Renewables and Electricity Spot Prices: An incentive-risk trade-off for contract design

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Insurance provision to mitigate costs

- Less variable/risky revenue means lower **risk premiums**
  - Lower cost of capital (Newbery, 2016; May, Neuhoff, 2018)
  - Lower bids placed by developers' in tenders (Kitzing, Weber,2014; Bunn, Yusupov, 2015)

→ and eventually **lower cost for consumers**

- Contract design determines the risk faced by contractors, in particular:
  - **Exposure to electricity spot price volatility** *(none with, e.g., Feed-in Tariffs or CfDs)*
  - *[Not covered] Other dimensions: risk on quantity produced, on construction costs...*

...may induce distortions

- Insurance provision kills incentives to **address the insured risk**
- In particular, being protected from the time-variability of electricity prices kills incentives to
  - *[Not covered] Respond to spot prices in dispatch decisions*
    - *Stop producing when prices are negative*
    - *Plan maintenance when prices are low*
  - **Invest in power plant more likely to produce when prices are high**
    - Technical choices affecting the timing of production (e.g., wind turbine's swept area, solar panels' orientation) (Meus et al., 2021; May, 2017; Hartner et al., 2015)
    - Geographic location (e.g., spatial diversification to limit time correlation with renewable total supply) (Schmidt et al., 2013)
- If spot prices reflect the **time-specific value of electricity** (i.e., marginal production costs), renewables developers should account for it

Empirical Research Question

- Contracts should insure against spot price volatility since it will **reduce the risk premiums** → *By how much?*
  - Depends on the actual risk faced by renewables
  - ⇒ Need to rely on data reflecting investors' beliefs about future spot prices
- Contracts should expose to spot prices since it will **incentivize to build more valuable power plants** → *By how much?*
  - Depends on how much leeway developers have to respond to incentives
  - ⇒ Need to rely on data reflecting the power plant design options at hand

+ Are there contracts that can do **most of the job** on both fronts?

Intermediate designs often used in practice

- Feed-in Tariffs or CfDs **fully insure** against spot prices
- Fixed Feed-in Premiums **fully expose** to spot prices
- Sliding Feed-in Premiums **partially expose** to spot prices
  - Output is sold on the spot market
  - Producer receives a premium equal to the difference $(b - \bar{p})$ between
    - A strike price b defined in the contract
    - The average price $\bar{p}$ observed on the spot market

  $\Rightarrow$ The contractor is hedged against variations in $\bar{p}$

  $\Rightarrow$ Revenues depend on **quantity & correlation with high prices**

$\rightarrow$ Sliding FiPs variants are used in France, Germany, Netherlands, Poland...

Outline

1. Motivation
2. Theoretical Framework
3. Empirical Implementation & Results
4. Conclusion

Model description I

- A set of $N \geq 2$ firms can build one (small) renewable power plant with
  - Any technology option $\omega \in \Omega$
    - Including technical characteristics, geographic location...
    - Defines the **production time profile** of the power plant
  - Any size (or capacity) $\lambda \in \mathbb{R}_+^*$
- Firms' cost to build and operate a power plant: $C(\omega, \lambda) = \lambda \cdot C(\omega)$
- Firms are risk-averse with a concave utility function $U(\cdot)$
- Firms are symmetric: C, U and Ω are shared and common knowledge among all firms

Model description II

- **Value of the power plant's output**: $V(\omega, \lambda; X) = \lambda \cdot V(\omega; X)$
- Depends on both:
  - The power plant's **characteristics**: ω and λ
  - The **state of the world** during operation: $X \in \mathcal{X}$ (random variable)
    - Weather conditions,
    - Demand for power,
    - Other power generation units available,
    - Fuel and CO2 costs...
- State of the world X is realized **after investment**
  (only the distribution of X over $\mathcal{X}$ is known ex ante)

