Understanding Power Contracts: The Costs of Counterparty Risk*

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PRELIMINARY AND INCOMPLETE

Abstract

Promoting renewable energy investments relies on the availability of long-term contracts that ensure a predictable energy price. However, there are concerns regarding the liquidity of such contracts. This paper models the market for long-term power contracts and characterizes its main features. It shows that the buyers' counterparty risk enlarges the probability of default on the contracts, reducing contract liquidity and giving rise to under-investment in renewable energy. It also studies the effects of proposed market interventions, such as public support for long-term power contracts, public guarantees, regulatory-backed contracts, and the introduction of buyers' obligations to enter into these contracts.

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1 Introduction

In the summer of 2022, electricity spot market prices in Europe exceeded a record high of 700€/MWh, well above the 50-60€/MWh pre-crisis average. These price spikes put electricity market design on the spotlight and long-term power contracts at the core of the debate (Fabra, 2023).

Almost a year later, the European Commission released its electricity market reform, which emphasized the need to promote long-term power contracts (European Commission, 2023). The objective was two-fold. First, to ensure that producers and consumers are protected against revenue and cost shocks. Second, to promote the deployment of renewable energy, which involves long-lived capital-intensive investments and is, therefore, particularly vulnerable to the volatility of spot market prices.[1] As the European Commission puts it, *"the ultimate objective is to provide secure, stable investment conditions for renewable and low-carbon energy developers by bringing down risk and capital costs while avoiding windfall profits in periods of high prices."* Long-term power contracts are not unique to European countries and they are also common in the electricity markets in the US, Canada and Australia, to name just a few examples (Research and Markets, 2024).

There are two broad categories of long-term power contracts. Power Purchase Agreements (PPAs) are private long-term contracts between a consumer and a generator (typically renewable) who agree to buy and sell electricity at a fixed price over a certain number of years (typically, from 10 to 15). The use of PPAs has been increasing over time (Figure 1) but is still considered insufficient to boost renewable energy investments at the required speed and scale (Polo et al., 2023). Contracts-for-Differences (CfD) differ from PPAs in that the counterparty is not a private buyer but the regulator acting on behalf of several buyers (typically, all the buyers connected to the network).[2] Several regulators around the world have also relied on CfDs as a way to promote renewable

[1]Indeed, existing evidence indicates that decreasing exposure to price variations lowers the cost of capital, promoting renewable investments at lower costs (Gohdes et al., 2022; Dukan and Kitzing, 2023).

[2]PPAs and CfDs can differ in numerous dimensions beyond the identity of the counterparty. For instance, PPAs are commonly negotiated bilaterally, whereas CfDs are allocated through centralized auctions. However, nothing stops private sellers from using auctions to allocate PPAs. Similarly, PPAs can be tailored to the needs of the buyer and seller, whereas CfDs tend to be more standardized contracts. However, nothing stops regulators from auctioning CfDs with certain characteristics, e.g., baseload contracts instead of pay-as-produced contracts.

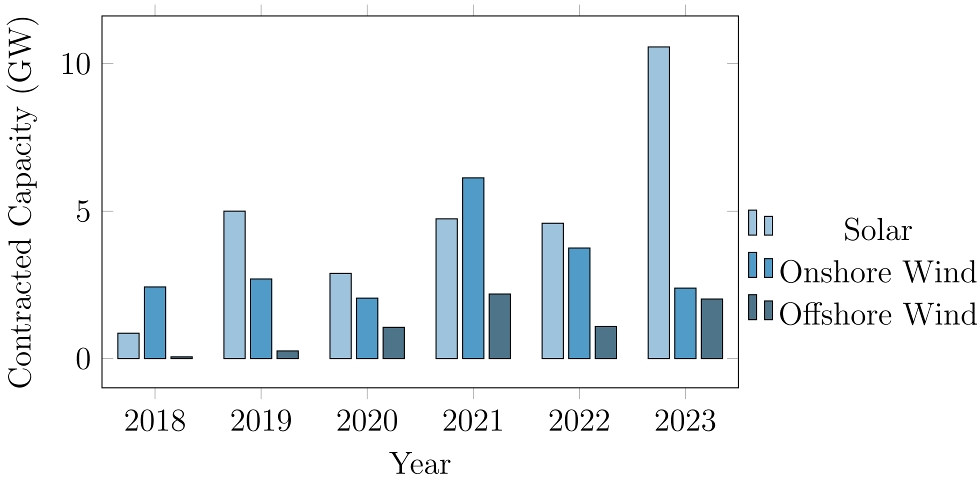

Figure 1: Volume of New PPA Contracts by Technology in Europe. Source: (Pexapark, 2024))

investments.[3] This paper provides a novel model of the PPA market and investigates the interaction between both types of long-term power contracts.

Despite the consensus on the need to promote long-term contracting, there is a lack of diagnosis as to why PPA markets have failed to provide enough liquidity for long-term power contracts. The report by the European Commission acknowledges that *"a barrier to the growth of this market is the credit risk that a consumer will not always be able to buy electricity over the whole period."* However, beyond expressing this concern, the implications of counterparty risk on the performance of PPA, markets have not been explored in detail. Our paper puts buyers' counterparty risk at the core of the analysis and uncovers how it affects PPA prices, the degree by which PPAs truly protect producers from spot price volatility considering the probability of contract default, and the resulting incentives to invest in renewable energy. We also use the model to analyze the properties of several public policies that have been proposed to overcome the market failures of the PPA market.

Our model considers sellers and buyers who trade one unit of electricity in a spot market. Risk-averse sellers suffer a utility loss when exposed to volatile prices. Buyers and sellers enter into fixed-price contracts that hedge them against the volatility of spot prices. However, buyers can decide to default on the contract if the spot price falls below the agreed price, exposing sellers to spot price volatility and the associated utility loss.[4]

[3] CfDs were first introduced in the UK Kröger et al. (2022). Since then, several countries have followed, including Denmark, Greece, Hungary, Ireland, Spain and Poland. Beyond Europe, CfDs have been used in Australia and Canada (Hastings-Simon et al., 2022).

[4] In our baseline model we normalize the costs of contract default to zero. However, in Section 5 we

Counterparty risk creates a trade-off for the seller, as increasing the contract's fixed price comes at the cost of raising the probability of contract default.

