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Right and duty: Investment risk under different renewable energy support policies

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- Renewable energy projects are usually subject to a regulated remuneration framework.
- Regardless of whether the incentive is set by a government or by an auction, we can categorize them according to the payment mechanism involved. We distinguish two general types of "fixed" payment mechanisms:
  - **Fixed-price (FP):** supplier faces uncertainty due to unknown generation levels.
  - **Fixed-revenue (FR):** supplier faces no uncertainty.
- There also exist various more flexible schemes which besides guaranteeing a minimum price also enable some potential benefit from market prices above a certain threshold:
  - **Shared-Upside (SU):** supplier and regulator share the excess remuneration according to a predefined percentage.

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- The support policy entails a reduction in the risk faced by the investor, which is then assumed by the regulator.
- However, most of these policies not only grant a right to the investor of receiving a guaranteed payment but also limit their potential benefits (i.e. impose an obligation).
- Over the past few years the obligation imposed was negligible in comparison with the right received. Now, in a context of increasingly competitive renewables and high electricity prices in many countries the obligation assumed becomes more important.

- We propose a simple model with analytic solutions in which, considering both the randomness of the market price as well as that of the energy production, we analyze the risk removed under different types of regulations and the importance of both the right and obligation that in each case the policy entails.
- The framework allows comparing different policies with different remuneration parameters.
- We apply the model to the case of Spain, which in recent years has undergone numerous changes in its green energy support system and has implemented the 3 mechanisms that we have discussed.

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- We propose to model the value of each regulatory scheme (V) as the result of two opposite contributions.
  - The investor may have the right to sell the electricity produced either at a minimum price per unit or for guaranteed revenue. The value of this right: R
  - The investor may have the obligation to sell the electricity produced either at a maximum price per MWh supplied or for a capped revenue. The value of this obligation: O
- We model the value of the support policy as:

$$V = R - O$$

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- For a given renewable technology, we model both the average annual price of electricity and the annual electricity production as two correlated Geometric Brownian Motion stochastic processes S_t and X_t respectively. The dynamics are described by:

$$\begin{cases} dS_t = \mu_S S_t dt + \sigma_S S_t dW_t^S \\ dX_t = \mu_X X_t dt + \sigma_X X_t dW_t^X \\ \rho = corr(dW_t^S, dW_t^X) \end{cases}$$

- We define the value of the right given by the regulation as the expected value of the discounted payoffs over the market that the right offers.
- We define the value of the obligation imposed by the regulation as the expected value of the discounted amount that the investor has to give up.

- The supplier receives a minimum price (K_{fp}) per generated MWh in a given period T. Hence, the value of the right offered at initial time $t = 0$ for exercise in $t = T$ is given by (where $z^+ \equiv max\{z, 0\}$):

$$R_{fp} = \mathbb{E}_0[e^{-rT} X_T (K_{fp} - S_T)^+]$$

- Similarly, the generator receives a maximum price (K_{fp}) per generated MWh. Thus, the value of the obligation imposed:

$$O_{fp} = \mathbb{E}_0[e^{-rT} X_T (S_T - K_{fp})^+]$$

- The value of the fixed-price scheme at $t = 0$ for exercise in $t = T$:

$$V_{fp} = \mathbb{E}_0[e^{-rT} X_T (K_{fp} - S_T)]$$

- Investors receive a guaranteed revenue (K_{fr}) for supplying all the electricity they generate in a given period T. Hence, the value of the right offered at initial time $t = 0$ for exercise in $t = T$ is given by:

$$R_{fr} = \mathbb{E}_0[e^{-rT}(K_{fr} - X_T S_T)^+]$$

- Similarly, the generator receives a maximum revenue (K_{fr}) for supplying all the electricity they generate. Thus, the value of the obligation imposed:

$$O_{fr} = \mathbb{E}_0[e^{-rT}(X_T S_T - K_{fr})^+]$$

- The value of the fixed-revenue scheme at $t = 0$ for exercise in $t = T$:

