Risk aversion in electricity markets: impacts on investment decisions under different hedging strategies

Oliver Tietjen

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Motivation

Debate about **efficient risk allocation in electricity markets with respect to renewables** (e.g. IEA RETD TCP 2016; Neuhoff et al. 2016; Newbery 2016).

“Fossil generators enjoy a natural hedge as they set the electricity price, and shift the volatility in fuel, carbon and electricity prices [...] on to most zero-carbon generators” Newbery (2016)
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**The argument:**
- Capital intensive plants (RES) face higher risks  
  + Risk has a higher impact on capital intensive plants since it increases the capital costs  
  + Risk markets are incomplete  
- Underinvestment in capital intensive plants
Motivation

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The argument:
Capital intensive plants (RES) face higher risks
+ Risk has a higher impact on capital intensive plants since it increases the capital costs
+ Risk markets are incomplete
= Underinvestment in capital intensive plants

However, so far equilibrium analysis about this (incl. hedging) is lacking...
Motivation

Risk-reducing strategies

1. **Plant portfolio diversification**: use correlation between plant profits (cp. Tietjen, Pahle, Fuss 2016)
2. **Forward contracts**: hedge profits via long-term contracts
3. **Vertical integration**: use correlation between production and retail segment
Motivation

Risk-reducing strategies

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Research question:

**What is the impact of these strategies on investment decisions (RES vs. FOS)?**

Related literature:

- Focus on impacts of risk aversion on **investment decisions** (Ehrenmann & Smeers 2011; Fan et al. 2010, 2012).

- Focus on **forward trading** (Bessembinder & Lemon 2002; Willems & Morbee 2010) and **vertical integration** (Aïd et al. 2011) but **only for demand-induced risks**. Empirical papers find that forward **risk premium is also affected by fuel and carbon price risks** (e.g. Daskalakis & Markellos 2009; Redl & Bunn 2013).
Outline

1. The model – general setup
2. Model analysis
   a) No risk-reducing strategy
   b) Plant portfolio diversification
   c) Forward trading
   d) Vertical integration
3. Conclusion
The Model

General setup – firms and markets

- Generators
  - Sell
  - Spot market
    - Buy
    - Retailers
      - Sell
      - Retail market
        - Buy
        - Consumers
The Model

General setup – firms and markets

- Generators
  - Sell
  - Buy/sell
- Speculators
  - Buy/sell
- Spot market
  - Sell
  - Buy
- Retail market
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General setup – firms and markets

- Generators
  - spot market
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Vertical integration

Buy/sell

Buy

Sell

Buy/sell

Buy/sell

Buy
The Model

General setup – firms and markets

- Generators
  - Sell
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- Spot market
  - Buy
  - Vertical integration

- Retailers
  - Buy/sell
  - Sell

- Forward market
  - Buy/sell

- Speculators
  - Buy/sell

- Retail market
  - Sell

- Consumers
  - Buy

- Model stages:
  - 1st stage: Investment, retail and forward market decisions under uncertainty
  - 2nd stage: Production and consumption (spot market), uncertainty is resolved

- Perfect competition
The Model

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General setup – firms and markets

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- Retail market
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- Perfect competition
- Model stages:
  - 1st stage: investment decisions under uncertainty
  - 2nd stage: retail and forward market decisions under uncertainty
  - 3rd stage: production and consumption (spot market), uncertainty is resolved
- Risk allocation is incomplete:
  - Not all risk factors are traded
  - (In-)sufficient time span of forward market
The Model

Firms: producer \((pr)\), retailer \((rt)\), integrated firm \((in)\), speculator \((sp)\), \(g = pr, rt, in, sp\)

2\(^{nd}\) stage: spot market
The Model

Firms: producer \((pr)\), retailer \((rt)\), integrated firm \((in)\), speculator \((sp)\), \(g = pr, rt, in, sp\)

2\textsuperscript{nd} stage: spot market

- **Producers:** max profit \(\pi^{pr}\) via generation level \(q_{t,i}\) in each period \(t\) of each plant type \(i\):

\[
\begin{align*}
  c_i - p_i^s + \mu_{t,i} & \geq 0 \quad \perp \quad q_{t,i} \geq 0 \\
  k_i a v_{t,i} - q_{t,i} & \geq 0 \quad \perp \quad \mu_{t,i} \geq 0
\end{align*}
\]