The equilibrium price for the contract is set through market clearing between the demand and supply for long-term contracts. Buyers are always willing to participate in fixed-price contracts as they can default if the spot price turns out to be below the contract price. However, the sellers' willingness to invest and sign a fixed-price contract depends on their outside options. Sellers with low investment costs find entry at spot prices profitable even if accounting for their risk aversion. Hence, they invest regardless of whether contracts are available and sign contracts as long as they give them a utility at least as profitable as relying on the spot market. In contrast, since a contract is required to make the entry of high-cost sellers profitable, its price must allow the marginal seller to break even. It follows that the supply of contracts is weakly increasing in the contract price up to the point where further price increases reduce the sellers' profits due to the higher risk of default. Investment beyond this point is never profitable, even if there exists excess demand for contracts at that price.

In this context, our model delivers two important results. First, it highlights the advantages that policymakers have attributed to long-term power contracts. Indeed, the market equilibrium with contracts is welfare superior to the no-contracts case. The reason is that contracts reduce the sellers' disutility from spot price volatility, and trigger investment that would not have arisen in the absence of contracts. However, this does not imply that promoting the demand for long-term contracts is always welfare-enhancing. Indeed, there is a trade-off, as strengthening contract demand also pushes contract prices up in order to make additional investments profitable, at the cost of raising the probability of contract default for all contracts, including the inframarginal ones. This result is in contrast with one of the policies put forward by the European Commission obliging suppliers to hedge appropriately, which will boost demand for PPAs.

Second, our model uncovers the cost of counterparty risk as a major market failure of PPA markets, leading to contract prices that are too high, excessive contract default, poor contract liquidity, and a weak ability to leverage investments in renewable energy. In our model, all sellers receive the market-clearing contract price, which is above the one that inframarginal sellers would require to sign the contract. Hence, contracts entail

show that the model's main results remain unchanged if we add a collateral (as long as it is not too valuable) that the buyer forgoes in case of default.

excessive counterparty risk. Therefore, there is scope to increase welfare through measures that allow for lowering contract prices and through that, a reduction in the probability of contract default. In turn, this intervention enhances the social profitability of entry, leading to increased investment in renewable energy.

We explore various welfare-enhancing market interventions, some of which have been proposed in the regulatory debate, including *"requiring Member States to ensure that instruments to reduce the financial risks associated with the buyer defaulting on its long-term payment obligations... These can be guarantee schemes at market prices, as well as public support for non-fossil fuels PPAs"* (European Commission, 2023). We show that these policy interventions can be welfare-enhancing as long as the funds that are required to provide public support or public guarantees are not too costly.

We first consider a regulator who can use subsidies contingent on the seller signing a fixed-price contract. When deciding on the contract price, the regulator faces a *rent-counterparty risk trade-off*: raising the contract price increases counterparty risk, but also increases the seller's profits, allowing for a reduction of the transfers needed for the marginal seller to break even. In turn, when deciding on the transfer, the regulator faces a *rent-investment trade-off*: the increase in the transfer promotes new entry but also raises the public cost of the transfers that are paid to inframarginal sellers, who would invest in any event.

The regulator strikes a balance over these two trade-offs to determine the fixed-price contract and transfer that maximize overall welfare. The optimal solution entails lower fixed prices, a lower probability of contract default, and higher investment if the cost of social funds is sufficiently low. Non-contingent transfers (i.e., paid to all sellers regardless of whether they engage in a fixed-price contract) are not as effective, although they can still improve upon the market solution.

We then consider the role of public guarantees, which transfer the cost of counterparty risk from the seller to the regulator. Hence, as above, there is a trade-off between the benefits of protecting sellers against contract default and the public cost of the guarantees. However, a new trade-off arises in this case. Namely, since sellers do not internalize the full cost of their investments, excessive entry can occur, particularly if the cost of public funds is high.

Lastly, our model highlights that the most effective intervention is to promote publiclybacked long-term contracts, the so-called Contracts-for-Differences (CfDs). These contracts not only provide a counterparty risk-free option, but they may also improve the performance of the private PPA contracts market. The reason is simple: since contract demand is satisfied through another channel, the demand for PPAs goes down and the market clearing PPA price is lowered, mitigating counterparty risk for all PPA contracts. Therefore, despite their concerns about CfDs crowding our PPAs, regulators should rely on CfDs as much as possible and promote PPAs only for the residual demand not satisfied with CfDs.[5]

The remainder of the paper is organized as follows. In Section 2, we describe the model. In Section 3, we characterize the contract market equilibrium and assess its welfare properties. In Section 4, we analyze several market interventions, including public subsidies and public guarantees. In Section 5, we study how the results change when we extend the model to features like the existence of collateral or discriminatory subsidies. Section 6 concludes.

2 Model Description

Consider a market with a mass θ of identical buyers, denoted as B, with a demand for one unit of electricity up to their reservation price $v > 1$. There is a unit mass of potential entrants, referred to as sellers, S. Each seller can invest in one unit of capacity at a cost c, allowing the production of one unit of electricity at zero cost. Investment costs are drawn from a distribution function $G(c)$, with positive density $g(c)$ in an interval $c \in [0, \bar{c}]$ for $\bar{c}$ sufficiently high.

Electricity is traded in a spot market, where demand is perfectly inelastic, and exogenously given. Furthermore, demand is large enough that renewable energies are never enough to satisfy it. Therefore, the equilibrium price in the spot market, denoted as p, reflects the volatile marginal cost of the existing conventional power producers. In particular, $p \sim \Phi(p)$, with density $\phi(p)$, positive and differentiable in the interval $p \in [0, 1]$. We further assume that the hazard rate,

$$\frac{\phi(p)}{1 - \Phi(p)},$$

[5]We take the constraint on the maximum number of available CfDs as exogenous. The reasons behind the limit in the regulators' ability to auction off a higher number of CfDs are outside the scope of this model.

is strictly increasing in p.

