Designing subsidy contracts for renewables: An incentive-risk trade-off

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Outline

Contract design: 2 polar cases

- **Feed-in Tariff**
  - Output is bought at a fixed price δ by the regulator
  - $\Rightarrow$ Revenues depend only on the **quantity** produced
- **Feed-in Premium**
  - Output is sold on electricity markets
  - Producer receives a fixed premium δ
  - $\Rightarrow$ Revenues depend on **quantity & prices**

The incentive-risk trade-off

- Feed-in Premiums **provide better incentives** than Feed-in Tariffs for:
  - "System friendly" technical choices (Meus et al., 2021; May, 2017; Hartner et al., 2015)
  - Spatial diversification (Schmidt et al., 2013)

($\Rightarrow$ *Incentives to mitigate cannibalization*)

- Feed-in Premiums **increase the risk for investors**, and thus:
  - Increase capital cost (Newbery, 2016; May, Neuhoff, 2018)
  - Increase risk premiums included in developers' bids (Kitzing, Weber,2014; Bunn, Yusupov, 2015)

Intermediate solutions often used in practice

- **Sliding Feed-in Premium**
  - Output is sold on electricity markets
  - Producer receives a premium $(\delta - \bar{p})$, which hedges against variation in the average price $\bar{p}$

$\Rightarrow$ Revenues depend...

  - on **quantity & correlation with high prices**,
  - but not on the **average price**

N.B.: As many variants as potential definitions of $\bar{p}$

Research Question

- Contract designs differ in VRE producers' exposure to electricity market prices
- Greater exposure to these prices implies:

1. Stronger incentives to choose projects with a high value per output
2. Greater risk associated with electricity price volatility $\Rightarrow$ risk premiums

Research Question: Among existing contract designs, which offers the best answer to this trade-off?

Game considered

A regulator is willing to subsidize a wind/solar power plant within a predetermined **expected budget constraint**

1. It organizes a tender, specifying a contract design R *(FiT, FiP...)*
2. Private firms:
   - Bid a required subsidy level δ within a competitive auction
   - Choose to build the project that maximizes their expected payoff considering the subsidy contract
3. The regulator:
   - Selects the firm with the lowest bid δ
   - Scales the power plant's size (capacity) to meet the expected budget constraint
4. The firm builds and operates the power plant and is subsidized according to $R(\boldsymbol{q}, \boldsymbol{p}; \delta)$

▸ Detailed Model

Contract design and welfare loss

- Welfare = Expected (gross) social benefits from the VRE project built
- **First Best** – W^*
  - The regulator directly selects the project with the **highest ratio of expected social value to cost**
  - The project is sized for its **cost to exactly meet the budget constraint**
- **Second Best with contract design** R – W_R
  - The firm selects the project with the highest ratio of expected revenue to cost **which may differ from the first best project**
  - The project is sized considering the bid placed by the firm **which includes a risk premium** when the firm is risk averse

Welfare loss with contract R

Proposition

Welfare with contract design R relative to first best welfare follows:

$$\frac{W_R}{W^*} = (1 - \mu_{R,\delta_R}(\omega_R)) \underbrace{\frac{\mathbb{E}_X[V(\omega_R, X)]/C(\omega_R)}{\mathbb{E}_X[V(\omega^*, X)]/C(\omega^*)}}_{\leq(1-\overline{\chi}_{R,\delta_R}(\omega_R))}$$

For VRE project ω_R chosen by the firm:

- $\mu_R(\omega_R)$ denotes the risk premium required by the firm ▸ Details
- $\overline{\chi}_R(\omega_R)$ denotes a measure of the distortion (discrepancy between private revenue and social benefits) which do not depend on $C(\cdot)$ ▸ Details

Application to sample of wind & solar projects in France

- Sample of 93 VRE projects in France (onshore wind and solar) $[\Omega]$
  - Location & technical characteristics based on actual projects built or submitted in tenders
  - Hourly production simulated based on historic weather data (2016-2019)
  - ➥ Social benefits $[V(\omega, X)]$ simulated with counterfactual simulations of a power dispatch model

▸ EOLES-Dispatch model

- Subsidy levels $[\delta_R]$ matched with average winning bids (strike price) in 2019 tenders:
  - 59.5 EUR/MWh for solar projects
  - 64.75 EUR/MWh for wind projects

Risk scenarios to derive risk premiums

- Risk distribution $[X]$ based on:
  - Yearly variability among 2016-2019
  - Natural gas price and CO_2 emission cost shocks on electricity prices
  - Development pace of VRE in the mix (high or low cannibalisation)

