The Costs of Counterparty Risk in Long-Term Contracts*

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August 18, 2025

Abstract

This paper investigates the implications of counterparty risk - stemming from potential defaults or renegotiations by buyers - on long-term contract markets. It develops a theoretical model highlighting how opportunistic buyer behavior leads to higher contract prices and underinvestment, potentially leading to the collapse of the contract market. The paper also evaluates public-policy interventions, including public subsidies, financial guarantees, regulator-backed contracts, and collateral requirements. While these measures can reduce price-related inefficiencies and promote investment, they involve trade-offs such as moral hazard or the reliance on costly public funds. These findings are particularly relevant for sectors with capital-intensive, long-lived assets exposed to price volatility, especially electricity markets, where underinvestment in renewable energy could delay the energy transition and hinder carbon-abatement goals. Simulations using data for the Spanish electricity market are used to quantify the theoretical predictions of the model.

Keywords: Imperfect Contract Enforcement, Counterparty Risk, Renewable Investments, Bilateral Contracts, Vertical Integration, Dynamic Incentives.
JEL Codes: L13, L94.

*Emails: natalia.fabra@cemfi.es and llobet@cemfi.es. This paper has benefited from comments by Guillermo Caruana, Caio Lorecchio, Massimo Motta, Patrick Rey, Anatoli Segura, and Sugandha Srivastav, as well as seminar audiences, among others, at Universidad Complutense, Universidad Carlos III, Universidad de Alicante, Innsbruck University, Universidad de Málaga, Barcelona School of Economics, the 2024 ULB Energy Workshop, the 2024 CEPR Conference on Climate Change and the Environment, CRESSE 2024, JEI 2024, Hanken School of Economics, ULB, EUI, DG Competition and DG Energy (European Commission), London School of Economics, Northwestern University, the University of Chicago, DTU (Copenhagen), and CEMFI. Sonnur Bas and Michael Duarte provided outstanding research assistance. The first author thanks the support of the European Research Council's Advanced grant ENERGY IN TRANSITION (Grant Agreement 101142583). The second author thanks the support of the Spanish Ministry of Science and Innovation through grant PID2021-128992NB-I00.

1 Introduction

Investment in capital-intensive, long-lived assets often depends on long-term contracts to reduce uncertainty around cost recovery, especially when market conditions over the lifetime of the assets are highly volatile. Imperfect contract enforcement can undermine the liquidity of these contracts, ultimately leading to underinvestment.

This phenomenon has been documented in commodity markets — such as coffee (Macchiavello and Morjaria, 2020), coal (Joskow, 1990), oil (Stroebel and van Benthem, 2013), or flowers (Macchiavello and Morjaria, 2015) — but it is especially relevant in the case of electricity, where underinvestment in renewable capacity could delay the energy transition and hinder carbon-abatement goals. Since renewable energy projects are particularly capital-intensive and long-lived, financing costs are critical in determining their profitability. However, the high volatility of electricity prices — driven by fluctuating supply and demand conditions alongside technological and policy uncertainties (Chen, 2024) — makes these projects particularly risky.[1] Moreover, as widely documented (Bessembinder and Lemmon, 2002; de Maere d'Aertrycke et al., 2017; Willems and Morbee, 2010), electricity markets are inherently incomplete, meaning that market participants cannot fully hedge against all price uncertainties, especially those arising in the distant future during the plants' long lifetimes.[2]

Against this backdrop, energy regulators envision long-term contracts between buyers and sellers as a way to reduce these risks and foster investments in renewable power sources, contributing to the energy transition and reducing the dependency on fossil fuels.[3] As the European Commission stated in its proposal to reform electricity markets, *"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"* (European Commission, 2023). In the same

[1]For instance, the Draghi Report emphasized that *"Energy prices have also become more volatile, increasing the price of hedging and adding uncertainty to investment decisions"* (Draghi, 2024). See Duma and Muñoz-Cabré (2023) for an overview of the risks facing renewable energy developers.

[2]The lack of financial instruments to hedge all electricity price risks is further exacerbated by technological and regulatory uncertainty (Fan et al., 2010).

[3]These issues are even more pronounced in the case of nuclear power plants, where investment costs are significantly higher, and lifetimes can extend up to 60 years. As a result, nearly all nuclear power plants are developed with public subsidies, often involving loans backed by public guarantees and long-term power contracts. See, for example, the European Commission's State Aid decisions on Hinkley Point in the UK, Paks II in Hungary, and Dukovany II in Czechia (European Comission, 2014, 2017, 2024).

spirit, the World Bank has expressed that long-term power contracts are "*central to the private sector participant's ability to raise finance for the project, recover its capital costs and earn a return on equity*" (World Bank, 2024).[4]

While the volume of long-term electricity contracts, usually referred to as Power Purchase Agreements (PPAs), has been growing in recent years, they are still considered insufficient to boost renewable energy investments at the required speed and scale (Polo et al., 2023). As acknowledged by the European Commission, one of the main obstacles for the take-up of these contracts is *"the difficulty to cover the risk of payment default from the buyer in these long-term agreements."*[5] However, beyond this concern, the implications on the performance of long-term contract markets of buyer counterparty risk — stemming from potential defaults or renegotiations by buyers — have not been explored in detail.