Spot price volatility entails a risk premium for sellers, which we denote as $r_S \in (0, E(p)]$. As a result, expected spot market revenues for buyers and sellers are

$$\Pi_B^0 = v - E(p),$$
$$\Pi_S^0 = E(p) - r_S.$$

Sellers can avoid the risk premium by entering into a fixed-price contract with a buyer who pays a price f for its unit demand. We assume that fixed-price contracts do not affect the spot market price.[6]

If this financial contract is honored, the buyer and the seller obtain revenues $v-f$ and f, respectively. However, the buyer can act opportunistically, default on the contract, and buy its unit demand at the spot market price, p. Defaulting is optimal for the buyer if the spot market price falls below the contract price, $p < f$.[7] As a result, expected contract revenues for the buyer and seller are

$$\Pi_B(f) = v - \int_0^f p\phi(p)dp - f(1 - \Phi(f)),$$
$$\Pi_S(f) = \int_0^f (p - r_S)\,\phi(p)dp + f(1 - \Phi(f)).$$

Importantly, the buyer's expected revenue is always decreasing in f. In contrast, under the hazard rate assumption, the seller's expected revenue is quasiconcave in f, which is maximal at a point below the highest spot market price, $\bar{f} < 1$.

Lemma 1. *The fixed price that maximizes the seller's profits, $\bar{f}$, is lower than 1 and decreasing in the seller's risk premium r_S.*

The quasiconcavity arises from the trade-off between higher revenue for the seller when f increases and the contract is honored and a higher probability of default due to counterparty risk. The maximum price $\bar{f}$ strikes a balance between these two forces. Since the buyer's profits are always decreasing in f, no price above $\bar{f}$ would ever arise.

[6] Recall that p reflects the marginal cost of the competitive conventional producers participating in the spot market. Hence, the assumption that contracts do not affect p is equivalent to assuming that the supply of conventional producers is perfectly elastic at the equilibrium spot market price. At least, their perfectly elastic supply has to be as large as the scale of the new investments under fixed-price contracts.

[7] We abstract from the possibility that the seller also acts opportunistically. In practice, it is usually the case that banks require sellers to have a fixed-price contract to obtain funding, discouraging them from later walking out of the contract.

The fixed-price contract must also yield higher profits than the spot market for the buyer and the seller to be willing to sign it. The result is straightforward for the buyer as he always has the option to default on the contract to avoid paying a higher price. Hence, $\Pi_B(f) \geq \Pi_B^0$ for all f. For the seller, the contract price must be above a threshold $\underline{f}$ to make it profitable, $\Pi_S(f) \geq \Pi_S^0$.

Lemma 2. *The seller is willing to sign the fixed-price contract if and only if $f \geq \underline{f}$. If $r_S = 0$, $\bar{f} = \underline{f} = 1$. If $r_S > 0$, $\bar{f} > \underline{f} \geq 0$.*

When there is a positive risk premium $r_S > 0$, fixed-price contracts are efficient as they allow sellers to eliminate it. Importantly, the above lemma shows that, in this case, there is always scope for contracting as $\underline{f} < \bar{f}$.

Putting the two lemmas together, it follows that the equilibrium contract must be in the interval $[\underline{f}, \bar{f}]$. Whether they are closer to $\underline{f}$ or to $\bar{f}$ will depend on the relative magnitude of the demand and supply for contracts, as characterized in the following section.

However, before we proceed, it is important to specify the timing of the game. First, sellers observe their investment cost c. Second, buyers and sellers choose whether to sign a fixed-price contract. Third, sellers decide whether to invest or not.[8] Finally, the spot market price p is realized, and buyers decide whether to honor the contract or walk away.

3 The Contract Market Equilibrium

The intersection between the demand and the supply for contracts determines the equilibrium price in the contract market. On the demand side, since buyers are always willing to sign contracts (recall that $\Pi_B(f) \geq \Pi_B^0$ for all f), the demand for contracts is perfectly inelastic at θ.

On the supply side, our previous analysis allows us to characterize the supply for contracts as a function of the investment cost c. First, if $c \leq \Pi_S^0$, the seller always invests regardless of whether a contract is signed. In this case, the seller accepts the contract as long as it is at least as profitable as the spot market, i.e., if $f \geq \underline{f}$. Second, if $c \in \left(\Pi_S^0, \Pi_S(\bar{f})\right]$, the seller invests if the investment cost is covered, which requires signing

[8] The costs of financing the investments depend on whether sellers have signed fixed-price contracts or are exposed to the spot market price volatility. Hence, contract decisions typically precede investment decisions.

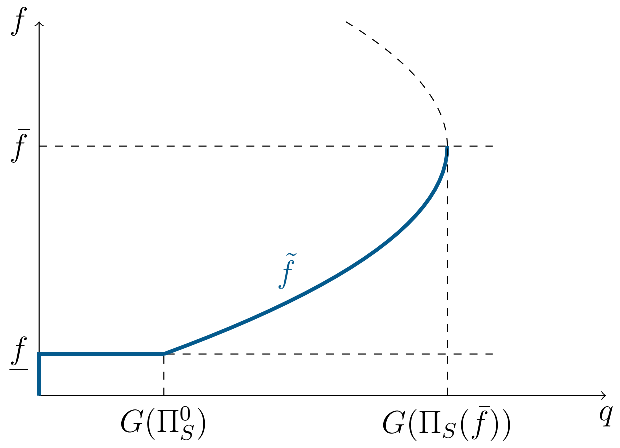

Figure 2: The supply curve for fixed-price contracts.

a contract. Therefore, the contract price must be above the break-even price, implicitly defined by

$$\Pi_S(\tilde{f}) = c. \tag{1}$$

Finally, if this price exceeds the seller's profit-maximizing level $\bar{f}$, or equivalently if $c > \Pi_S(\bar{f})$, the seller never invests, as the highest possible profits that can be attained with the contract are not enough to cover the investment costs.

Figure 2 illustrates the supply function for contracts, which is weakly increasing in the contract price f. Notice that the supply function bends backward for for $f > \bar{f}$ since, from Lemma 1 above, the seller's profits decrease as the contract price increases beyond that point. Since the contract price never exceeds the seller's profit-maximizing price $\bar{f}$, that region of the supply curve can be ignored.

Having characterized demand and supply for contracts, we are now ready to derive the equilibrium contract price, denoted f^c. Figure 3 illustrates market clearing in the three relevant cases.

