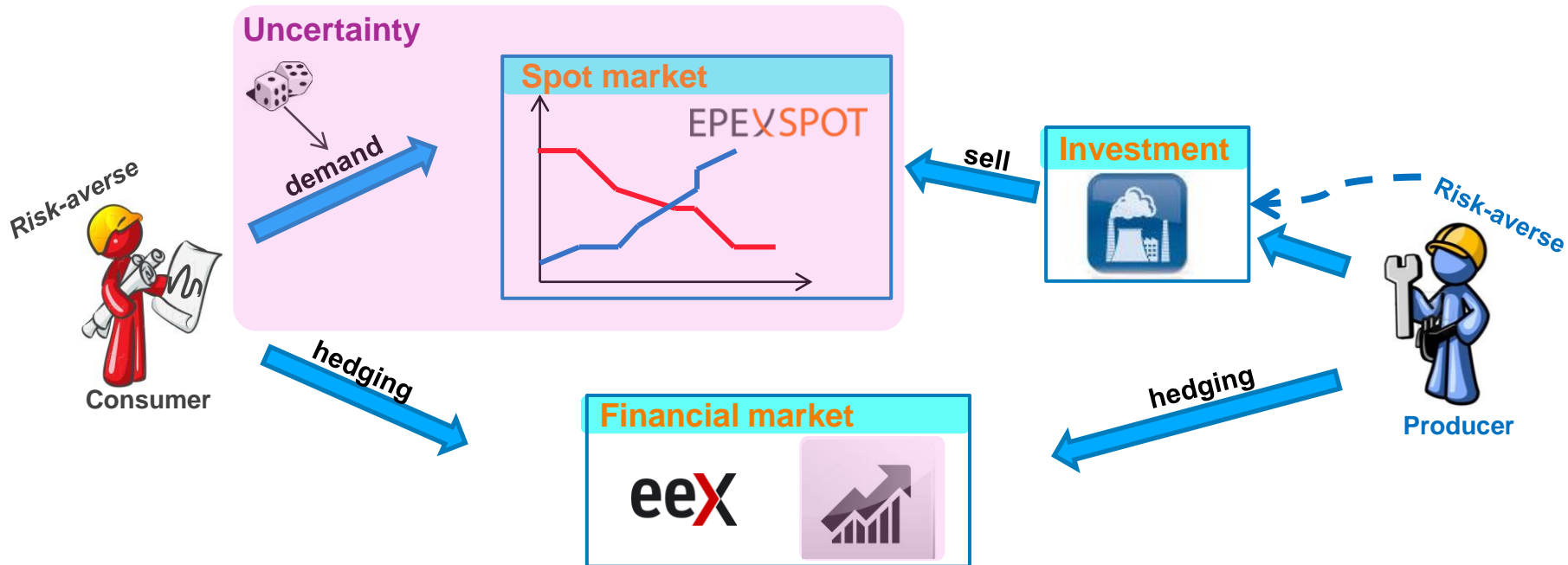
- Risk intervenes through many facets in investment problems.
 - Discount factor that depends on forthcoming risk.
 - Plant portfolio that changes forthcoming risk and hence discount factors.
 - Instruments to incentivize investment here formalized as contracts (e.g. contracts for differences).
- These instruments interact: Investor hold portfolios of plants and contracts
- in an incomplete market (there is residual risk).
- We try to model these interactions through a stochastic equilibrium model.
- We assume an energy only market endowed with a high price cap to which we add more exotic instruments like long-term contracts



Illustration of the model structure

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

- **Two market players**, a producer and a 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 outcomes.
The payoff of a financial contract is also uncertain (based on the spot market)

We take **15 scenarios** of residual demand reflecting the uncertainties on: demand growth and energy efficiency. The peak demand is assumed to be particularly volatile.

Stochastic generation capacity expansion models

Optimization problem

- Straightforward adaptation of the deterministic models

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

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

Primal Variables

V_k : Investment in technology k

$y_{k,l}(\omega)$: Production

$z_l(\omega)$: Curtailment

Parameters

$(\tau_{\ell} , d_{\ell}(\omega))$: Load duration curve

I_k : Overnight cost of technology k

$C_k(\omega)$: Operating cost of technology k

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/ share the same WACC.

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

$$\begin{aligned} 0 &\leq v_k - y_{k,\ell}(\omega) && \perp && \mu_{k,\ell}(\omega) \geq 0 \\ 0 &\leq \sum_k y_{k,\ell}(\omega) + z_\ell(\omega) - d_\ell(\omega) && \perp && \pi_\ell(\omega) \geq 0 \\ 0 &\leq C_k(\omega) + \mu_{k,\ell}(\omega) - \pi_\ell(\omega) && \perp && y_{k,\ell}(\omega) \geq 0 \\ 0 &\leq VOLL - \pi_\ell(\omega) && \perp && z_\ell(\omega) \geq 0 \end{aligned}$$

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

Stochastic-endogeneous generation capacity expansion equilibrium

- Models where market participants are risk averse

- Risk-aversion is modelled through coherent risk measure (Artzner et al. 1997)

$$\rho(\Pi) = \min_{Q \in \mathcal{Q}} \mathbb{E}_Q[\Pi]$$

- The measures \mathcal{Q} are endogeneous to the problem.

- The model for the risk-averse producer

$$\mathcal{P}^{\text{prod}}(\pi_\ell(\omega)) \equiv \mathbf{Max} \quad \rho^{\text{prod}} \left\{ \sum_{\ell} \sum_k \tau_{\ell} (\pi_{\ell}(\omega) - C_k(\omega)) y_{k,\ell}(\omega) - \sum_k I_k v_k \right\}$$
$$0 \leq v_k - y_{k,\ell}(\omega)$$

- The model for the risk-averse consumer

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

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

$$0 \leq \text{VOLL} - \pi_{\ell}(\omega) \quad \perp \quad z_{\ell}(\omega) \geq 0$$

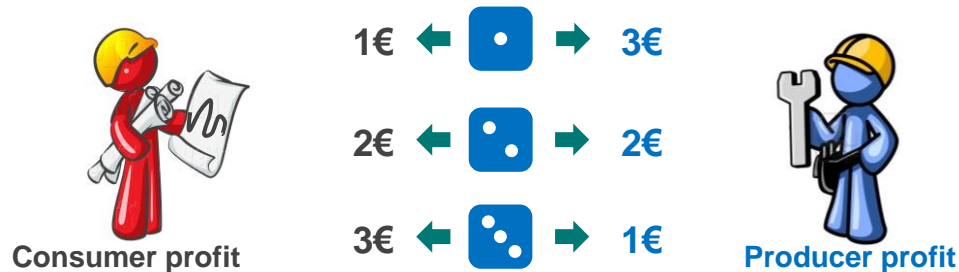
Two important benchmarks

- 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 (minimizing total cost, except that the cost is under a risk measure)
 - 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 extreme cases for trading: No trading and Complete

A dice game example

The approach is based on a producer and a consumer that are both risk-averse. The two reference cases are the extreme cases that span the impacts of market incompleteness.



No trading

There is no financial market. The market participants cannot trade their risks.

The average profit is 2€ for the consumer and the producer.

They are *risk-averse*: they value their uncertain profit strictly less than its average, here 2€.