- Since:

\[
\mu_{t,i} = \begin{cases} 
0, & \text{if } q_{t,i} < k_i a v_{t,i} \\
 p_i^s - c_i, & \text{if } q_{t,i} = k_i a v_{t,i}
\end{cases}
\]

\(\pi^{pr}\) can be written as:

\[
\pi^{pr} = \sum_{t,i} \mu_{t,i} a v_{t,i} k_i - i c_i k_i
\]
The Model

Firms: producer \((pr)\), retailer \((rt)\), integrated firm \((in)\), speculator \((sp)\), \(g = pr, rt, in, sp\)

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  \]

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    \]

  \(\pi^{pr}\) can be written as:
  
  \[
  \pi^{pr} = \sum_{t,i} \mu_{t,i} a v_{t,i} k_i - i c_i k_i
  \]

- **Retailers**: buy electricity to serve consumer demand \(d_t(p^{rt})\)

- **Equilibrium**: the wholesale spot price \(p^s_t\) satisfies:
  
  \[
  \sum_i q_{t,i} = D_t(p^s_t, p^{rt})
  \]

  Total consumer demand \(D_t\) depends on the spot \(p^s_t\) and flat retail \(p^{rt}\) price.
The Model

1st stage (index \( t \) skipped for simplicity)

- Uncertainty about market outcomes: \( \tilde{c}_i, \tilde{d}, \tilde{p}^s \) and thus profits \( \tilde{\pi}^g \) are risky.
- I consider only marginal cost \( \tilde{c}_i \) induced uncertainties!
The Model

1st stage (index t skipped for simplicity)

- Uncertainty about market outcomes: $\tilde{c}_i, \tilde{d}, \tilde{p}_s$ and thus profits $\tilde{\pi}^g$ are risky.
- I consider only marginal cost $\tilde{c}_i$ induced uncertainties!
- Each firm $g$ maximizes expected utility:

\[
E[u^g] = E[\pi^g] - \frac{\lambda}{2} Var[\pi^g]
\]

$\lambda$: coefficient of absolute risk aversion.

- Risk-neutral ($\lambda = 0$) benchmark condition for plant investments:

\[
E[\mu_ia_i] - ic_i = 0
\]
The Model

1st stage (index $t$ skipped for simplicity)

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  \[ E[u^g] = E[\pi^g] - \frac{\lambda}{2} Var[\pi^g] \]
  $\lambda$: coefficient of absolute risk aversion.

- Risk-neutral ($\lambda = 0$) benchmark condition for plant investments:
  \[ E[\mu_i a v_i] - ic_i = 0 \]

Four cases with risk averse producers ($\lambda > 0$):
1. No risk-reducing strategy
2. Plant portfolio diversification
3. Forward trading
4. Vertical integration

For simplicity, I just consider one RES and one FOS plant.
Model analysis

1. No risk-reducing strategy

   • Optimal investment decisions:
     \[ k_i^* = \frac{E[\mu_i \alpha_i] - \lambda c_i}{\lambda \text{Var}[\mu_i \alpha_i]} \]
     \( \lambda \text{Var}[\mu_i \alpha_i] \): marginal costs of risk

   • Since \( \text{var}[\pi_{res}] > \text{var}[\pi_{fos}] \), risk averse firms underinvest in RES
1. No risk-reducing strategy
   - Optimal investment decisions:
     $$k_i^* = \frac{E[\mu_i - c_i]}{\lambda \text{Var}[\mu_i]}$$
     \(\lambda \text{Var}[\mu_i]:\) marginal costs of risk
   - Since \(\text{var}[\pi_{res}] > \text{var}[\pi_{fos}]\), risk averse firms underinvest in RES

![Distribution of RES and FOS profits](image)

![Equilibrium capacities](image)

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Model analysis

2. Plant portfolio diversification

- Firms additionally consider the covariance between plant profits:

\[
\kappa_i^* = \frac{E[\mu_{iav_i}]-ic_i}{\lambda Var[\mu_{iav_i}] - \sum_j Cov[\mu_{iav_i} ; \mu_{jav_j}]k_j} \text{ with } j \neq i
\]