First, suppose that demand is high, meaning that θ exceeds the supply for contracts. As there are insufficient sellers, the equilibrium price is the maximum possible, $f^c = \bar{f}$. Since sellers make profits $\Pi_S(\bar{f})$, they are willing to invest for all values of c that satisfy

$$c \leq c^c \equiv \Pi_S(\bar{f}).$$

This means that the high-demand case arises if demand exceeds the mass of sellers willing to invest, i.e., if $\theta > q^c = G(c^c) = G(\Pi_S(\bar{f}))$, where we use q^c to denote equilibrium capacity.

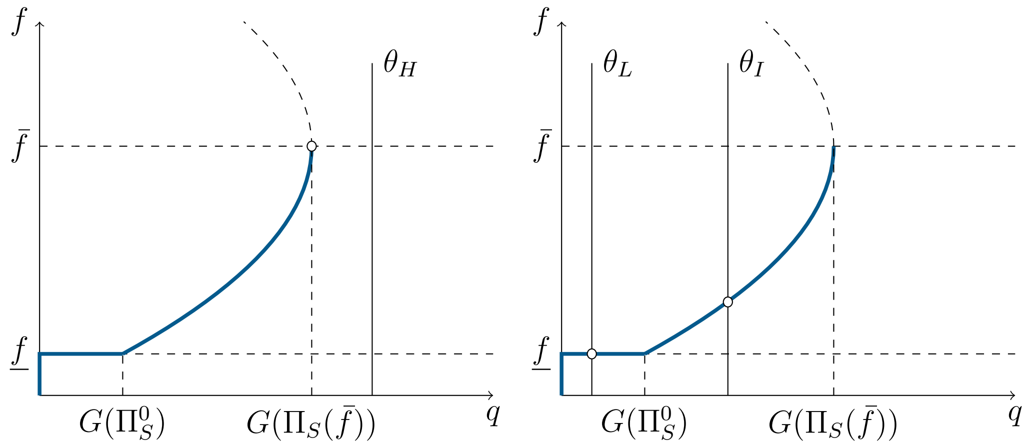

Figure 3: Equilibrium prices in the contract market (high demand case on the left, and intermediate and low demand cases on the right).

Supply is enough to cover demand for lower values of θ, implying $f^c < \bar{f}$. In particular, if demand is low, meaning that the required investment always takes place regardless of the contract, i.e., $\theta \leq G(\Pi_S^0)$, the equilibrium price is the minimum possible, $f^c = \underline{f}$. If demand takes an intermediate value, $G(\Pi_S^0) < \theta < G(\Pi_S(\bar{f}))$, additional investment is required to satisfy demand. This means that the marginal firm must break even. Hence, the market clearing price is determined by

$$G(\Pi_S(\tilde{f})) = \theta,$$

where $f^c = \tilde{f}$ is defined in (1).

Two important results come from the previous analysis. First, the equilibrium contract price is weakly increasing in θ from $\underline{f}$ to $\bar{f}$. Furthermore, it is strictly increasing in θ when demand takes intermediate values, as the break-even price $\tilde{f}$ is strictly increasing in θ. Second, equilibrium investment, q^c, equates demand in the low and intermediate cases, but it is always limited by $G(\Pi_S(\bar{f}))$ even when demand is above this level.

3.1 Welfare under the Contract Market Equilibrium

We now characterize the contribution of contracts to social welfare under the market solution. First, consider the low-demand case. Contracts do not increase investment relative to the no-contract case and they simply reduce sellers' risk premium whenever they are honored. Hence, the contribution of contracts to social welfare can be written as:

$$W = \theta(1 - \Phi(\underline{f}))r_S. \tag{2}$$

For higher demand levels, contracts further affect welfare by increasing investment, as captured in the second term of the following expression:

$$W = (1 - \Phi(f^c))r_S G(\Pi_S^0) + \int_{\Pi_S^0}^{q^c} [E(p) - \Phi(f^c)r_S - c]\, g(c)dc. \tag{3}$$

The contribution to social welfare of the additional investment, net of its cost c is twofold. First, it displaces conventional power plants in the spot market, thus saving the difference between their expected marginal costs, $E(p)$, and the (zero) marginal cost of renewable production. Second, it reduces the expected all the sellers' risk premium by $\Phi(f^c)r_S$.

Naturally, the market equilibrium with contracts is always welfare superior to the no-contract case. When demand is low, investment with or without contracts is the same, but fixed-price contracts reduce the sellers' risk premium, generating an additional surplus of $\theta(1 - \Phi(\underline{f})r_S$. When demand is intermediate or high, contracts also allow for efficient investment that would not take place when sellers are exposed to the price volatility of the spot market.

However, the market equilibrium also gives rise to inefficiencies. In particular, the market equilibrium entails excessive counterparty risk for intermediate and high demands.[9] The reason is that all sellers receive a uniform fixed price. Since this price is determined by the cost of the marginal seller, it is above the minimum prices that the inframarginal sellers would be willing to accept to participate in the contract. Hence, there is scope to reduce the prices for the inframarginal sellers, mitigating the probability of contract default and increasing social welfare. This result is in contrast with what occurs in standard markets, where inframarginal rents typically affect the division of surplus between buyers and sellers but have no impact on efficiency.

Excessive counterparty risk explains why, under the market equilibrium, welfare may not be increasing in the demand for contracts. In particular, while an increase in demand yields higher investment, it also increases the equilibrium contract price, raising the counterparty risk for all inframarginal contracts. Indeed, as the following result shows, when θ is sufficiently high, welfare is decreasing in the demand for contracts.

Proposition 1. *There exists $\theta^* < G(\Pi_S(\bar{f}))$ such that the contribution of contracts to social welfare is strictly decreasing in θ for all $\theta \in [\theta^*, G(\Pi_S(\bar{f}))]$.*

[9] When demand is low, i.e., $\theta \leq G(\Pi_S^0)$, all sellers receive their outside option, and inframarginal rents do not generate inefficiencies.

To interpret this result, it is useful to consider the case where $\theta = G(\Pi_S(\bar{f}))$. In that situation, since the supply of contracts is vertical — see Figure 2 —, a negligible reduction in demand significantly decreases the equilibrium price. Therefore, the large reduction in counterparty risk that can be achieved for all inframarginal contracts dominates the cost of minimally reducing investment. Such an efficient demand curtailment could also be achieved with a regulation of the maximum contract price. In particular, there is a one-to-one correspondence between θ^* and the price cap that would accomplish the same reduction in investment and counterparty risk.