$$V_{fr} = \mathbb{E}_0[e^{-rT}(K_{fr} - X_T S_T)]$$

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- The supplier receives a minimum price (K_{su}) per generated MWh in a given period T. Hence, the value of the right offered at initial time $t = 0$ for exercise in $t = T$ is given by:

$$R_{su} = \mathbb{E}_0[e^{-rT} X_T (K_{su} - S_T)^+]$$

- The investor can benefit from higher than expected electricity prices. When the market price of electricity exceeds the guaranteed floor, the investor and the policymaker share the excess remuneration. If α represents the predefined share of the market upside received by the investor, then the value of the imposed obligation:

$$O_{su} = \mathbb{E}_0[e^{-rT}(1-\alpha) X_T (S_T - K_{su})^+]$$

- The value of the shared-upside scheme at $t = 0$ for exercise in $t = T$:

$$V_{su} = R_{su} - O_{su}$$

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- Under each policy the risk exposure is of different nature. Assuming that two incentives of different types A and B, with a set of retributive parameters Ω_A and Ω_B respectively, are offered with a duration of T_f years. Then, both policies will have an identical regulatory value if:

$$\sum_{T=1}^{T_f} V_A(T,\Omega_A) = \sum_{T=1}^{T_f} V_B(T,\Omega_B)$$

- Similarly, the right/obligation granted by the two policies is identical if:

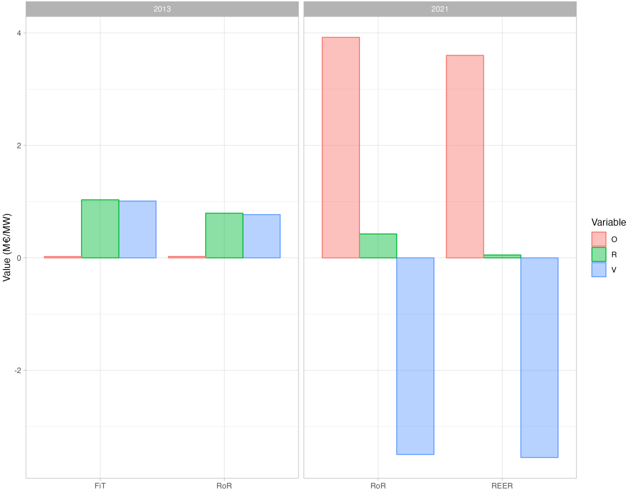
$$\sum_{T=1}^{T_f} R_A(T,\Omega_A) = \sum_{T=1}^{T_f} R_B(T,\Omega_B)$$

$$\sum_{T=1}^{T_f} O_A(T,\Omega_A) = \sum_{T=1}^{T_f} O_B(T,\Omega_B)$$

- We apply the model to the case of Spain at 2 different times:
  - **2013:** transition from the Feed-in Tariff regulation (fixed-price) to the Rate of Return regulation (fixed-revenue).
  - **2021:** older projects are subject to the Rate of Return regulation (fixed-revenue), new projects are awarded under a new regulation consisting of a shared-upside system.
- We calibrate the model and use a 15 year policy duration for each system and show some results for each MW of capacity promoted.

▶ Application of the model

▷ Wind Power in Spain



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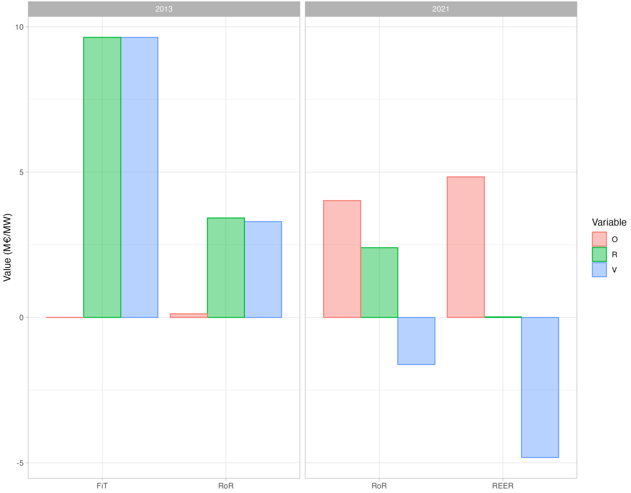