▸ Detailed Scenarios

➥ Electricity prices simulated through power dispatch modeling

▸ EOLES-Dispatch model

Results without assumptions on costs

- No assumption on the costs of projects $C(\omega)$
- Compute the distortion measure $\overline{\chi}_{R,\delta_R}(\omega_R)$
  - Provides an **upper bound** on distortion-induced welfare loss
  - Conditional on one project ω_R selected by the firm
- Risk premium $\mu_{R,\delta_R}(\omega_R)$
  - is a point estimate (not an upper bound)
  - also depends on the selected project ω_R
  - depends on assumed firms' risk aversion (RRA $= 1$)

Yearly sliding feed-in premiums minimize the welfare loss

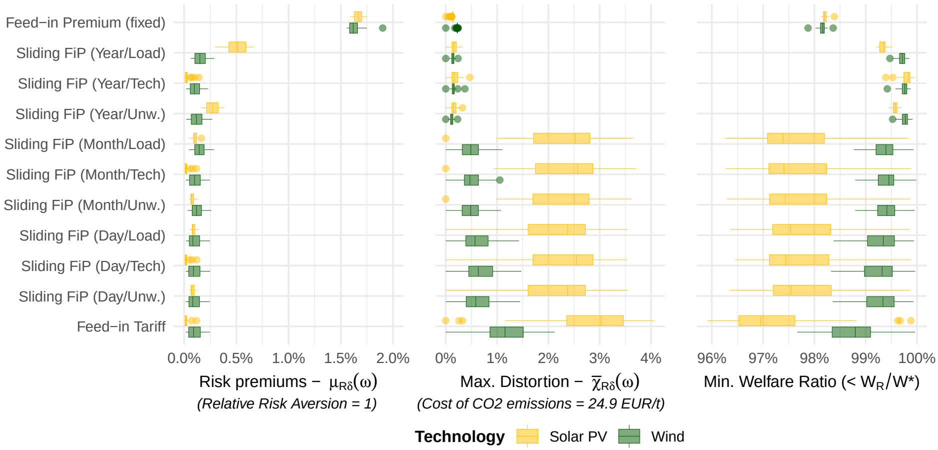


Figure: Distortions and risk premiums induced by each contract design

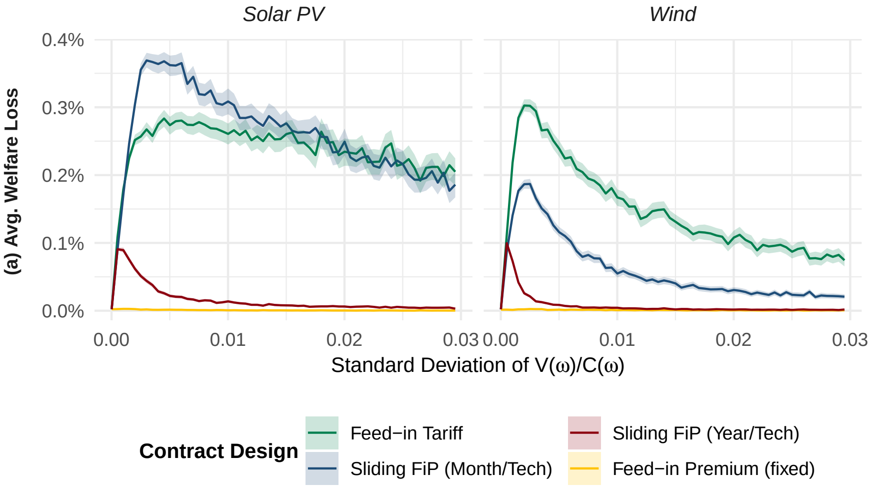
Assuming costs distribution

Exact distortion-induced welfare loss =

$$\frac{\mathbb{E}_X[V(\omega_R, X)]/C(\omega_R)}{\mathbb{E}_X[V(\omega^*, X)]/C(\omega^*)}$$

- **Assumption:** $\forall \omega \in \Omega \quad \frac{V(\omega)}{C(\omega)} \sim \mathcal{N}(1, \sigma)$
- Simulation of the game's outcome and comparison to first best ($n = 2000$)

Distortion-induced welfare losses remain small



Conclusions & Discussions

- Risk premiums appear as a greater concern than distortions
- Sliding feed-in premium offer a good compromise, but:
  - **Mostly if the reference price is a yearly average**
  - Tech.-weighted average is slightly better at limiting risk premiums

- Distortions may matter more in the future, with increased cannibalisation

$\Rightarrow$ *Future research: Assess the performance of contract designs in a future VRE-rich electric mix*

Thank you for your attention.