4 Market Interventions

The previous inefficiencies open the door to welfare-improving market interventions.

4.1 Public Subsidies

Suppose that the regulator can propose a contract with fixed-price f and a uniform subsidy $T \geq 0$ conditional on the seller accepting the contract. In the tradition of the literature on market regulation, this subsidy implies a social cost of funds $\lambda \geq 0$. We now characterize the optimal fixed price, f^*, and subsidy, T^*. As in previous cases, we will distinguish between the low-demand case, where all sellers invest even without the contract, and the intermediate and high-demand cases, where contracts spur investment.

When demand is low, the regulator's problem can be written as

$$\max_{f,T} \; \theta[(1-\Phi(f))r_S - \lambda T]$$
$$\text{s.t.} \;\; \Pi_S(f) + T \geq \Pi_S^0,$$
$$f \in [0,1], T \geq 0.$$

The objective function reflects the welfare measure in (2), reduced by the cost of subsidizing all entrants. The first constraint requires that all sellers are willing to accept the contract as opposed to obtaining spot market profits. Since the objective function is decreasing in T for $\lambda > 0$, the first constraint is always binding. For $\lambda = 0$, the constraint is also binding because a lower fixed price f decreases counterparty risk. The other constraints restrict the contract price within the feasible range and guarantees that the transfer is non-negative, i.e., the regulator does not tax sellers.[10]

[10] In a general regulation problem, when the social cost of funds is sufficiently high, the regulated firm might be taxed to raise public revenue. This objective is not realistic in the current context.

The first-order characterizes the interior candidate solution, f^T, as

$$-\phi(f^T)r_S + \lambda\frac{\partial\Pi_S(f^T)}{\partial f} = 0. \tag{4}$$

This equation reflects what we call a *rent-counterparty risk* trade-off. Raising f increases counterparty risk, as captured by the first term. However, the second term account for the fact that raising f also increases the seller's profits, allowing a reduction of the transfer T (and the associated cost of public funds). In the optimal price the regulator strikes a balance between these two effects. This implies choosing a fixed price that it is increasing in the cost of public funds. This price has corner solutions for extreme values of λ. If λ is sufficiently close to 0, the first-order condition (4) is negative, implying that social welfare always decreases in f. Therefore, it is optimal to set $f^* = 0$ and fully subsidize the seller through a transfer that makes the seller willing to accept the contract, i.e., $T^* = \Pi_S^0$.

At the other extreme, when λ is sufficiently high, transfers are very costly and using them is always suboptimal, i.e., $T^* = 0$. As a result, the optimal fixed price coincides with the market solution, $f^* = \underline{f} = f^c$.

The previous results are summarized in the following proposition.

Proposition 2. *When $\theta \leq G(\Pi_S^0)$, there exist $\lambda_2 > \lambda_1 \geq 0$ such that the optimal contract can be characterized as follows:*

$$f^* = \begin{cases} 0 & \text{if } \lambda \leq \lambda_1, \\ f^T(r_S, \lambda) \in (0, \underline{f}) & \text{if } \lambda \in (\lambda_1, \lambda_2], \\ \underline{f} & \text{if } \lambda > \lambda_2, \end{cases}$$

where f^T is the solution to (4)*. This fixed price (weakly) decreases in r_S and (weakly) increases in λ.*

When demand takes an intermediate or high value, the regulator's problem becomes

$$\max_{f,T}\ (1 - \Phi(f))r_S G(\Pi_S^0) + \int_{\Pi_S^0}^{c^*} [E(p) - \Phi(f)r_S - c]g(c)dc - \lambda G(\hat{c})T,$$
$$\text{s.t. } \Pi_S(f) + T = c^*,$$
$$f \in [0,1], T \geq 0,$$
$$G(c^*) \leq \theta.$$

The welfare function arises from (3) and, as mentioned in the previous section, accounts in the second term for the additional welfare brought about by the new investment. The scale of the investment is governed by the first constraint, which determines the cost of the marginal seller c^*. The last condition is a feasibility constraint indicating that investment does not exceed demand.

In an interior solution, because counterparty risk affects all inframarginal contracts in the same way, the choice of f is governed by the same first-order condition and the same rent-counterparty risk trade-off identified in (4).

Choosing T is equivalent to choosing c^*, as they are both tied through the first constraint. When the solution is interior, the first-order condition characterizes the marginal investment as

$$\left[E(p) - \phi(f^T)r_S - c^* - \lambda(c^* - \Pi_S(f^T))\right] g(c^*) - \lambda G(c^*) = 0. \tag{5}$$

This expression reflects a *rent-investment trade-off.* The first term captures the social value of the marginal investment, while the second term accounts for the social cost of the higher rents of the inframarginal due to the higher cost of the marginal investment, which sets the transfer for all.

As in the low-demand case, the regulator can reduce counterparty risk by decreasing the fixed price. While this would yield a lower investment, transfers can overturn this effect. When the cost of social funds is small, it is optimal to set high transfers, implying that the second effect dominates and that total investment is above the market solution. However, when λ is sufficiently high, transfers are lower, and the first effect might dominate, leading to less investment than under the market solution. Indeed, as shown in Proposition 1, when demand is high, and transfers are infinitely costly, optimal investment is lower than under the market solution.

Proposition 3. *When $\theta > G(\Pi_S^0)$, there exist $\lambda_3 > \lambda_1 > 0$ such that the optimal contract can be characterized as follows:*

$$f^* = \begin{cases} 0 & \text{if } \lambda \leq \lambda_1, \\ f^T(r_S, \lambda) < \bar{f} & \text{if } \lambda \in (\lambda_1, \lambda_3), \\ f^T(r_S, \lambda_3) \leq \bar{f} & \text{if } \lambda \geq \lambda_3. \end{cases}$$

where f^T is the solution to (4)*. This fixed price (weakly) decreases in r_S and (weakly) increases in λ.*

In sum, the market solution gives rise to excessive counterparty risk and, in the high-demand case, to underinvestment. Both inefficiencies can be addressed through transfers when they have a low social cost. In particular, it is optimal to reduce the fixed price below the one that allows the marginal investor to break even and compensate the difference with transfers. Consequently, counterparty risk decreases for all contracts while investment increases relative to the market solution. However, when transfers are costly, the regulator sacrifices investment in order to keep counterparty risk low. The market solution does not lead to underinvestment when demand takes an intermediate value since all demand is satisfied. Hence, the optimal solution can involve less investment than the market outcome.