This paper builds a framework to analyze the implications of buyer counterparty risk on equilibrium market outcomes. We show that the presence of opportunistic buyers pushes equilibrium contract prices up, which in turn raises the probability of contract default. The resulting decline in contract liquidity — including the possibility of the collapse of the contract market — undermines sellers' ability to leverage investments. We use our framework to evaluate the welfare effects of public policies designed to mitigate buyer counterparty risk in the context of electricity markets. Using data from the Spanish market, our model simulations indicate that, from a welfare perspective, public guarantees and regulator-backed contracts outperform public subsidies. These instruments enable a more efficient allocation of risk between buyers and sellers, leading to lower equilibrium contract prices, a reduced likelihood of default, and greater investment.

In our model, sellers make investment decisions to supply a homogeneous good in a spot market with volatile prices. Sellers incur an extra cost when exposed to volatile prices,[6] driving equilibrium investment below the level that a social planner would choose. The possibility to sign fixed-price contracts with risk-neutral buyers restores the social optimum by insulating sellers from the costs of spot price volatility. However, if contracts are not perfectly enforceable, some buyers may opportunistically default when the spot

[4] See also Gohdes et al. (2022) and Dukan and Kitzing (2023).

[5] In the context of electricity markets, buyer counterparty risk and not seller counterparty risk is the main concern given that the renewable energy deployment is expected to depress future spot prices.

[6] As it will be made explicit later, this extra cost could be due to seller risk aversion or higher cost of capital when lenders face a state-verification problem *à la* Gale and Hellwig (1985).

price falls below the contract price.[7] In this case, contracts provide only partial insurance against price volatility, and the first-best outcome is no longer attainable.

More specifically, the presence of opportunistic buyers introduces two sources of distortion. First, to compensate for the default risk, the equilibrium price of long-term contracts increases. In turn, this raises the probability of default for all contracts — not just the marginal ones — as it makes spot trading relatively more attractive. Although higher contract prices compensate sellers for default risk, there is a limit to how much they can rise. In particular, prices cannot exceed the expected spot market price — otherwise, only opportunistic buyers would be willing to contract, leading to adverse selection à la Stiglitz and Weiss (1981). This creates a second distortion: investment is limited to projects that remain profitable when contracts are priced at the expected spot price. As buyer counterparty risk increases default costs, fewer sellers are willing to invest, potentially leaving contract demand unmet, resulting in inefficient contract rationing.

Paradoxically, buyers are disproportionately harmed by buyer counterparty risk, even opportunistic ones. Individually, they benefit from defaulting when spot prices fall below contract prices. But collectively, this behavior drives up equilibrium contract prices and reduces investment, often leaving them worse off. Notably, the pass-through of the default risk into contract prices might insulate sellers from the cost of buyer counterparty risk.

The introduction of collateral requirements, while a natural remedy to counterparty risk, introduces an additional trade-off: the cost of collateral reduces contract demand and, consequently, limits investment opportunities. As a result, setting collateral requirements high enough to eliminate default is often inefficient. Instead, optimal collateral levels should balance the seller's expected default cost against the buyer's cost of posting collateral.

Our analysis suggests that public policies addressing buyer counterparty risk can yield welfare gains. Several such measures have already been proposed in regulatory debates or implemented in electricity markets in Europe and the United States, including public subsidies, financial guarantees, and regulator-backed contracts.[8] We analyze their impli-

[7]In our baseline model, we normalize the cost of contract default to zero. In Section 4, we show that the model's main results continue to hold if we introduce collateral that is forfeited upon default, provided its value is not too high.

[8]In Europe, these contracts are commonly referred to as Contracts-for-Differences (CfDs). In the United States, contracts signed by public utilities may serve a similar role, as they can pass on contract

cations theoretically and, motivated by the recent boom in renewable energy investment in Spain, we also provide an empirical assessment using detailed cost data from renewable projects that began operating in 2022. We perform counterfactual analyses to quantify the impacts on prices, investment, and welfare under scenarios in which all projects had competed for long-term contracts, both with and without public-policy support.

Our simulations reveal that long-term power contracts significantly boost investment, generating welfare gains of approximately €0.7 million per MW per year, provided counterparty risk remains moderate. Notably, public guarantees outperform output subsidies in stimulating investment, as they are more effective in reducing contract prices. This, in turn, lowers the probability of default and reduces the expected cost of guarantees. Consequently, when public spending is held constant, the welfare generated by public guarantees exceeds that of public subsidies by 45% when half of the buyers are opportunistic and demand is high. This welfare gap narrows with fewer opportunistic buyers or lower demand for contracts.