Regulator's objective

- A regulator has a budget of 1 to build a new renewable power plant

Objective: $\max_{\omega\in\Omega,\lambda\in\mathbb{R}_+^*} \mathbb{E}_X[\lambda \cdot V(\omega;X)] \quad s.t. \quad \lambda \cdot C(\omega) \leq 1$

First best solution $\rightarrow$ The regulator knows Ω, C, V and imposes

- A technology with the highest ratio of expected value to cost ω^*

$$\omega^* \in \operatorname*{Arg\,max}_{\omega\in\Omega} \frac{\mathbb{E}_X[V(\omega;X)]}{C(\omega)}$$

- The size that exhausts the budget constraint $\lambda^* = \frac{1}{C(\omega)}$

Procurement

- In practice, the regulator does not know Ω, C or V
- Instead procures the new power plant through a tender:

Tender procedure

1. The regulator specifies a contract design $R : \Omega \times \mathcal{X} \times \mathbb{R} \to \mathbb{R}$
2. Participating firms:
   - Place a bid $b_R \in \mathbb{R}$
   - Choose a technology $\omega_R \in \Omega$
3. The regulator:
   - Selects the firm with the lowest bid b_R
   - Set the capacity $\lambda_R \in \mathbb{R}_+$ to meet the budget constraint (in exp. over X)
4. The winning firm/contractor:
   - Builds and operates the power plant
   - Receives $\lambda_R \cdot R(\omega; X, b_R)$

Examples of contract designs

Procurement Equilibrium Outcome

Participating firms...

- **Maximize their expected utility** over available technologies Ω, **considering the contract design** R

$$\omega_R \in \operatorname*{Arg\,max}_{\omega \in \Omega} \mathbb{E}_X \left[U\left(\lambda_R \cdot R(\omega; X, b_R)\right)\right] - U(\lambda_R \cdot C(\omega))$$

- **Compete away all rents** *(symmetric firms with complete information)*

$$b_R \quad s.t. \quad \mathbb{E}_X[U(\lambda_R \cdot R(\omega_R; X, b_R))] = U(\lambda_R \cdot C(\omega_R))$$

- With the regulator setting the project's size at: $\lambda_R = \frac{1}{\mathbb{E}_X[R(\omega_R; X, b_R)]}$

Procurement vs. First Best

The procurement outcome differs from the first best solution

$$W_R \equiv \mathbb{E}_X[V(\omega_R, \lambda_R; X)] \leq \mathbb{E}_X[V(\omega^*, \lambda^*; X)] \equiv W^*$$

in that:

- $\omega_R \neq \omega^*$: the contract design R may induce **distortions**

  → *The firm does not necessarily pick the most valuable technology*

  → *The effect is small if $R(\cdot)$ is close to providing marginal rewards*

- $\lambda_R \leq \lambda^*$ (for a same ω): the firm requires a **risk premium** to break even

  → *The budget constraint forces to downsize the power plant*

  → *The effect is small if $R(\cdot)$ limits the variability of revenues*

Welfare loss with contract design R

Proposition

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

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

For 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)* ▸ Details

→ *Neither depends on costs* $\{C(\omega)\}_{\omega \in \Omega}$

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Key inputs to the empirical analysis

- The set of technology options Ω determines
  - Heterogeneity in value (for the regulator) across projects/technologies
  - How likely it is that a change in contract design R will lead to a change in technology
- The probability distribution of X determines
  - The variability of the contractor's revenue (risk)
  - How much this risk is mitigated by each contract design R

Ω – A sample of wind & solar projects in France

- Sample of 93 renewable projects in France (onshore wind and solar) [Ω]
  - Location & technical characteristics based on actual projects built or submitted in tenders
  - Hourly production simulated based on historic weather data (2016-2019)
  - ➥ Projects' value [$V(\omega, X)$] simulated with counterfactual simulations of a power dispatch model *(= avoided generation costs)* ▸ EOLES-Dispatch model