4.2 Public Guarantees

Suppose now that instead of a conditional subsidy, the regulator can now offer public guarantees. These guarantees are meant to secure revenue f for the seller even if the buyer defaults on the contract. That is, public guarantees are structured as a payment for the seller that compensates for the revenue shortfall $f - p$ in case of default. As in the previous case, the disbursement of public funds is also subject to a social cost $\lambda \geq 0$.

Because the seller does not incur in any counterparty risk, gross profits under the contract are now $\Pi_S(f) = f$, regardless of the value of $f \in [0, 1]$. Buyer's profits remain unchanged.

Suppose first that demand is either low or intermediate so that, without guarantees, investment equals demand, $q^c = \theta$. The following condition determines whether public guarantees should be used or not,

$$\theta \left[\Phi(f^c) r_S - \lambda \int_0^{\hat{f}^c} (\hat{f}^c - p)\phi(p)dp \right] \lessgtr 0,$$

where $\hat{f}^c$ is the equilibrium price that arises when public guarantees are in place. Since the seller's profits are now higher, the break-even competitive price is lower than under the market solution without guarantees for any given demand θ, $\hat{f}^c < f^c$. Therefore, public guarantees involve a trade-off between eliminating counterparty risk for the seller, as captured by the first term in brackets, and incurring the social cost of the public funds, as captured by the second term in brackets. Clearly, for public guarantees to be optimal, λ must be sufficiently low.

Alternatively, if demand is high, public guarantees induce new investment because the seller can now profitably charge a price above $\bar{f}$ without facing counterparty risk.

Hence, the new equilibrium price is now defined as

$$G\left(\Pi_S(\hat{f}^c)\right) = G\left(\hat{f}^c\right) = \theta.$$

Interestingly, this case implies a new trade-off, as shown in the following expression:

$$G(\Pi_S(f^c))\Phi(f^c)r_S - \theta\lambda \int_0^{\hat{f}^c} (\hat{f}^c - p)\phi(p)dp + \int_{\Pi_S(f^c)}^{\hat{f}^c} (E(p) - c)g(c)dc \lesseqgtr 0.$$

The first two terms are counterparts of the benefits of reducing counterparty risk and the cost of public funds identified in the previous case. The main difference is that, in this case, counterparty risk is also removed from sellers who would have participated even without public guarantees. Still, the cost of public funds applies to all sellers, especially those for which guarantees facilitate entry. The last term is interesting in that it captures the social value of new investment absent counterparty risk. However, if θ is sufficiently large, it is easy to see that $E(p) < c$ can arise for some sellers and in particular for the marginal investment, $c = \hat{f}^c$. This would mean that inefficient entry might occur, as the cost savings induced by the new capacity are below the investment cost of some sellers. This outcome is due to a kind of Moral Hazard. Sellers do not fully internalize the social costs of increasing f. The large fixed-price set for the contract encourages excessive default which, in turn, makes the investment socially inefficient.

5 Robustness and Extensions

In this section, we discuss changes in our assumptions, how they affect our main results, and the additional insights that they may bring about.

5.1 The Role of Collateral

Throughout the paper, we have assumed that the buyer could default on the contract at no cost. While this is a useful simplification, real contracts usually have provisions that penalize the buyer in that case. Among them, it is typical that the buyer needs to post some collateral $k > 0$ which the seller can appropriate if the contract is not honored. It is easy to see that a large collateral (e.g., $k = 1$) would eliminate counterparty risk. In practice, such a large collateral is uncommon as it implies large financial costs for the buyer.

Instead, suppose that $k > 0$ is relatively small. In that case, profits for the buyer become

$$\Pi_S(f) = \int_0^{f-k} (p + k - r_S)\,\phi(p)dp + f(1 - \Phi(f-k)) - c.$$

as default is now optimal when $p < f - k$. Since profits are increasing in k, participation in the contract, as opposed to offering energy in the spot market, is now optimal for lower values of f. This means that the new minimum price, $\underline{f}'$, is decreasing in k. The maximum price for the contract (which is also the equilibrium price when θ is sufficiently high) becomes $\bar{f}' = \bar{f} + k$, where $\bar{f}$ is the equivalent threshold in the baseline model. When default is less likely, the seller can profitably ask for a higher price.

Regarding the buyer, it is no longer true that contracts are beneficial regardless of the value of f. The decision to accept the contract now depends on the fixed-price f and the size of the collateral k. In particular, the difference in the buyer's profits from accepting or rejecting the contract is given by

$$\Pi_B(f) - \Pi_B^0 = \int_{f-k}^{1} (p - f)\phi(p)dp - k\Phi(f-k).$$

This means that the buyer will only accept the contract if f is sufficiently low, f_B. When k small and by continuity with our baseline case, we have that $f_B > \bar{f}'$ and results would be qualitatively unchanged. However, for higher values of k, the size of the collateral will affect the range of feasible contract prices, that will not go from $\underline{f}'$ and f_B.

5.2 Discriminatory Transfers

In section 4.1, we consider the optimal subsidy when all sellers are offered the same contract. As discussed in that case, inframarginal firms receive a price that results in excessive counterparty risk and positive rents. The need to limit this distortion implies that the regulator often prefers to restrict investment even below the competitive outcome.

When the regulator has access to discriminatory contracts, investment is bound to rise. Consider first the situation where no transfers are available, $T = 0$, consistent with $\lambda \to \infty$. In that case, for a given level of investment, social welfare is decreasing in f. This means that it is optimal to assign a contract with a fixed price that depends on the cost as follows

$$f^*(c) = \begin{cases} \underline{f} & \text{if } c \leq \Pi_S^0, \\ \tilde{f}(c) & \text{otherwise.} \end{cases}$$

Since, in that case, there is no trade-off between increasing investment and the counterparty risk of inframarginal sellers, Proposition 1 does not apply. This implies that the socially optimal investment coincides with the competitive one, $q^* = q^c$.

