Grid expansion investment when production is uncertain - a RO approach in the context of RES

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Introduction

- Market liberalization as strong orientation of recent energy policy. Unbundling $\longrightarrow$ boost in renewable investments.
- EU's climate change package: 20-20-20 target
- Feature of RES: much less forecastable than fuel based production.
- Separated investment decisions for up- and downstream firms in the deregulated electricity markets $\longrightarrow$ affecting each other
- Two investment decisions are brought together in a real options framework:
  - Impact of arising uncertainty on the value and the timing of the generation investments
  - Optimal investment timing of the grid expansion and price cap to connect the new RES

Model

- Total electricity production at time t:

$$Q_t = Q_0 + X_t(Q_i - Q_0); \qquad \forall \;\; i = 1, ..., n.$$

Q_0 - Initial production level without RES $\rightarrow$ constant production
i - Level of renewable penetration increasing in i
Q_i - Total installed production capacity level $\rightarrow$ subject to production uncertainty variable, X_t

X_t - follows a geometric Brownian motion process

$$dX_t = (r - \delta)X_t dt + \sigma X_t d\tilde{W}_t$$

where r risk free rate, δ convenience yield and σ volatility of X_t

Model II

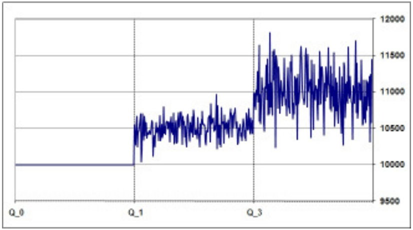


Figure: Electricity production with increasing share of renewables

- A linear inverse industry demand function for electricity

$$P_t = D - \phi Q_t = D - \phi(Q_0 + X_t(Q_i - Q_0).$$

P_t - market price for electricity
Q_t - demand for electricity (equals to electricity supply for every t)

Investment into RES

- Feed-in tariff: support scheme for promoting renewable electricity, assuring grid access and long-term contracts

- With FIT, the profit flow for the generator

$$f_i = P_t(Q_t)Q_0 + \bar{P}X_t(Q_i - Q_0) - F_i.$$

  Electricity from non-RES is sold at the market price, while the price for the electricity coming from the RES is fixed at $\bar{P}$.

- For production level Q_i, the overall value of assets in place V_i^A

$$V_i^A(X) = \frac{X(Q_i - Q_0)(\bar{P} - \phi Q_0)}{\delta} - \frac{F_i + \phi Q_0^2 - DQ_0}{r}.$$

Investment into RES II

- The value of the firm for a given RES penetration level

$$V_i(X) = V_i^A(X) + \sum_{j=i+1}^{\infty} V_j^G(X).$$

- Assumption: Expansion only by exogenously given amounts and for finitely many times at investment cost I
- Optimal investment timing (related to X) can be derived by backward solution

$$X_i^* = \frac{\delta\beta_2}{(1-\beta_2)} \left(\frac{(rI_i + F_i - F_{i-1})}{r(Q_i - Q_{i-1})(\bar{P} - \delta Q_0)} \right); \qquad \forall \ \ i = 1, ..., n,$$

where β_2 correspond to the positive root of the characteristic eq.

$$\beta_2 = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{\mu}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} > 1.$$

Grid investment

- Additional electricity $\rightarrow$ adaption of the existing system
- Price cap regulation: transmission price is kept constant until the new production expansion
- The profit flow for the transmission utility with a price cap P_i

$$f_i^T = (P_i - m)(Q_0 + X_t(Q_i - Q_0)).$$

- The optimal timing of the grid investment with $\vec{P} = (P_0, P_1, ..., P_n)$

$$X_i^{T*} = \frac{\beta_2 \delta}{\beta_2 - 1} \frac{(rI_i^T - Q_0(P_i - P_{i-1})}{(P_i(Q_i - Q_0) - P_{i-1}(Q_{i-1} - Q_0) - m(Q_i - Q_{i-1}))}; \qquad \forall i = 1, ..., n.$$