- Given that the risk is driven by the marginal costs of the fossil plants \( \bar{c}_{fos} \):

\[
Cov[\mu_{resav_{res}} ; \mu_{fosav_{fos}}] < 0
\]
Model analysis

2. Plant portfolio diversification
   • Firms additionally consider the covariance between plant profits:
     \[
     k_i^* = \frac{E[\mu_i \alpha_i] - ic_i}{\lambda \text{Var}[\mu_i \alpha_i]} - \frac{\Sigma_j \text{Cov}[\mu_i \alpha_i ; \mu_j \alpha_j]k_j}{\text{Var}[\mu_i \alpha_i]} \text{ with } j \neq i
     \]
   • Given that the risk is driven by the marginal costs of the fossil plants \(\bar{c}_{fos}\):
     \[
     \text{Cov}[\mu_{res} \alpha_{res} ; \mu_{fos} \alpha_{fos}] < 0
     \]
   • At low RES shares: overinvestment in RES compared to the risk neutral benchmark
   • At high RES shares: underinvest in RES compared to the risk neutral benchmark
   • At some threshold RES share: risk aversion has no effect

![Graph showing RES share in production vs. increasing risk aversion with carbon tax at different rates](image)
3. Forward trading

Producers:

\[ \tilde{\pi}^{pr}_i = \tilde{\mu}_i a v_i k_i - i c_i k_i + (p^f - \tilde{p}^s) f_i \]
Model analysis

3. Forward trading

Producers:
\[ \tilde{\pi}_i^{pr} = \tilde{\mu}_i a v_i k_i - i c_i k_i + (p^f - \tilde{p}^s) f_i \]

Optimal forward positions:
\[ f_i^* = \frac{p^f - E[p^s]}{\lambda \text{Var}[p^s]} + \frac{\text{Cov}[\mu_i a v_i ; p^s] k_i}{\text{Var}[p^s]} \]

Speculation \hspace{1cm} Hedging
Model analysis

3. Forward trading

Producers:
\[ \tilde{\pi}_i^{pr} = \bar{\mu}_i a v_i k_i - ic_i k_i + (p^f - \bar{p}^s)f_i \]

Optimal forward positions:
\[ f_i^* = \frac{p^f - E[p^s]}{\lambda \text{Var}[p^s]} + \frac{Cov[\mu_i av_i \cdot p^s]k_i}{\text{Var}[p^s]} \]
Speculation    Hedging

Retailers:
\[ \tilde{\pi}^{rt} = (p^{rt} - \bar{p}^s)\bar{d}\alpha + (p^f - \bar{p}^s)f_{rt} \]

Optimal forward positions:
\[ f_{rt}^* = \frac{p^f - E[p^s]}{\lambda \text{Var}[p^s]} + \frac{Cov[(p^{rt} - p^s)d \cdot p^s]\alpha}{\text{Var}[p^s]} \]
Model analysis

3. Forward trading

Producers:

$$\tilde{\pi}_i^{pr} = \tilde{\mu}_i a v_i k_i - i c_i k_i + (p^f - \tilde{p}^s) f_i$$

Optimal forward positions:

$$f_i^* = \frac{p^f - E[p^s]}{\lambda \text{Var}[p^s]} + \frac{\text{Cov}[\mu_i a v_i ; p^s] k_i}{\text{Var}[p^s]}$$

Speculation Hedging

Ignoring speculation motive...

...RES firms sell forwards, $f_{res}^* > 0$, because $\text{Cov}[\mu_{res} a v_{res} ; p^s] > 0$

...FOS firms buy forwards, $f_{fos}^* < 0$, because $\text{Cov}[\mu_{fos} a v_{fos} ; p^s] < 0$

...retailers buy forwards, $f_{rt}^* < 0$, because $\text{Cov}[(p^{rt} - p^s)d ; p^s] < 0$

Retailers:

$$\tilde{\pi}^{rt} = (p^{rt} - \tilde{p}^s)d \alpha + (p^f - \tilde{p}^s)f_{rt}$$

Optimal forward positions:

$$f_{rt}^* = \frac{p^f - E[p^s]}{\lambda \text{Var}[p^s]} + \frac{\text{Cov}[(p^{rt} - p^s)d ; p^s] \alpha}{\text{Var}[p^s]}$$
Model analysis

3. Forward trading

**Producers:**
\[ \tilde{\pi}_i^{pr} = \tilde{\mu}_i a v_i k_i - i c_i k_i + (p^f - \bar{p}^s) f_i \]

Optimal forward positions:
\[ f_i^* = \frac{p^f - E[p^s]}{\lambda Var[p^s]} + \frac{Cov[\mu_i a v_i; p^s] k_i}{Var[p^s]} \]

Speculation  Hedging

Ignoring speculation motive...