Complete market

There is a financial market where market participants can trade every risk.

Contract C1 :	1 dot → 1€	2 dots → 0€	3 dots → 0€
Contract C2 :	1 dot → 0€	2 dots → 1€	3 dots → 0€
Contract C3 :	1 dot → 0€	2 dots → 0€	3 dots → 1€

At *equilibrium*, the financial markets clear.

- For this example, we take 0.5€ for each contract.

⇒ Consumer buys C1 and sells C3.

Final profit is **2€** whatever the dice outcome

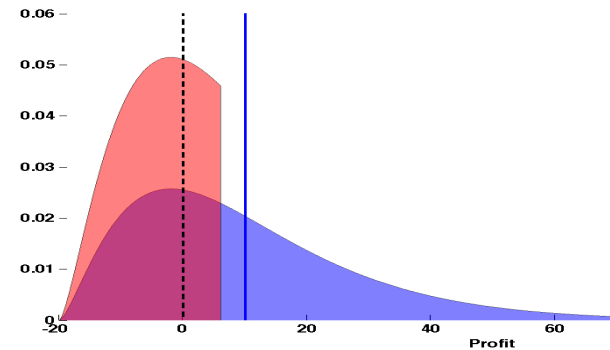
⇒ Producer sells C1 and buys C3.

Final profit is **2€** whatever the dice outcome

The Cost of capital

Risk premia in incomplete markets

- Risk is obviously related to the cost of capital.
 - The standard reasoning of the missing money does not touch the cost of capital of plants that it supposes known.
 - One of the advantages of the risk measures is to dispense with a lot of assumption on risk premium by making it endogenous and differentiating it by capacity as a function of their risk exposure.
- 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 (E-CVaR).
- **Opportunity to trade?** : The producer and a consumer are exposed - to some extent - to the risks generated by the other player



Introducing Contracts

Remedies for risk

- Discussions of adequacy are generally centred on energy only and capacity payments.
- Contracts have also been proposed (Futures contract [Ausubel and Cramton (2010)], Reliability options [Oren (2005)], Reliability options linked to physical quantities [Oren (2005) - Chao and Wilson (2004) – Vasquez et al. (2003)]) that can take different forms.
 - Baseload forwards as traded today for limited timeframes
 - Contract for Differences that have been implemented in the UK
 - Reliability Option contracts proposed by different authors.
- A contract is a two-stage process: one takes a position in the first stage (one enters a contract) and collects revenue (positive or negative) in the second stage.
- Contract prices and volumes are part of the equilibrium model.
- Contracts require two parties that should ideally be the generator and the consumer. We are very far from that situation today (contracts for differences in the UK are concluded between generators and public authorities)



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 scenario. The average ($\mathbb{E}[\Pi]$) and the volatility⁽¹⁾ ($\text{vol}[\Pi]$) of the distributions are also printed.

Why: Illustrate the risks behind the 15 scenarios.

(1) *volatility*: standard deviation divided by the average

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?

The two Reference cases

Risk-Adjusted Welfare

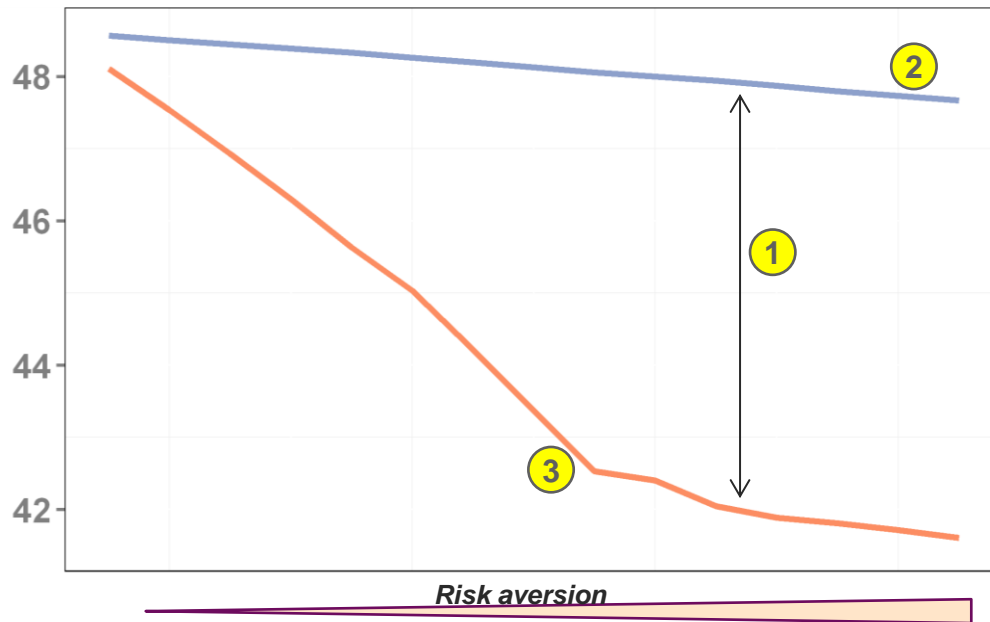
The reference cases are extreme cases: all mechanisms will stay in this range. ①

No trading

Complete market

A

Risk-adjusted Welfare – M€



Comments

② Welfare in the **complete market** is the highest possible.

③ 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.

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.

No trading

Complete market

The two Reference cases

Profit distribution

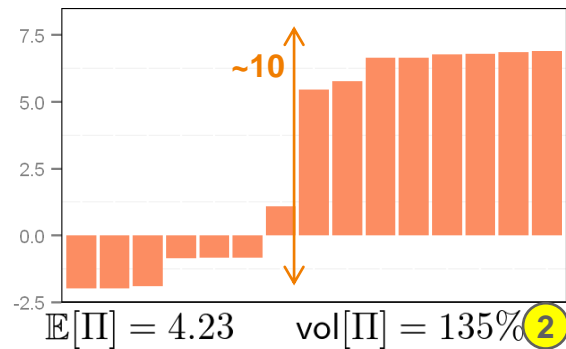
1

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

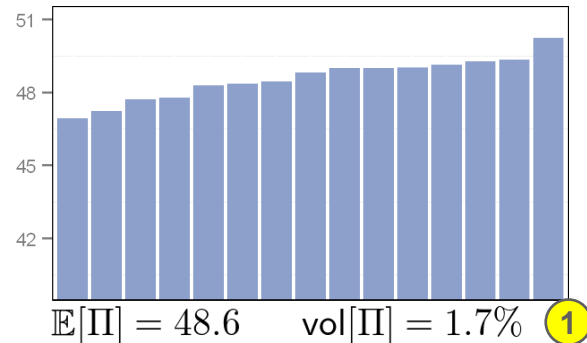
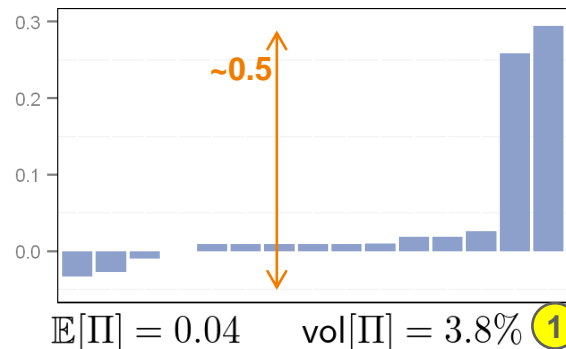
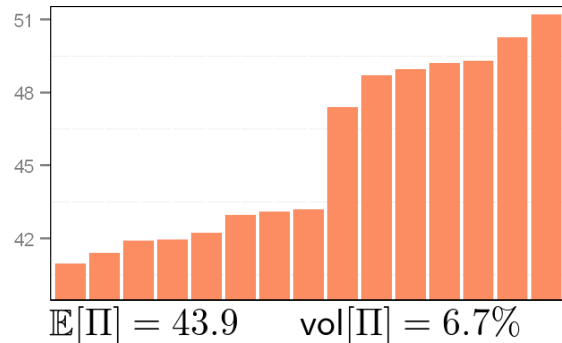
B