X – A set of weather years and fuel costs scenarios

- Risk distribution $[X]$ based on:
  - Yearly variability across 2016-2019
  - Scenarios for natural gas price and CO_2 emission cost shocks on electricity prices
  - Scenarios for renewables development pace (high or low cannibalisation)

Detailed Scenarios

➥ Electricity prices simulated through power dispatch modeling

EOLES-Dispatch model

Comparing contract designs without cost assumptions

Assuming we **observe that technology ω_R is selected** by the firm, we compute

- The risk premium $\mu_{R,b_R}(\omega_R)$
  - A **point estimate** (not an upper bound)
  - Depends on the risk distribution X and on firms' risk aversion (RRA $= 1$)
- The distortion measure $\overline{\chi}_{R,b_R}(\omega_R)$
  - An **upper bound** on distortion-induced welfare loss
  - Depends on the set of other options that have been left out $\Omega \setminus \{\omega_R\}$

Neither rely on assumptions on the costs of projects $C(\omega)$

Yearly sliding feed-in premiums minimize the welfare loss

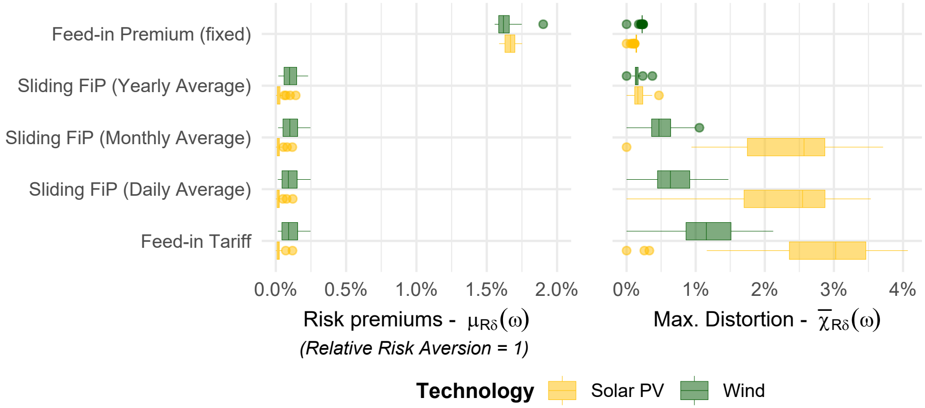


Figure: Distortions and risk premiums induced by a selection of contract design

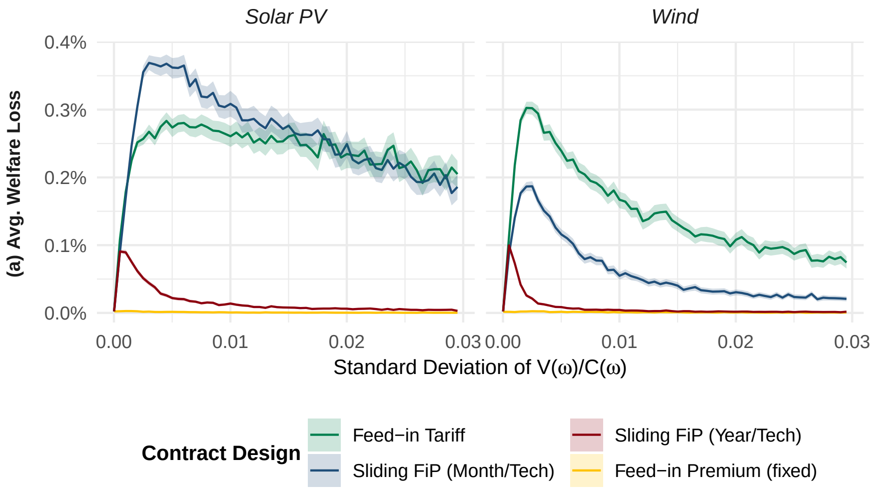
Assuming costs distribution

To assess an average value of the (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



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Conclusion

- In FiT vs. fixed FiP, risk premiums appear as a greater concern than distortions
  - Projects chosen under FiT are less valuable, but not by much
  - Risk premiums under fixed FiP significantly harm the budget constraint

- Sliding feed-in premiums offer a good compromise, but...
- **...mostly if the reference price is a yearly average**

Thank you for your attention.