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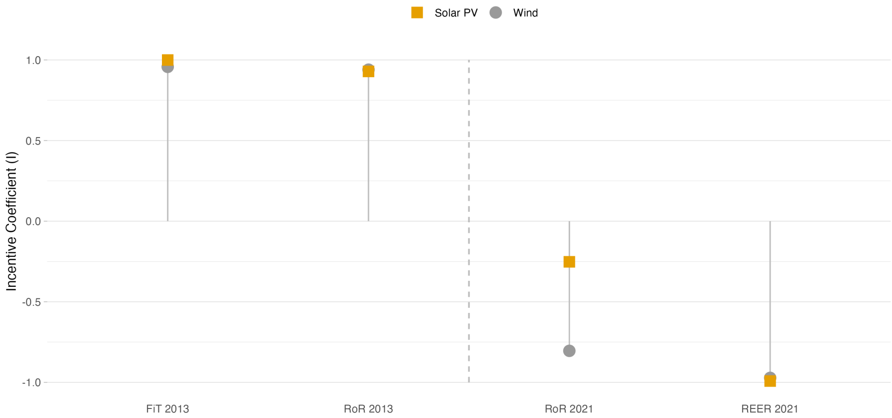
Solar PV
Wind
Incentive Coefficient (I)
1.0
0.5
0.0
-0.5
-1.0
FiT 2013
RoR 2013
RoR 2021
REER 2021

$$I = \frac{R - O}{R + O}$$

- We contribute to the literature with a simple analytical model to estimate the investment risk removed under different types of renewable energy policies and the importance of both the right and the obligation that the policy entails, taking into account both the randomness of the market price and the randomness of energy production.
- Our model allows, given the characteristics of one of the incentive mechanisms (prices, duration, etc.), to determine the design under another scheme so that the value of both schemes is identical.

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- The application of the model to the specific case of wind and PV in Spain shows that years ago the obligation imposed was negligible compared to the right received, but in a context of high electricity prices and increasingly competitive renewables, the obligation assumed becomes more important in this trade-off, which may cause the support scheme to become a liability.
- This may have a number of important consequences, especially for new investments yet to be made in future auctions. As an illustration, Spain's 2022 renewable energy auction was a failure due to the cap price set by the government (only 1.3% of the auctioned capacity was awarded).
- As the incentives were too generous years ago in Spain, changes in support policies were introduced to reduce the regulatory costs. Today, however, the situation is reversed. Not only have investment incentives been reduced, but there is now a strong disincentive to invest.

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Thank you for your attention