Profit distribution – M€

Producer



Consumer



Comments

2 When there is **no trading** possibilities, the profit of the producer is particularly volatile.

Profit distribution – M€

What: The profit distribution shows the agent's profit in each scenario.

The average ($E[\Pi]$) and the volatility ($vol[\Pi]$) of the distributions are also printed.

Why: Illustrate the risks behind the 15 scenarios.

(1) *volatility*: standard deviation divided by the average

No trading

Complete market

The two Reference cases

Installed Capacity

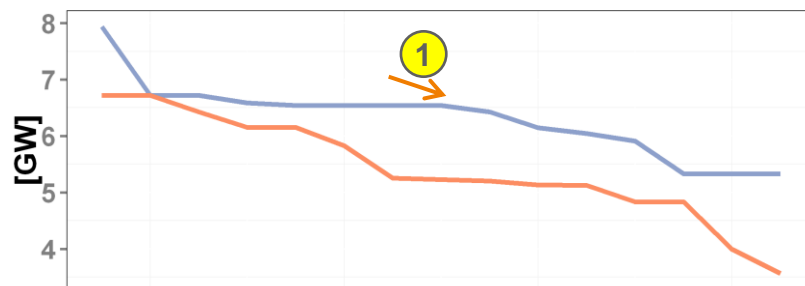
1

In both cases, investment decreases with producer risk aversion .

C

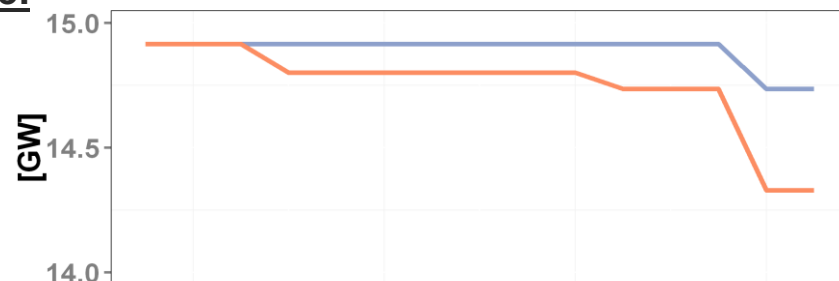
Installed Capacity - GW

Peak:



Risk aversion

Base:



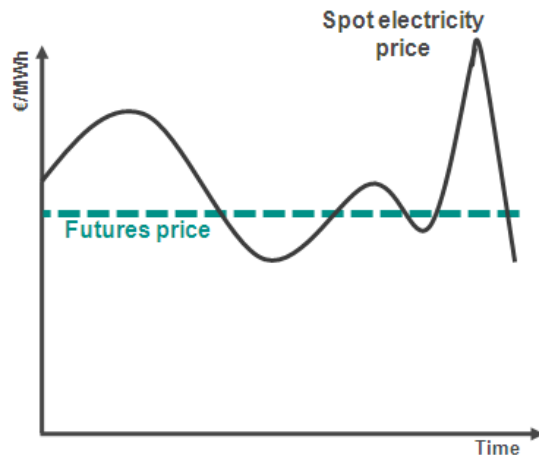
Case Study

Three mechanisms to mitigate the risk

We study the impact of three mechanisms to mitigate the risk. The **yearly futures** are the most popular contract traded (but liquidity ≤ 3 yrs). The **reliability options** have been proposed in the UK discussion (DECC consultation). The **forward capacity market** is implemented in NY-ISO.

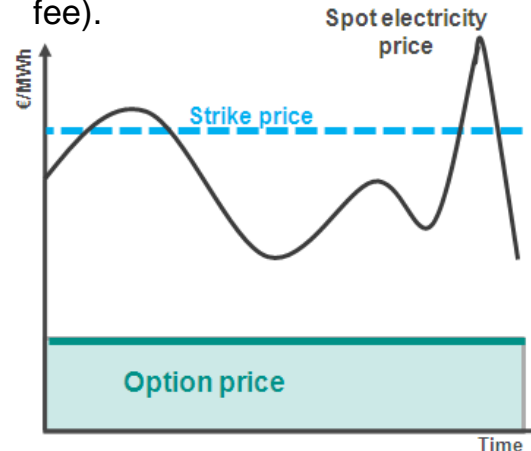
YEARLY FUTURES

- The yearly futures is a financial product where the buyer and the seller agree to settle the price difference between the **futures price** (quotation) and the spot price at delivery.
- The delivery period is the full year



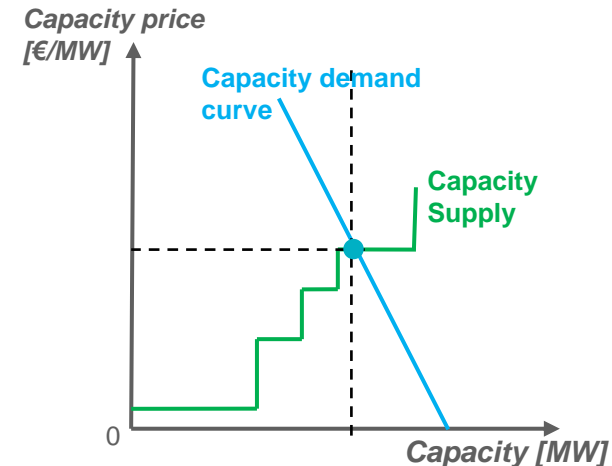
RELIABILITY OPTIONS

- The reliability option is an energy call option (financial) giving the right - but not the obligation - to buy electricity at the **strike price** instead of the spot price.
- The seller receives in exchange the **option price** (a premium fee).



FORWARD CAPACITY MARKET

- A central body defines a **capacity demand curve**.
- Supply of capacity comes from existing and capacity to be built (forward).
- The capacity price is then charged to the consumer.