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Contract Design R – Examples

In practice, contract designs considered here all make revenues depend only on the time-series of production $\boldsymbol{q}$ and prices $\boldsymbol{p}$ over the contract duration T

ω, λ and $X \longrightarrow \boldsymbol{q} = (q_t)_{t \in T}$

$X \longrightarrow \boldsymbol{p} = (p_t)_{t \in T}$

b_R

$\boldsymbol{q}, \boldsymbol{p}, b_R \longrightarrow R(\boldsymbol{q}, \boldsymbol{p}; b_R)$

Examples

Feed-in Tariff: $R^{FiT}(\boldsymbol{q}; b^{FiT}) = \sum_{t \in T} b^{FiT} \cdot q_t$

Fixed FiPs: $R^{fFiP}(\boldsymbol{q}, \boldsymbol{p}; b^{fFiP}) = \sum_{t \in T} (p_t + b^{fFiP}) \cdot q_t$

Sliding FiPs: $R^{sFiP}(\boldsymbol{q}, \boldsymbol{p}; b^{sFiP}) = \sum_{S \in \mathcal{S}} \sum_{t \in S} (p_t + (b^{sFiP} - \bar{p}_S)) \cdot q_t$

with $\mathcal{S}$ a partition (years, months, days...) of T
and $\bar{p}_S$ the 'reference price' in time period $S \in \mathcal{S}$

Risk premium's expression

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

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

return

Distortion measure

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

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

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

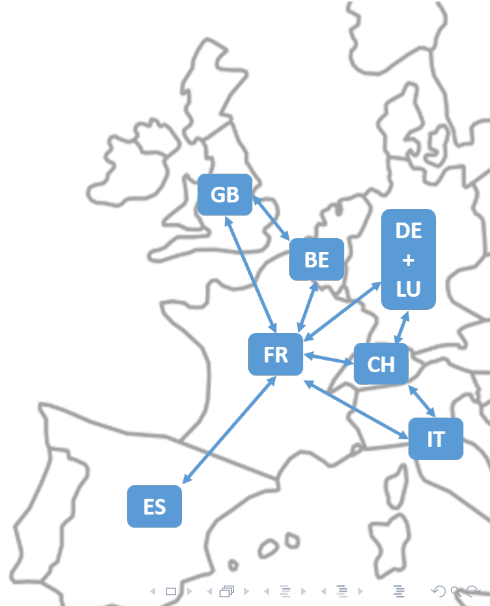
$$\overline{\chi}_{R,b}(\omega_R) \equiv \max_{\omega'\in\Omega} \chi_{R,b}(\omega_R,\omega')$$

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



Subsidy Levels/Equilibrium bids

- Subsidy levels [b_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

			Solar projects ($n = 50$)			
Contract Design				Revenue (per output)		
	Period	*Weighting*	b_R	*mean*	*min*	*max*
Feed-in tariff			59.49	*59.49*	59.49	59.49
Feed-in premium			18.32	*59.49*	58.70	61.16
sl. FiP	Year	Load	64.02	*59.49*	58.64	61.29
sl. FiP	Month	Load	60.07	*59.49*	59.19	60.30
sl. FiP	**Month**	**Technology**	**59.50**	*59.49*	59.18	60.30
				Value (per output)		
Social Benefits			δ	*mean*	*min*	*max*
Baseline			18.31	*59.49*	58.69	61.18

Notes: "sl. FiP": (Two-sided) Sliding feed-in premiums.

Table: Calibration of bids and renewable energy externality (short) [EUR/MWh]

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