Suppose now that transfers are meaningful (i.e., λ is low). Because the regulator can now condition on the realized cost of each firm, c, the contract can be seller-specific, $\{f(c), T(c)\}$. Consider first the case where $c \leq \Pi_S^0$. In that case, the optimal contract coincides with the case analyzed in Proposition 2 with uniform contracts. In that situation, when $\theta \leq G(\Pi_S^0)$, all sellers are identical in that their outside option is to offer their production in the spot market, and c does not play a role. Therefore, whether the regulator has access to discriminatory contracts or not is irrelevant.

Suppose now that $c > \Pi_S^0$. In that case, the regulator's problem becomes

$$\begin{aligned} \max_{f,T} \; & E(p) - \Phi(f) r_S - c - \lambda T, \\ \text{s.t.} \; & \Pi_S(f) + T \geq c, \\ & T \geq 0. \end{aligned}$$

As opposed to the optimal contract characterized in Section 4.1, the regulator can now deal with each producer independently based on the investment cost c.

The next proposition summarizes the solution to this problem.

Proposition 4. *Suppose the regulator can offer discriminatory contracts. When $c \leq \Pi_S^0$, the optimal fixed price can be characterized as*

$$f^*(c) = \begin{cases} 0 & \text{if } \lambda \leq \lambda_1, \\ f^T(r_S, \lambda) \in (0, \underline{f}) & \text{if } \lambda \in (\lambda_1, \lambda_2], \\ \underline{f} & \text{if } \lambda > \lambda_2, \end{cases}$$

where f^T is the solution to (4) and λ_1 and λ_2 are defined in Proposition 3.

If $c > \Pi_S^0$, the optimal fixed price can be characterized as

$$f^*(c) = \begin{cases} 0 & \text{if } \lambda \leq \lambda_1, \\ f^T(r_S, \lambda) \in (0, \underline{f}) & \text{if } \lambda \in \left(\lambda_1, \hat{\lambda}_3(c)\right], \\ \tilde{f}(c) & \text{if } \lambda > \hat{\lambda}_3(c), \end{cases}$$

where f^T is the solution to (4) and λ_1 is defined in Proposition 2.

The marginal seller has a cost

$$c^* = \min\left\{G^{-1}(\theta), \frac{E(p) - \Phi(f^*) r_S + \lambda \Pi_S(f^*)}{1+\lambda}\right\},$$

so that $q^* \geq q^c$.

Interestingly, this solution implies that when transfers are used in equilibrium, $T > 0$, investment is higher in the socially optimal solution. The reason is that the marginal firm now receives a lower fixed-price, $f^* < f^c$, which makes the investment worthwhile for a higher range of costs c. Following previous arguments, when λ is high, and as a result $T = 0$, investment in the market solution coincides with the optimal allocation despite the higher counterparty risk that it entails for inframarginal sellers.

6 Concluding Remarks

This paper is one of the first attempts to model the markets for long-term power contracts. One of its main contributions is to study the consequences of counterparty risk by the buyer in combination with the presence of a spot market where buyers and sellers can trade and investment is endogenous. Our paper shows that inefficiencies arise both in investment and in excessive counterparty risk, mainly for inframarginal sellers that would invest anyway. Interventions aimed at fostering investment might exacerbate this cost.

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A Proofs

Proof of Lemma 1: We first show that the profit function of the seller is quasiconcave. Notice that

$$\frac{\partial \Pi_S}{\partial f}(f) = 1 - \Phi(f) - \phi(f) r_S.$$

The previous derivative is 0 when

$$\frac{\phi(f)}{1 - \Phi(f)} = \frac{1}{r_S}.$$

This solution is unique due to the hazard rate assumption. This solution, that we denote as $\bar{f}$, determines an interior maximum since

$$\frac{\partial^2 \Pi_S}{\partial^2 f}(\bar{f}) = -\phi(\bar{f}) - \phi'(\bar{f}) r_S < 0,$$

where the inequality comes from the fact that, due to the increasing hazard rate of $\Phi(p)$ and the definition of $\bar{f}$,

$$\phi'(\bar{f}) > -\frac{\phi(\bar{f})^2}{1 - \Phi(\bar{f})} = -\phi(\bar{f}) \frac{1}{r_S}.$$

Notice that $\frac{\partial \Pi_S}{\partial f}(1) = -\phi(1) r_S < 0$ and $\frac{\partial \Pi_S}{\partial f}(0) = 1 - \phi(0) r_S > 0$ if $r_S < \frac{1}{\phi(0)}$, so that the profit function cannot be monotonically increasing or decreasing.

Finally, since $\frac{\partial \Pi_S}{\partial f \partial r_S} < 0$, using the implicit function theorem we can establish that $\bar{f}$ is decreasing in r_S. $\square$

Proof of Lemma 2: First notice that when $r_S = 0$, $\Pi_S(f)$ is always increasing in f and equal to Π_S^0 if and only if $f = 1$. Hence, $\bar{f} = \underline{f} = 1$.

Suppose now that $r_S > 0$. From the FOC condition $\frac{\partial \Pi_S}{\partial f}(\bar{f}) = 0$ we can obtain, using the Implicit Function Theorem,

$$\frac{\partial \bar{f}}{\partial r_S} = -\frac{1}{1 + \frac{\phi'(\bar{f})}{\phi(\bar{f})} r_S} > -\frac{1}{1 - \frac{\phi(\bar{f})}{1 - \Phi(\bar{f})} r_S}.$$

Using the definition $\Pi_S(\underline{f}) = \Pi_S^0$ we obtain, again using the Implicit Function Theorem that

$$\frac{\partial \underline{f}}{\partial r_S} = -\frac{1}{1 - \frac{\phi(\underline{f})}{1 - \Phi(\underline{f})} r_S}.$$

To show that $\bar{f} > \underline{f}$ first notice that, using the previous expressions, $\left.\frac{\partial \bar{f}}{\partial r_S}\right|_{r_S = 0} > \left.\frac{\partial \underline{f}}{\partial r_S}\right|_{r_S = 0}$, meaning that, by continuity, for values of r_S close to 0, $\bar{f} > \underline{f}$. Suppose now towards a contradiction that there exists a value of r_S' for which $\bar{f} < \underline{f}$. In that case, again by continuity, there exists a value $\tilde{r}_S < r'_S$ for which $\bar{f} = \underline{f}$ and for all $r_S \in (\tilde{r}_S, r'_S]$ $\bar{f} < \underline{f}$. At $\tilde{r}_S$, however, $\left.\frac{\partial \bar{f}}{\partial r_S}\right|_{r_S=\tilde{r}_S} > \left.\frac{\partial \underline{f}}{\partial r_S}\right|_{r_S=\tilde{r}_s}$, which is a contradiction.