Yearly futures

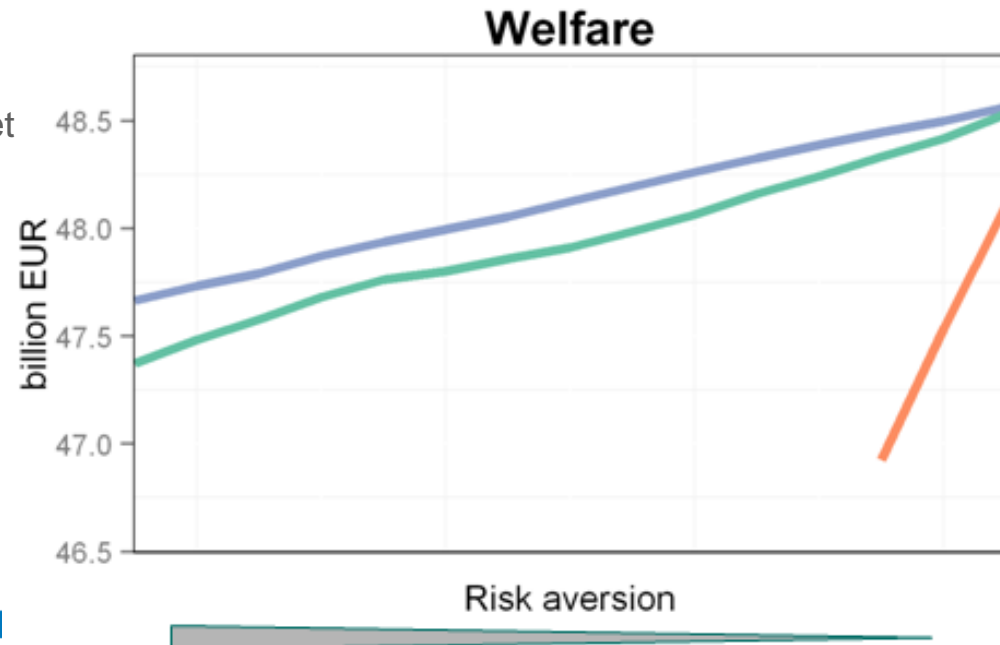
Contract purely financial

■ Proposed (among others) by Ausubel and Cramton, 2010

- “Forward markets, both medium term and long term, should complement the spot market in order to reduce risk, mitigate market power and coordinate new investment”.
- Yearly futures is the most popular contract traded
- Payoff: yearly average of electricity prices (*endogeneous*)
- Liquidity is not there for the long term

└ Welfare effect:

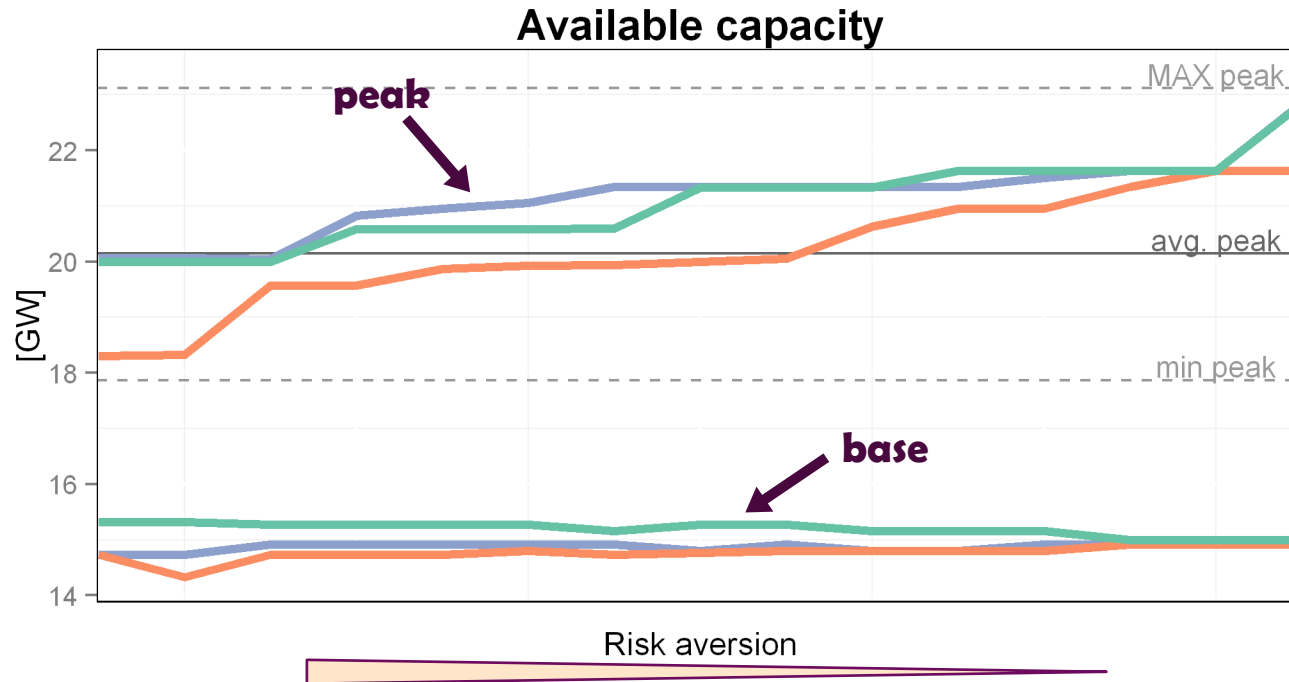
- Not sufficient to fully complete the market but already a big improvement !



Yearly futures

Contract purely financial

■ Investment



- Incentivize investment but lead to the “wrong” technology mix:
Promote (more than efficiently) the base technology

CAPEX : 110 k €/MW

OPEX : 30 €/MWh

BL-futures : ~ 45 €/MWh

availability : ~ 80 %



About 95 % of the CAPEX can be hedged !

Reliability options

Contract purely financial

■ Proposal found in Oren, 2005

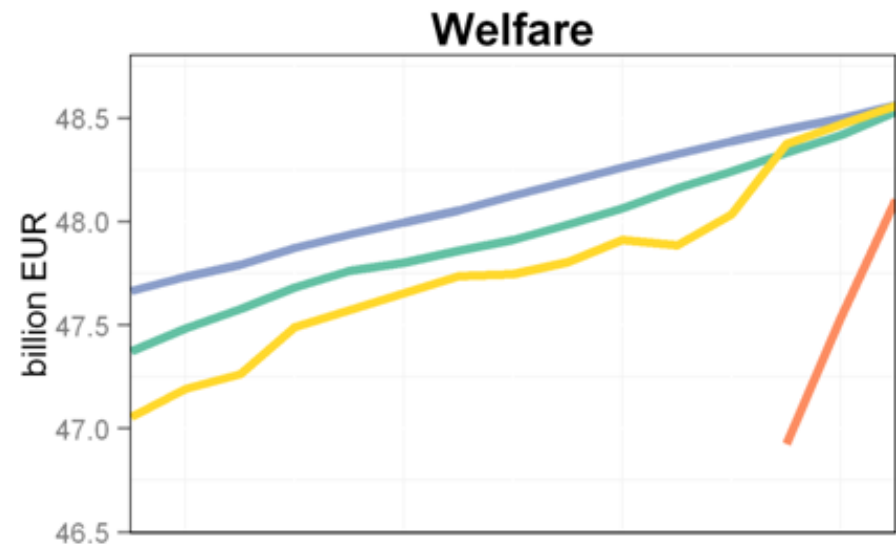
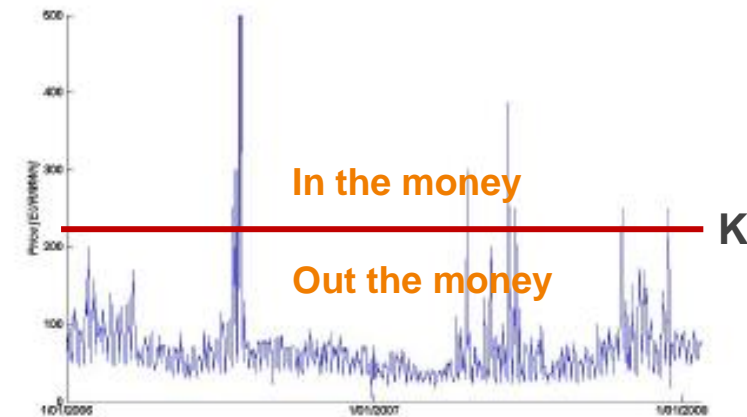
- “In normal risk management practices, options do not have physical cover, which allows the volume of risk hedging activities to exceed the actual volume of physically energy delivered. This capacity improves market liquidity and contribute to the efficiency of the energy market.”
- Financial reliability options are classical European options with a rather high strike price
- The pay off is given by:

$$\text{Payoff}(\omega) = \sum_t \max(0, \text{price}_t(\omega) - K)$$

■ Welfare effect:

- Welfare is lower than for Yearly futures
- Sensitivity on the strike price does not change the picture (here 60% of VOLL)

Financial options

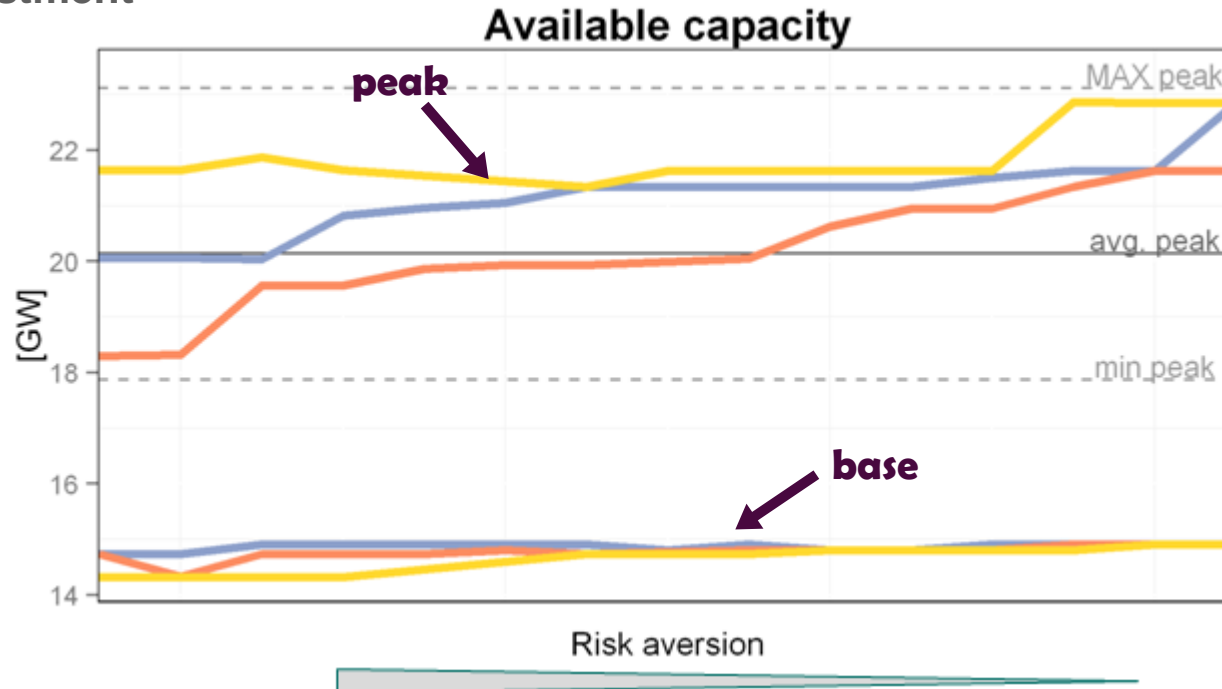


Risk aversion

Reliability options

Contract purely financial

■ Investment



- Financial reliability options penalize the base technology and promote more than efficiently the peak units.

CAPEX : 60k €/MW

REL-opt : ~ 31k €/MW

- *In this case study it leads to over-investment; but on other cases we experienced the opposite (ambiguous results are in line with the literature)*

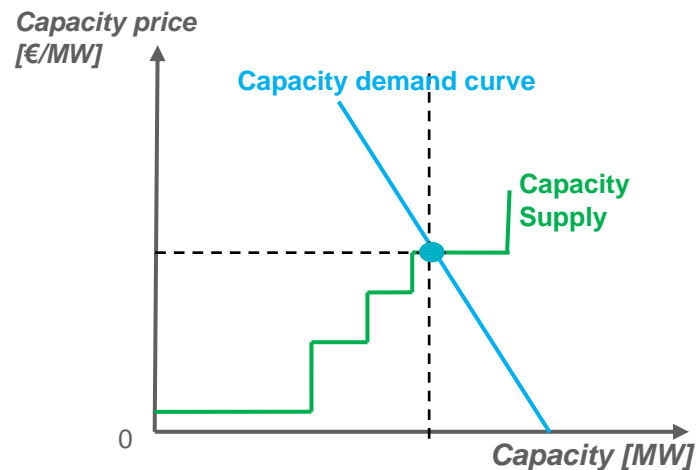
Capacity market

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.

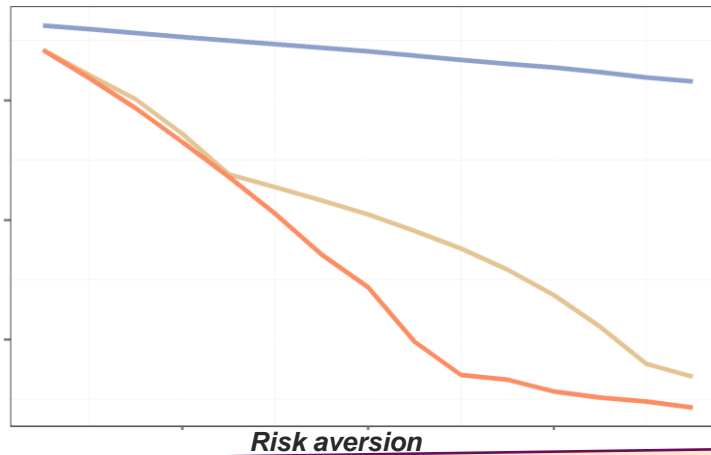
- **CASE 2:** targeted capacity above the maximum demand (the risk of price spikes is eliminated).