...**RES firms sell forwards**, \( f_{res}^* > 0 \), because \( Cov[\mu_{res} a v_{res}; p^s] > 0 \)

...**FOS firms buy forwards**, \( f_{fos}^* < 0 \), because \( Cov[\mu_{fos} a v_{fos}; p^s] < 0 \)

...**retailers buy forwards**, \( f_{rt}^* < 0 \), because \( Cov[(p^r - p^s)d; p^s] < 0 \)

Given the forward market equilibrium, \( f_{res}^* + f_{fos}^* + f_{rt}^* + f_{sp}^* = 0 \), the risk premium is
\[ p^f - E[p^s] = -\frac{\Lambda}{4} \left( Cov[\mu_{res} a v_{res}; p^s] k_{res} + Cov[\mu_{fos} a v_{fos}; p^s] k_{fos} + Cov[(p^r - p^s)d; p^s] \right) \]

**Retailers:**
\[ \tilde{\pi}^{rt} = (p^{rt} - \bar{p}^s) \tilde{d} \alpha + (p^f - \bar{p}^s) f_{rt} \]

Optimal forward positions:
\[ f_{rt}^* = \frac{p^f - E[p^s]}{\lambda Var[p^s]} + \frac{Cov[(p^{rt} - p^s)d; p^s] \alpha}{Var[p^s]} \]
3. Forward trading

\[ p^f - E[p^s] = -\frac{\Lambda}{4} \left( \text{Cov}[\mu_{res}a_{res}; p^s]k_{res} + \text{Cov}[\mu_{fos}a_{fos}; p^s]k_{fos} + \text{Cov}[(p^{rt} - p^s)d; p^s] \right) \]

- The sign of the risk premium is determined by the **hedging pressure**:  
  \[ p^f - E[p^s] < 0 \text{ if the need for reducing risk is higher for RES than for FOS + retailer} \]
  \[ p^f - E[p^s] > 0 \text{ if the need for reducing risk is lower for RES than for FOS + retailer} \]
3. Forward trading

\[ p^f - E[p^s] = -\frac{\Lambda}{4} (\text{Cov} [\mu_{res} \alpha_{res}; p^s] k_{res} + \text{Cov} [\mu_{fos} \alpha_{fos}; p^s] k_{fos} + \text{Cov} [(p^t - p^s) d; p^s]) \]

- The sign of the risk premium is determined by the **hedging pressure**:
  - \( p^f - E[p^s] < 0 \) if the need for reducing risk is **higher for RES** than for FOS + retailer
  - \( p^f - E[p^s] > 0 \) if the need for reducing risk is **lower for RES** than for FOS + retailer

- Optimal investment decisions:

\[
k^*_i = \frac{1}{\lambda (1 - r_i^2)} \left( \frac{E[\mu_i \alpha_i - ic_i]}{\text{Var}[\mu_i \alpha_i]} + \frac{\text{Cov}(\mu_i \alpha_i; p^s) E[p^f - p^s]}{\text{Var}[\mu_i \alpha_i] \text{Var}[p^s]} \right)
\]

\( r_i^2 \in [0; 1] \): correlation between plant profits \( \pi_i^{pr} \) and price \( p^s \).
Model analysis

3. Forward trading

\[ p^f - E[p^s] = -\frac{\Lambda}{4} \left( \text{Cov}[\mu_{res}a_{res}; p^s]k_{res} + \text{Cov}[\mu_{fos}a_{fos}; p^s]k_{fos} + \text{Cov}[(p^r - p^s)d; p^s] \right) \]

- The sign of the risk premium is determined by the hedging pressure:
  \( p^f - E[p^s] < 0 \) if the need for reducing risk is higher for RES than for FOS + retailer
  \( p^f - E[p^s] > 0 \) if the need for reducing risk is lower for RES than for FOS + retailer

- Optimal investment decisions:

\[
k^*_i = \frac{1}{\lambda(1-r_i^2)} \left( \frac{E[\mu_i a_{i}v_i] - c_i}{\text{Var}[\mu_i a_{i}v_i]} + \frac{\text{Cov}(\mu_i a_{i}v_i; p^s)E[p^f - p^s]}{\text{Var}[\mu_i a_{i}v_i]\text{Var}[p^s]} \right)
\]

\( r_i^2 \in [0; 1] \): correlation between plant profits \( \pi_{i}^{pr} \) and price \( p^s \).