Optimal price cap

- Regulator's objective: assure the optimal grid expansion timing undergoes before production expansion at lowest possible transmission price.
- Opt inv. timing $\Rightarrow$ the higher the chosen price cap, the earlier the investment.
- To obtain the lowest price cap with regulator's objective

$$X_i^{T*} = X_i^*, \qquad \forall \;\; i = 1, ..., n.$$

yielding to

$$P_i^* = \frac{arI_{i+1}^T + mX_{i+1}^*(Q_{i+1} - Q_i) - P_{i+1}^*(aQ_0 + X_{i+1}(Q_{i+1} - Q_0))}{aQ_0 + X_{i+1}^*(Q_i - Q_0)}; \quad \forall i = 0, ..., n$$

Numerical simulations

- Complete analytical solution, it is divided into three parts:
  - Decreasing feed-in tariff: optimal timing and optimal price cap
  - Electricity storage
  - Comparative statics
- 5 possible capacity increase, Production capacity increase 10%
- Initial electricity price 40EUR/MWh

	Benchmark Value
Discount rate, r	0.05
Convenience yield, δ	0.02
Initial production level, Q_0	10000
Unit fixed production costs, F	0.1
Volatility of the demand shock, σ	0.45
Marginal costs of transmission, MC	1
Unit investment costs of production IC	250
Unit investment costs of transmission IC^T	2000
Constant part of the linear demand equation, D	50
Slope of the linear demand equation, ϕ	0.001

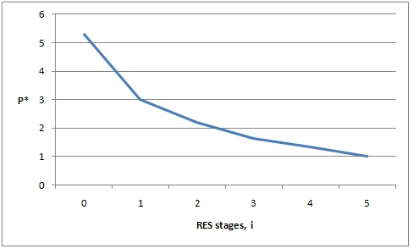
Decreasing feed-in tariff

- Feature of FIT: degression rate
- Our model: $\bar{P}$ set at the market price level $\longrightarrow$ adjustment with new capacity level
- Results: increasing production uncertainty from higher RES penetration $\longrightarrow$ profitable to postpone the RES expansion.

RES stage, i	0	1	2	3	4	5
Average electricity prod., Q_i	10000	11000	12100	13310	14641	16105
Optimal investment timing, X^*	1	1.39	1.46	1.55	1.67	1.87
Threshold el. price, (new FIT level)	40	38.61	36.94	34.87	32.24	28.57
Optimal price cap, P_i^*	5.29	3.02	2.21	1.63	1.33	1

Decreasing feed-in tariff II

- Figure: decreasing optimal investment incentives in RES penetration.
  - The uncertainty coming from the later RES expansion has to be considered in the earlier stages.
  - High level of efficiency → decrease less probable → lower risk for the transmission utility → lower transmission prices.



Electricity Storage

- Electricity storage becomes vital with high RES production.
- Our model: decrease in volatility $\rightarrow$ positive effect on further expansions.
- Lower production uncertainty decreases the risk of the capacity expansion $\Rightarrow$ earlier investment.
- Transmission: stable production reduces risk for the transmission company $\rightarrow$ lower incentives.

RES stage, i	0	1	2	3	4	5
Volatility of the demand shock, σ	0.45	0.45	0.4	0.4	0.4	0.4
Average electricity prod., Q_i	10000	11000	12100	13310	14641	16105
Optimal investment timing, X^*	1	1.39	1.26	1.32	1.41	1.53
Threshold el. price, (new FIT level)	40	38.61	-	-	33.47	30.62
Optimal price cap, P_i^*	4.86	3.25	-	-	1.44	1

Comparative statics

Role of the parameter values:

- **production uncertainty**: $\uparrow \sigma \rightarrow$ investment postponement. Waiting enables an investor to avoid the downside risk coming from uncertainty.
  $\uparrow \sigma \rightarrow$ lower optimal price cap. Reason is the later RES penetration: actual price cap longer in the business $\rightarrow$ higher profits for the grid owner.
- **Investment cost,** I: same effect as σ. $\uparrow I \rightarrow$ investment delay $\rightarrow$ riskier investment.
- **Grid investment cost,** I^T: $\uparrow I^T \rightarrow$ no influence on generation expansion, but higher incentive price cap

Summary

- Effect of the production uncertainty on the investment timing of the generation- and grid facilities
- Combined investment decisions in real options framework
- Derivation of optimal investment timings with incentive price cap
- Investment is postponed with higher production volatility
- Lower production uncertainty yields to lower transmission price cap
  $\rightarrow$ importance of storage incentives