Capacity market

A

Risk-adjusted Welfare

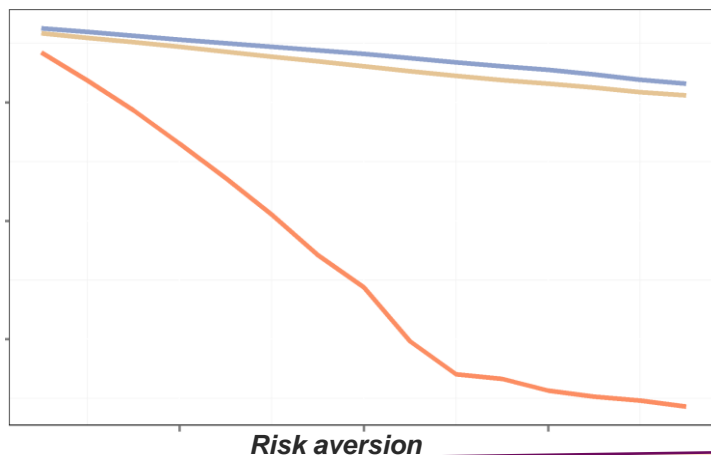


Comments

- **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)

A

Risk-adjusted Welfare



- **CASE 2:** targeted capacity above the maximum demand
- Significant welfare improvement risk reduction if the regulator fixes a capacity target that avoid spikes

Case Study

Market size

YEARLY FUTURES

RELIABILITY OPTIONS

FWD CAPACITY MKT

The risk reduction in the yearly futures and reliability options cases require a important level of trading. In reality this is not achievable.

D

The Size of Financial market

YEARLY FUTURES

- The total volume exchange represents more than **150%** than the expected power consumption.
- This 'over-hedging' is optimal to hedge both price and volume risks.
- No power exchange exhibits today such a liquidity.

RELIABILITY OPTIONS

- The total of reliability options is roughly **160%** of the total capacity.
- It is again very unlikely to have such liquidity.
- A central body will only require consumer/producer to trade 100% of the capacity

FORWARD CAPACITY MARKET

- No financial market. The capacity payments are organized by a central body.

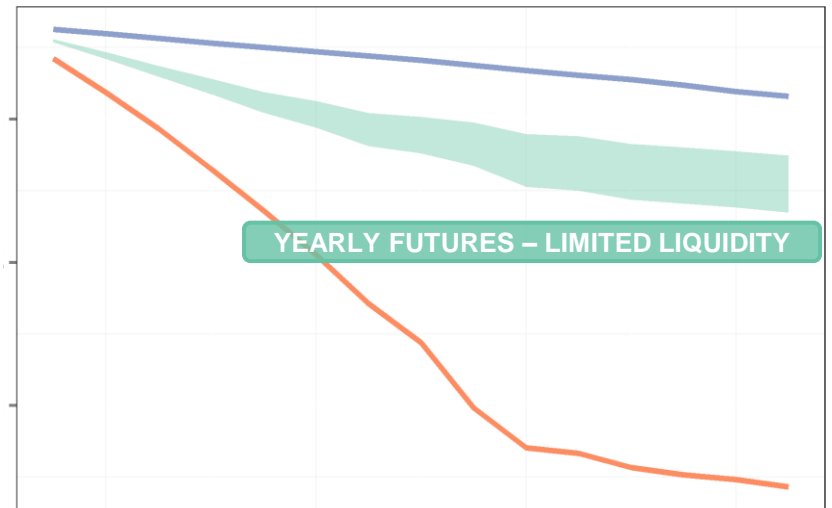
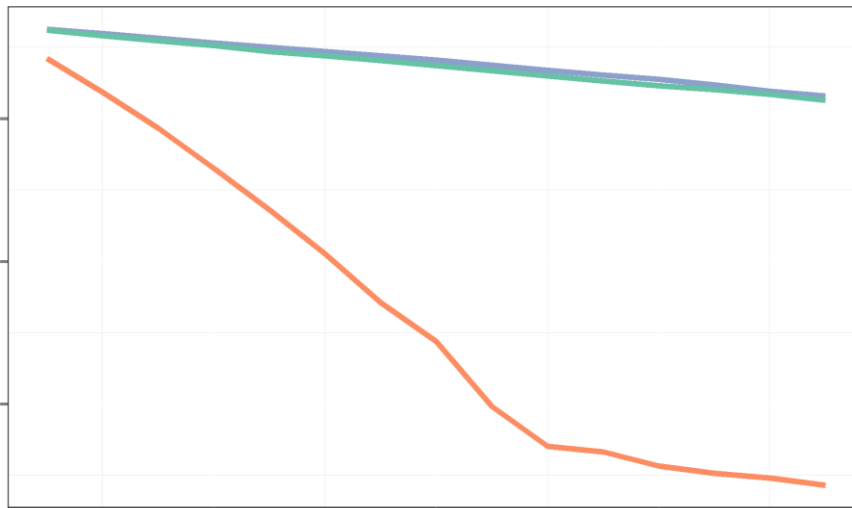
No intervention: forward contracts

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

A

Risk-adjusted Welfare

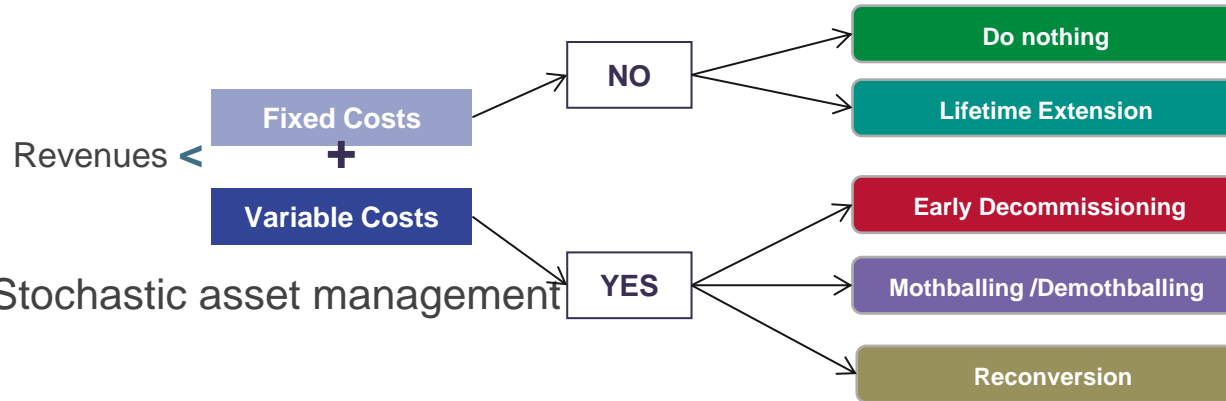


Risk aversion

Risk aversion

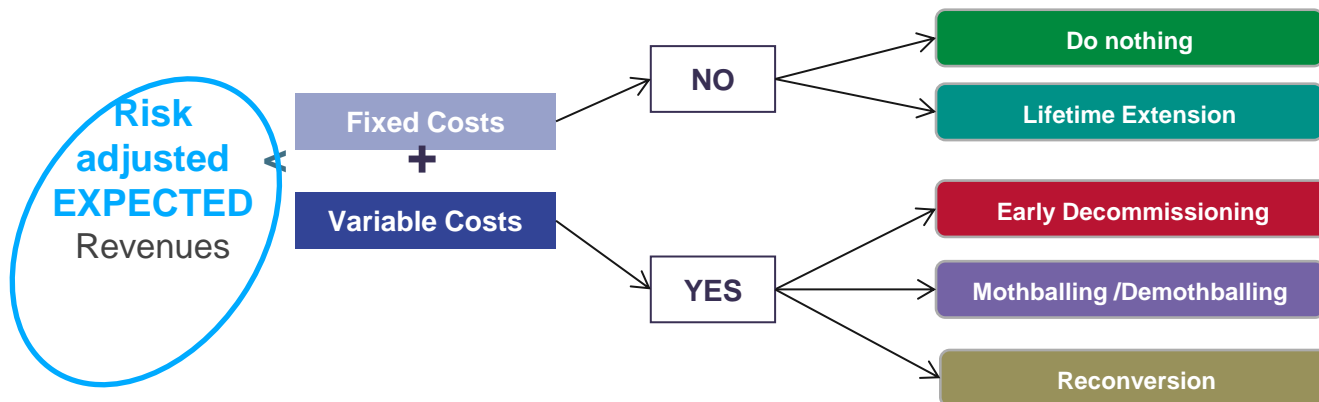
Asset Management under uncertainty

- Deterministic asset management:



- Stochastic asset management

Key focus in period of overcapacity



Capturing the dynamics of mid-term uncertainties

The Fishbone tree

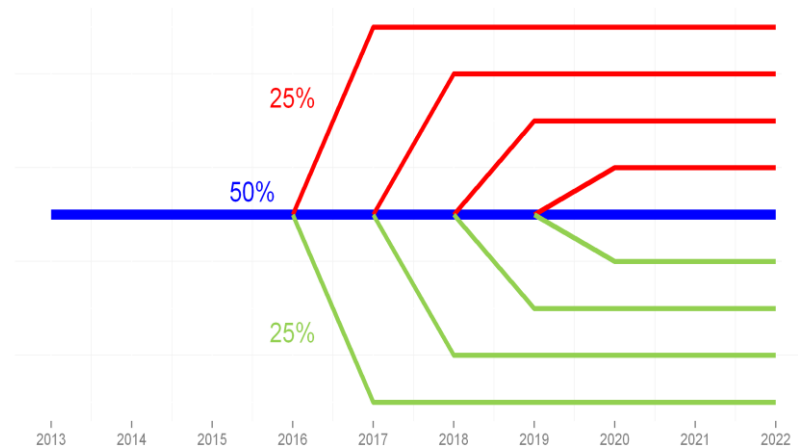
- We construct the following decision tree for European country where each year you have a chance

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

Impact of market incompleteness

Base case

Calculation for the example of a European country

We model the entire production park.
Differences in prices are explained by asset management decisions.

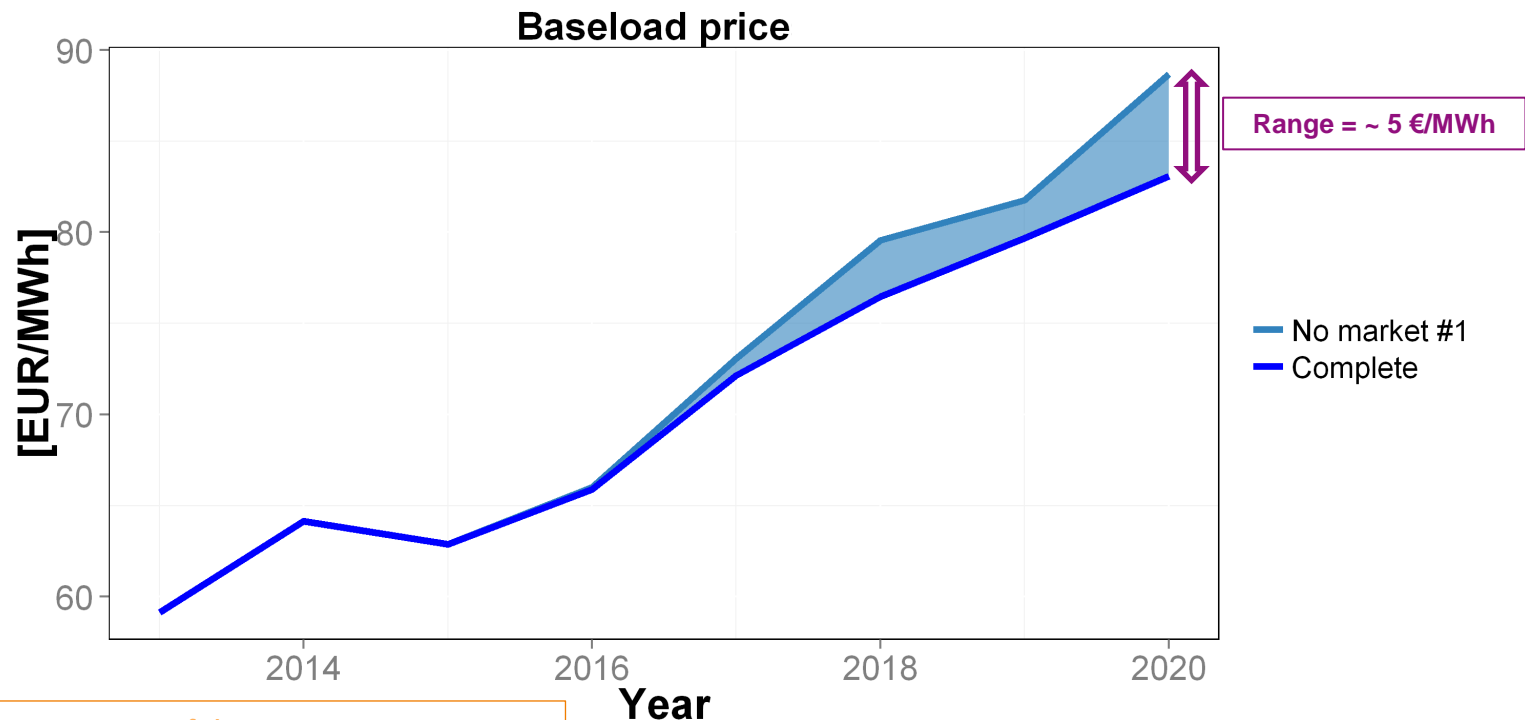
Runs settings:

Good-deal measure calibrated with

– Sharpe ratio = 0.52

Recourse option

– demand curtailment = 3000 [€/MWh]



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

Conclusions

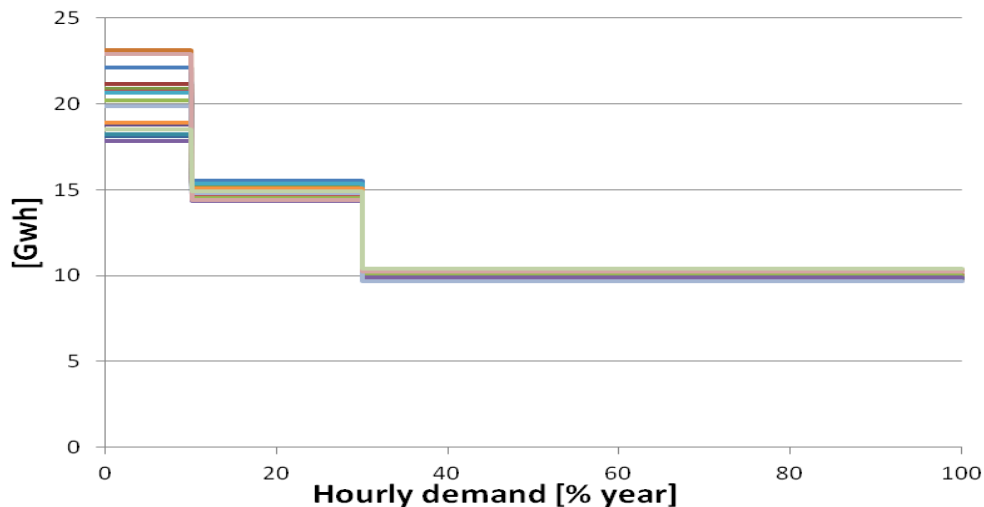
- Not all instruments that are designed to solve the missing money problem perform well in incomplete markets
- Risk trading contracts incentivize investments. These contracts have been proposed in the literature.
- These positive results require a liquidity of the market that largely goes beyond what has been observed in electricity market.
- Contract for differences with public authorities may be the way to go to procure the investment security that the two current transitions to the internal energy market and the carbon free energy system make so difficult to envisage.
- It would also force these authorities to better assess what they are asking.