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	Fixed-price	**Fixed-revenue**	**Shared-upside**
R	$R_{fp} = \mathbb{E}_0[e^{-rT} X_T (K_{fp} - S_T)^+] =$ $X_0 e^{(\mu_X - r)T} \left(K_{fp} \Phi(-d_{fp}) - S_0 e^{(\mu_S + \sigma_S \sigma_X \rho)T} \Phi(-d_{fp} - \sigma_S \sqrt{T}) \right)$	$R_{fr} = \mathbb{E}_0[e^{-rT} (K_{fr} - X_T S_T)^+] =$ $e^{-rT} \left(K_{fr} \Phi(-d_{fr}) - X_0 S_0 e^{(\mu_S + \mu_X + \sigma_S \sigma_X \rho)T} \Phi\left(-d_{fr} - \sqrt{(\sigma_S^2 + \sigma_X^2 + 2\sigma_S \sigma_X \rho)T} \right) \right)$	$R_{su} = \mathbb{E}_0[e^{-rT} X_T (K_{su} - S_T)^+] =$ $X_0 e^{(\mu_X - r)T} \left(K_{su} \Phi(-d_{su}) - S_0 e^{(\mu_S + \sigma_S \sigma_X \rho)T} \Phi(-d_{su} - \sigma_S \sqrt{T}) \right)$
O	$O_{fp} = \mathbb{E}_0[e^{-rT} X_T (S_T - K_{fp})^+] =$ $X_0 e^{(\mu_X - r)T} \left(S_0 e^{(\mu_S + \sigma_S \sigma_X \rho)T} \Phi(d_{fp} + \sigma_S \sqrt{T}) - K_{fp} \Phi(d_{fp}) \right)$	$O_{fr} = \mathbb{E}_0[e^{-rT} (X_T S_T - K_{fr})^+] =$ $e^{-rT} \left(X_0 S_0 e^{(\mu_S + \mu_X + \sigma_S \sigma_X \rho)T} \Phi\left(d_{fr} + \sqrt{(\sigma_S^2 + \sigma_X^2 + 2\sigma_S \sigma_X \rho)T} \right) - K_{fr} \Phi(d_{fr}) \right)$	$O_{su} = \mathbb{E}_0[e^{-rT} (1-\alpha) X_T (S_T - K_{su})^+] =$ $(1-\alpha) X_0 e^{(\mu_X - r)T} \left(S_0 e^{(\mu_S + \sigma_S \sigma_X \rho)T} \Phi(d_{su} + \sigma_S \sqrt{T}) - K_{su} \Phi(d_{su}) \right)$
V	$V_{fp} = \mathbb{E}_0[e^{-rT} X_T (K_{fp} - S_T)] =$ $X_0 e^{(\mu_X - r)T} \left(K_{fp} - S_0 e^{(\mu_S + \sigma_S \sigma_X \rho)T} \right)$	$V_{fr} = \mathbb{E}_0[e^{-rT} (K_{fr} - X_T S_T)] =$ $e^{-rT} \left(K_{fr} - X_0 S_0 e^{(\mu_S + \mu_X + \sigma_S \sigma_X \rho)T} \right)$	$V_{su} = R_{su} - O_{su}$
	$d_{fp} = \dfrac{\log\left(\frac{S_0}{K_{fp}}\right) + \left(\mu_S + \sigma_S \sigma_X \rho - \frac{\sigma_S^2}{2} \right) T}{\sigma_S \sqrt{T}}$	$d_{fr} = \dfrac{\log\left(\frac{X_0 S_0}{K_{fr}}\right) + \left(\mu_S + \mu_X + \sigma_S \sigma_X \rho - \frac{\sigma_S^2 + \sigma_X^2 + 2\sigma_S \sigma_X \rho}{2} \right) T}{\sqrt{(\sigma_S^2 + \sigma_X^2 + 2\sigma_S \sigma_X \rho)T}}$	$d_{su} = \dfrac{\log\left(\frac{S_0}{K_{su}}\right) + \left(\mu_S + \sigma_S \sigma_X \rho - \frac{\sigma_S^2}{2} \right) T}{\sigma_S \sqrt{T}}$

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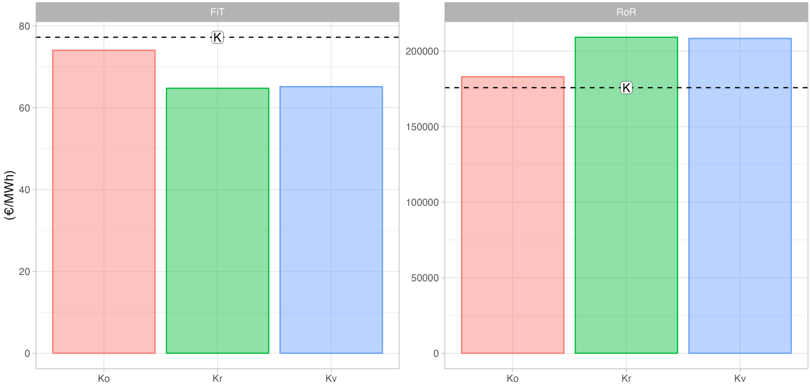