Finally, notice that when $r_S = E(p)$, $\Pi_S(\bar{f}) > \Pi_S(1) = \Pi_S^0$ and so we have $\bar{f} > 0$. □

Proof of Proposition 1: Consider a demand $\theta \in (G(\Pi_S^0), G(\Pi_S(\bar{f}))]$. In that case, welfare could be written as

$$W = (1 - \Phi(\tilde{f}(\theta)))r_S G(\Pi_S^0) + \int_{\Pi_S^0}^{G^{-1}(\theta)} \Big[E(p) - \Phi(\tilde{f}(\theta))r_S - c\Big]\, g(c)dc,$$

where we indicate that the equilibrium price, defined as $G(\Pi_S(\tilde{f})) = \theta$ is increasing in θ.

The derivative concerning the demand can be obtained as

$$\frac{\partial W}{\partial \theta} = -r_S\phi(\tilde{f}(\theta))\theta\frac{\partial \tilde{f}}{\partial \theta} + \Big[E(p) - G^{-1}(\theta) - \Phi(\tilde{f}(\theta))r_S\Big]\, g(G^{-1}(\theta)).$$

When evaluated at $\theta = G(\Pi_S(\bar{f}))$, $\frac{\partial \tilde{f}}{\partial \theta} \to \infty$ since $\tilde{f} = \bar{f}$ at which the first order condition of the seller's profit-maximizing problem is satisfied. As a result, $\left.\frac{\partial W}{\partial \theta}\right|_{\theta=G(\Pi_S(\bar{f}))} < 0$. By continuity, there exists $\theta^* < G(\Pi_S(\bar{f}))$ for which social welfare is also decreasing in θ. □

Proof of Proposition 2: Most of the arguments are outlined in the text. First, notice that the FOC in (4) can be written as

$$\frac{\phi(f^T)}{1 - \Phi(f^T)} = \frac{\lambda}{1+\lambda}\frac{1}{r_S}.$$

Due to the hazard rate condition on $\Phi(p)$, this solution is unique and determines a maximum. Furthermore, this condition implies that f^T increases in λ and r_S. When λ is sufficiently close to 0, this condition might yield a negative value for f^T, and the optimal price is $f^* = 0$. Using the previous expression, this would be the case if

$$\lambda \leq \lambda_1 \equiv \max\left\{0, \frac{r_S\phi(0)}{1 - r_S\phi(0)}\right\}, \tag{6}$$

increasing in r_S. Similarly, the FOC will yield $f^T > \underline{f}$ if λ is sufficiently high. This solution implies $T = \Pi_S^0 - \Pi_S(f^T) < \Pi_S^0 - \Pi_S(\underline{f}) = 0$ which does not satisfy the non-negative transfer constraint. As a result, $f^* = \bar{f}$ and $T^* = 0$. This case arises when

$$\lambda \geq \lambda_2 \equiv \frac{r_S\phi(\underline{f})}{1 - \Phi(\underline{f}) - r_S\phi(\underline{f})} > \lambda_1.$$

□

Proof of Proposition 3: Arguments are similar to those in Proposition 2. First, notice that when the solution is interior, it implies $f^* = f^T$. As a result, when $\lambda \leq \lambda_1$ as defined in (6), $f^* = 0$.

Since the optimal transfer T is increasing in λ, there exists a threshold $\lambda_3 > \lambda_2$ such that $T^* = 0$. Due to Proposition 1, this means that the optimal fixed-price is $f^* \leq f^c = \bar{f}$. $\square$

Proof of Proposition 4: As explained in the text, the case where $c \leq \Pi_S^0$ is identical as the situation analyzed in Proposition 2.

When $c > \Pi_S^0$, standard arguments imply that the first condition in the problem outlined in the text is always binding and, therefore, the problem of the regulator becomes

$$\max_f \; E(p) - \Phi(f) r_S + \lambda \Pi_S(f) - (1+\lambda)c,$$
$$\text{s.t. } T \geq 0.$$

Absent the constraint, the FOC of this problem is identical to (4), which implies that the candidate solution, f^T, is increasing in λ and this, in turn, implies that T is decreasing in λ. Hence, for low values of λ the constraint is not binding, and the regulator's solution is $f^* = f^T$, provided that this is positive (i.e., $\lambda > \lambda_1$ as defined in (6)). The monotonicity of f^T with respect to λ also implies that there exists a threshold for λ defined as

$$f^T(r_S, \hat{\lambda}_3(c)) = \tilde{f}(c),$$

so that for higher values of λ, $f^* = \tilde{f}(c)$ and the seller breaks even without the need for transfers, $T = 0$.

Regarding investment, first notice that when demand is low, $\theta \leq G(\Pi_S^0)$, we have that $q^* = \theta$. When $\theta > G(\Pi_S^0)$, the previous problem implies that investment is socially valuable if

$$E(p) - \Phi(f^*) r_S + \lambda \Pi_S(f^*) - (1+\lambda)c \geq 0.$$

This expression, when feasible (i.e., it is lower than demand, θ), leads to the condition in the text of the Proposition.

To show that $q^* \geq q^c$, notice that when $q^* = \theta$, this is always the case as all demand is satisfied. Therefore, assume that $q^* = G(c^*)$. In that case, we know that

$$c^* = \frac{E(p) - \Phi(f^*) r_S + \lambda \Pi_S(f^*)}{1+\lambda} \geq \frac{E(p) - \Phi(f^c) r_S + \lambda \Pi_S(f^c)}{1+\lambda},$$

since f^* maximizes welfare. In turn,

$$\frac{E(p) - \Phi(f^c) r_S + \lambda \Pi_S(f^c)}{1+\lambda} > \Pi_S(f^c) = c^c,$$

because $E(p) - \Phi(f^c) r_S - \Pi_S(f^c) = \Pi_B(f^c) - \Pi_B^0 > 0$. Hence, in that case $q^* = G(c^*) > G(c^c) = q^c$. $\square$