Case study: Uncertain residual demand / Investment costs

We take 15 scenarios of demand that has to be covered by thermal assets (residual demand). The peak demand is assumed to be particularly volatile.

Residual load duration curve



The scenarios of residual demand reflect the uncertainties on:

- demand growth
- renewable penetration
- energy efficiency

Technology cost structure

		BASE	PEAK
CAPEX annuity	[k €/MW]	110	60
OPEX	[€/MWh]	30	60
availability	[%]	$\mathcal{N}(0.8, 0.02)$	$\mathcal{N}(0.9, 0.05)$

General characteristics of the models discussed

- Standard representation of the technologies (old capacity expansion models).
- Two types of models: without and with financial products.
- Standard scenario tree representing uncertainty.
- Two stages:
 - one invests in physical and financial assets in stage 0.
 - One collects revenue in stage 1.
- Two types of agents: Producers and a consumer trading physical quantities (electricity) on the spot market and financial contracts in forward market.
- Risk averse agents modeled by risk functions: terminology is risk adjusted valuation (closer to the language of investment).
- Price inelastic demand. (can be relaxed)



Reliability options

Contract linked to physical capacity

Physical options

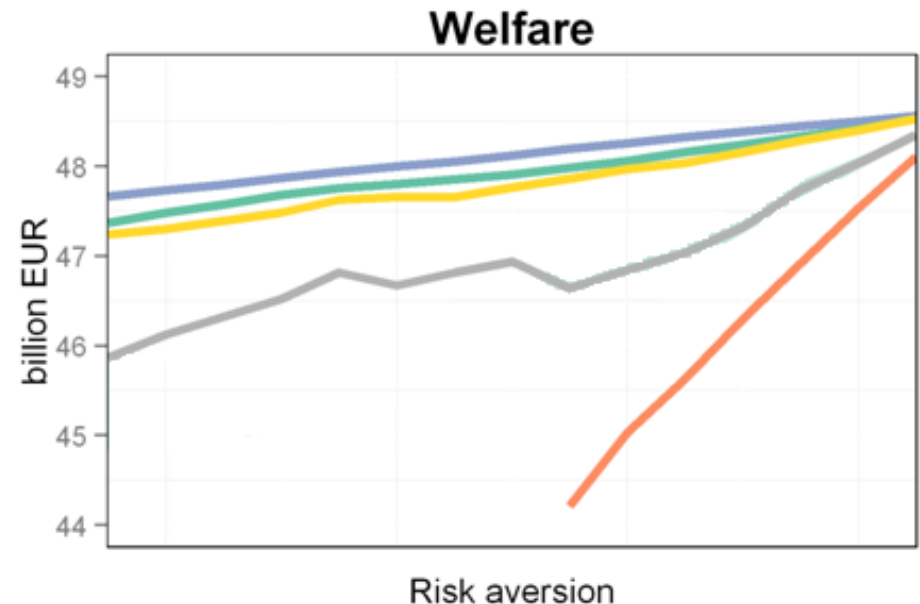
■ Proposal found in Oren, 2005 – Chao and Wilson, 2004 – Vasquez et al. 2004

- A way to promote investment accruing from reliability options seems to link them to physical capacity
- “Each contract is an option on physical capacity since it requires the supplier to back the contract with available capacity”
- Here: we only limit the volume to the total capacity

$$0 \leq x_{\text{options}} \leq y_{\text{base}} + y_{\text{peak}}$$

■ Welfare effect:

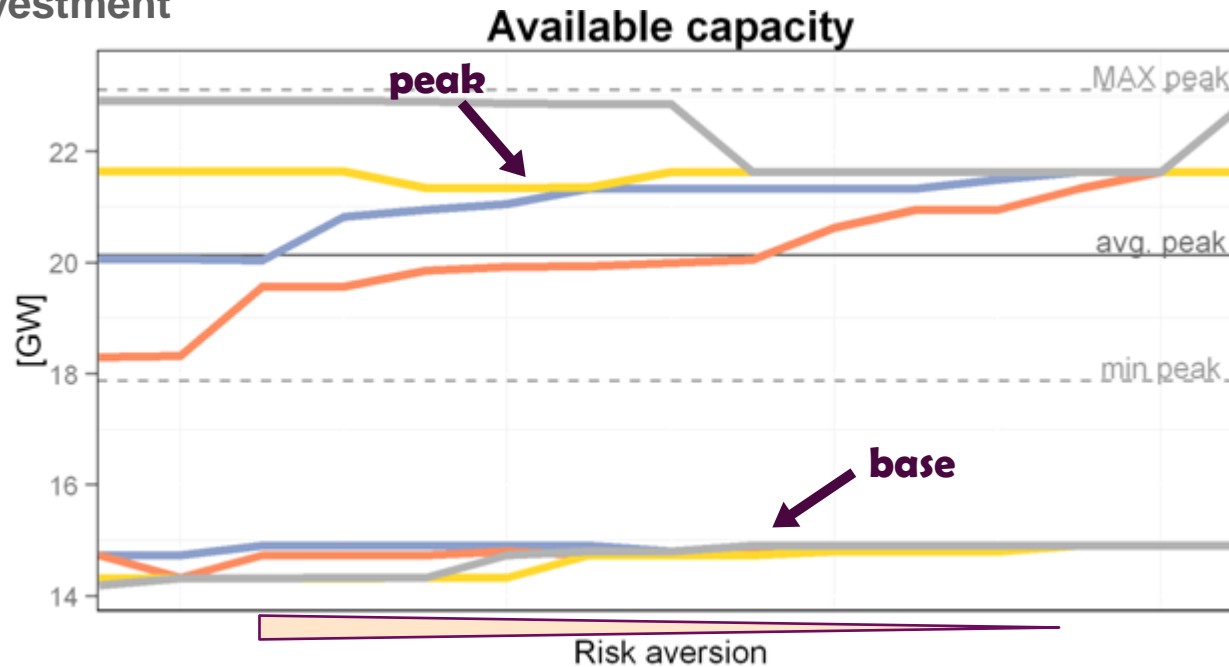
- Welfare is lower than for the welfare of a purely financial system



Reliability options

Contract linked to physical capacity

■ Investment



- Here: the effect to link the option to the physical capacity promote investment (but more than efficiently)