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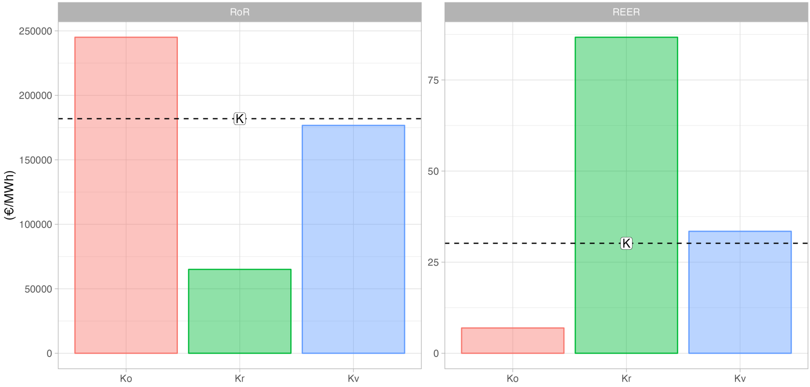

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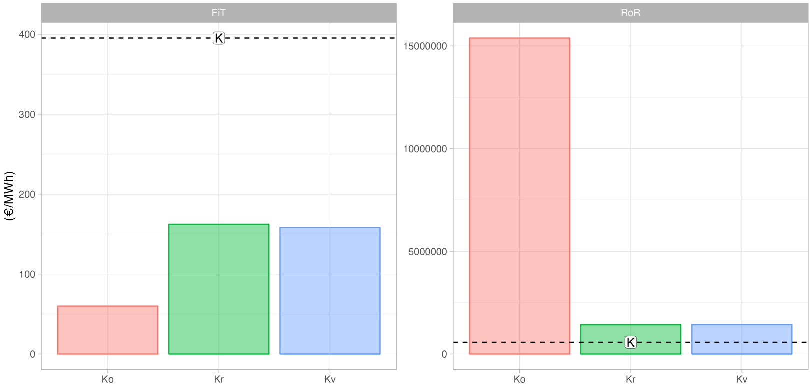

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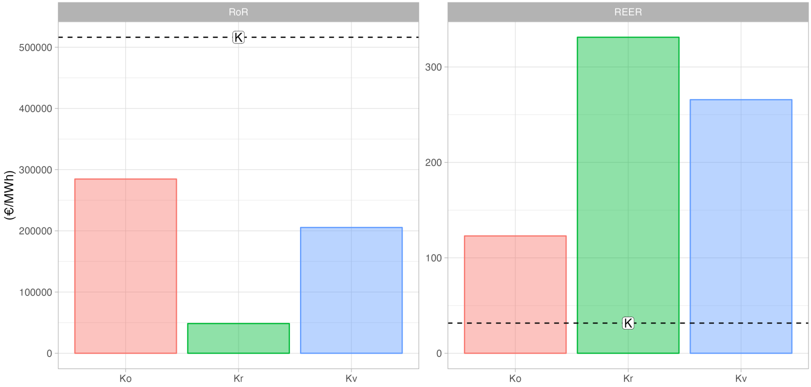

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- Suppose that the support offers at time $t = 0$ the right to trade their electricity produced at time T for at least a revenue Rev_R.
  - If $(Rev_R > X_T S_T) \rightarrow$ payoff $= (Rev_R - X_T S_T)$
  - If $(Rev_R \leq X_T S_T) \rightarrow$ payoff $= 0$
- We define the value of the right given by the support as the expected value of the discounted payoffs that the right offers considering the likelihood of the market not reaching the guaranteed revenue:

$$R(T) = \mathbb{E}_0[e^{-rT} \, (Rev_R - X_T S_T)^+]$$

- where $z^+ \equiv max\{z, 0\}$

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- Suppose that the support obliges at time $t = 0$ to trade their electricity produced at time T for at maximum, a revenue Rev_O.

  - If $(X_T S_T > Rev_O) \rightarrow$ give up to $= (X_T S_T - Rev_O)$
  - If $(X_T S_T \leq Rev_O) \rightarrow$ give up to $= 0$

- We define the value of the obligation imposed by the support as the expected value of the discounted amount that the investor has to give up under the policy considering the likelihood of the market exceeding the cap allowed:

$$O(T) = \mathbb{E}_0[e^{-rT}(X_T S_T - Rev_O)^+]$$

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