Therefore, if the demand-side is sufficient risk averse such that \( p^f - E[p^s] > 0 \) holds:

**investments in RES increase with the risk premium.**

Potentially, firms invest more in RES compared to the risk neutral benchmark.
Model analysis

3. Forward trading

Impact of forward trading

- no risk-reducing strategy
- increasing risk aversion of speculator
- risk neutral benchmark

- RES
- FOS
- risk premium

€ / MWh

GW
Model analysis

3. Forward trading

Impact of forward trading

Here: forward market does not cover whole life time of the plants

- no risk-reducing strategy
- increasing risk aversion of speculator
- risk neutral benchmark

RES
FOS
risk premium

GW
MW€
0
10
20
30
40
50
60
70
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

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Model analysis

4. Vertical integration

- Optimal retail decisions:

\[ \alpha_i^* = \frac{E[(p^r_t - p^s)t]}{\lambda_i \text{Var}[(p^r_t - p^s)t]} - \frac{\text{Cov}[\mu_i v_i ; (p^r_t - p^s)t]k_i}{\text{Var}[(p^r_t - p^s)t]} \]
Model analysis

4. Vertical integration

• Optimal retail decisions:

\[ \alpha_i^* = \frac{E[(p^r_t - p^s) \Delta]}{\lambda_i \text{Var}[(p^r_t - p^s) \Delta]} - \frac{\text{Cov}[\mu_i \alpha_i \Delta; (p^r_t - p^s) \Delta \kappa_i]}{\text{Var}[(p^r_t - p^s) \Delta]} \]

• Since: \[ \text{Cov}[\mu_{res} \alpha_{res} \Delta; (p^r_t - p^s) \Delta] < \text{Cov}[\mu_{fos} \alpha_{fos} \Delta; (p^r_t - p^s) \Delta] \]

vertical integration with RES is more beneficial.
Model analysis

4. Vertical integration

- Optimal retail decisions:

\[ \alpha_i^* = \frac{E[(p^r - p^s)d]}{\lambda_i \text{Var}[(p^r - p^s)d]} - \frac{\text{Cov}[\mu_i, av_i; (p^r - p^s)d]k_i}{\text{Var}[(p^r - p^s)d]} \]

- Since:

\[ \text{Cov}[\mu_{res}, av_{res}; (p^r - p^s)d] < \text{Cov}[\mu_{fos}, av_{fos}; (p^r - p^s)d] \]

vertical integration with RES is more beneficial.
Model analysis

4. Vertical integration

- Optimal retail decisions:
  \[
  \alpha_i^* = \frac{E[(p_r^t - p_s^t)d]}{\lambda_i \text{Var}[(p_r^t - p_s^t)d]} - \frac{\text{Cov}[\mu_i \text{Var}_i ; (p_r^t - p_s^t)d] k_i}{\text{Var}[(p_r^t - p_s^t)d]}
  \]

- Since:
  \[
  \text{Cov}[\mu_{\text{res}} \text{Var}_{\text{res}} ; (p_r^t - p_s^t)d] < \text{Cov}[\mu_{\text{fos}} \text{Var}_{\text{fos}} ; (p_r^t - p_s^t)d]
  \]
  vertical integration with RES is more beneficial.

The more often the retail price is adjusted, the less beneficial is vertical integration.
Conclusion

Indeed, risk aversion can lead to underinvestment in RES, but at least large firms

• with different plant types in their portfolio
• which are vertically integrated

also have incentives to invest more in RES due to risk.
Conclusion

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also have incentives to invest more in RES due to risk.

Given the transition from OPEX to CAPEX world,
is a market structure with a few large firms superior for a capital intensive industry?
• market power
• at odds with political targets (at least in Germany)
Conclusion

Indeed, risk aversion can lead to underinvestment in RES, but at least large firms
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• which are vertically integrated
also have incentives to invest more in RES due to risk.

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Ideal way: improve risk markets
• consumers hedging demand increases RES share even above risk neutral share
• support efficient risk allocation (e.g. reduce transaction costs, market maker obligations)
• last resort: regulatory determined long-term contracts
Thank you!