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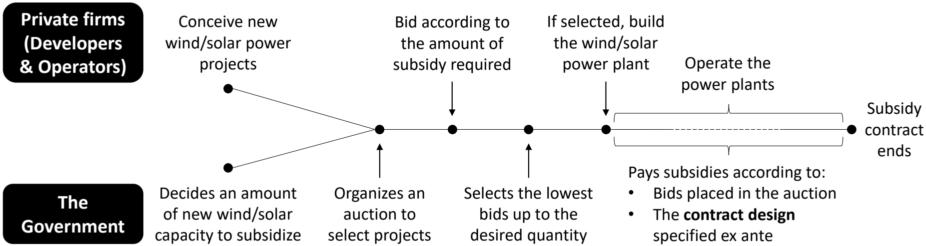
Wind and solar subsidies allocated through tenders



Research focus: **Contract design** (Feed-in Tariff, Feed-in Premium, ...)

Detailed Model

The VRE project ω is selected among a set of potential projects Ω, and its size is adjusted by a factor $\lambda \in \mathbb{R}_+^*$

- $C(\lambda \cdot \omega) = \lambda \cdot C(\omega)$ – cost of building and operating the project
- $V(\lambda \cdot \omega, X) = \lambda \cdot V(\omega, X)$ – social benefits of the project's output
- $R(\lambda \cdot \omega, X; \delta) = \lambda \cdot R(\omega, X; \delta)$ – private revenues raised by the project
- X – conditions unknown ex ante (weather, demand for power, fuel prices, etc.)
- δ – winning bid and effective subsidy level

Game equilibrium:

- ω^* – First best project choice
- ω_R – Project selected under contract design R
- δ_R – Equilibrium bid with contract design R

return

Risk premium's expression

- Firms have a monotone and concave utility function denoted $U(\cdot)$
- For chosen project ω and equilibrium bid δ, their risk premium is expressed:

$$\mu_{R,\delta}(\omega) \equiv 1 - U^{-1}\left(\mathbb{E}_X\left[U\left(\frac{R(\omega, X; \delta)}{\mathbb{E}_X[R(\omega, X; \delta)]}\right)\right]\right)$$

return

Distortion measure

- The distortion induced by the contract design R between two projects ω and ω' is measured by:

$$\chi_{R,\delta}(\omega,\omega') \equiv \frac{\mathbb{E}_X[R(\omega,X;\delta)]/\mathbb{E}_X[V(\omega,X)] - \mathbb{E}_X[R(\omega',X;\delta)]/\mathbb{E}_X[V(\omega',X)]}{\mathbb{E}_X[R(\omega,X;\delta)]/\mathbb{E}_X[V(\omega,X)]}$$

- Conditional on project ω_R being selected by the firm, the maximum distortion induced welfare loss is:

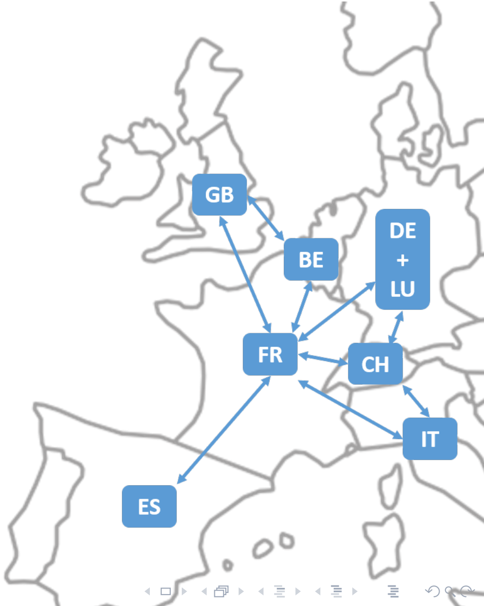
$$\overline{\chi}_{R,\delta}(\omega_R) \equiv \max_{\omega'\in\Omega} \chi_{R,\delta}(\omega_R,\omega')$$

return

EOLES-Dispatch: Modeling the French power dispatch

- **Inputs:**
  - Operation costs and Installed capacity in each of 14 generation technologies
  - Hourly demand for power, VRE generation
- **Simulation:** Minimizing total cost while meeting hourly demand
- **Outputs:**
  - Overall total cost
  - Marginal cost in each country and each hour *(proxy for prices)*

return



Scenarios for risk on electricity prices

Table: Scenarios on fuel prices and CO2 emissions cost

	(baseline)	Low	Median	High
Probability		*10%*	*80%*	*10 %*
Natural Gas Price [USD/mmbtu]	*6.62*	4.5	8.5	15.0
EU ETS Allowances [EUR/tonCO2]	*24.9*	20	40	100

Table: Scenarios on VRE capacities installed in France [GW]

	(baseline)	VRE-	VRE+
Probability		*50%*	*50%*
Solar PV	*9.158*	13.7	20.1
Onshore Wind	*14.551*	20.6	24.1
Offshore Wind	*0.000*	0.02	2.4

return