When the regulator backs the same volume of contracts as would be covered by public guarantees, the resulting welfare gains are unambiguously larger. Regulator-backed contracts eliminate default risk without incurring a fiscal cost and further promote efficient investment by expanding demand for long-term contracts. However, this demand expansion leads to higher contract prices, which may adversely affect buyers. In our simulations, total welfare gains relative to a no-intervention benchmark remain positive but decline from 198% to 135% as the share of opportunistic buyers increases from zero to one-half. In contrast, buyer-specific gains decline more sharply — from 137% to 69% — underscoring that, from buyers' perspective, the rise in contract prices can outweigh the benefits of increased demand.

We have intentionally kept our setup simple to highlight the main mechanisms, but the implications of our analysis are robust to alternative specifications. Our model incorporates a cost to sellers when exposed to volatile prices by introducing a generic premium that is increasing in the probability of contract default, consistent with (but not limited to) mean-variance preferences. This parametrization simplifies the analysis while remaining equivalent to a framework where sellers have a concave utility function, as we show

costs to final consumers without enforcement issues. Because the regulator acts as the counterparty, these contracts are effectively risk-free and promote more efficient investment by expanding demand (Beiter et al., 2024).

in Section 6.

Although we focus on contract default as the manifestation of buyer opportunism, the results are more general. Our model can be easily reinterpreted to accommodate buyer renegotiation after investment has taken place. This concern is relevant in the case of renewable plants, as with nearly zero variable costs, assets retain a positive market value once investment is sunk, making owners more likely to accept lower renegotiated prices if later on buyers have access to cheaper alternatives.[9] In addition, energy intensive users (or electricity retailers) are particularly interested in signing long-term contracts to reduce their price exposure. But, at the same time, they are most vulnerable to the competitive pressure exerted by rivals who could secure lower prices in the future, limiting their ability to honor contracts. Unlike in other contexts (Klein et al., 1978; Baker et al., 2002), this feature implies that vertical integration does not address the exposure to volatile spot prices in the presence of downstream competition and becomes less effective as a hedge against future price reductions.

We also show that enhancing buyers' incentives to enter long-term contracts — by introducing a positive premium for buyers — helps in aligning the incentives of both parties, thus reducing the costs associated with counterparty risk. Finally, incorporating dynamics, such as time-varying spot prices, enriches the model's predictions by uncovering the evolution of default probabilities while maintaining its main qualitative insights. In particular, the analysis demonstrates that dynamic incentives can help induce trade in the contract market, even when the share of opportunistic buyers is large.

Related Literature This paper contributes to the literature on contracting with imperfect enforcement. Our research is grounded on the classical theory of the firm (e.g., Baker et al. (2002), Hart (1995, 2009) and Klein (1996)). In recent years, the effects of imperfect enforcement have been empirically documented in various commodity markets as our initial examples indicated. Guiso et al. (2013) examine strategic default in mortgage markets when owners have negative equity. Blouin and Macchiavello (2019) analyze bilateral negotiations in coffee markets where sellers may strategically default on con-

[9] There is abundant anecdotal evidence of renegotiation of these contracts. For instance, during a panel on power contract renegotiation, when asked,"*Have you had to renegotiate any Power Purchase Agreements (PPAs)?*" an expert replied, "*Yes, several. We are currently renegotiating the timelines and pricing in several of them. It has been an opportunity to increase value for the customer*" (Gamache, 2022).

tracts if market prices rise, even at the risk of damaging the relational contract with the buyer. Antràs and Foley (2015) explore default in trade relationships between exporters and importers. A key difference with the existing literature on imperfect contract enforcement is that we characterize the probability of contract default as an endogenous outcome determined in equilibrium, often making counterparty risk a self-defeating phenomenon for opportunistic buyers.

Long-term bilateral contracts have also been studied in the context of electricity markets, particularly in developing countries where governments often guarantee a wholesale price. In a study of solar auctions in India, Ryan (2024) identifies the impact of counterparty risk by comparing auctions where state governments with low credit scores purchase energy with or without the intermediation of the more reliable central government. His findings indicate that the counterparty risk associated with an average Indian state increases prices by 10% and significantly reduces investment.[10] Hara (2024) provides evidence on renewable investors' risk aversion in Brazilian wind-energy actions. More recently, Chen (2024) empirically studies the market for bilateral power contracts in the US, with a focus on how regulatory uncertainty delays investment through these contracts. Our work provides a theoretical framework consistent with these empirical findings. While our focus is on long-term contracts between private parties, we also relate to this body of work by examining the design of regulator-backed contracts in contexts where regulators can act as a safer alternative.

The remainder of the paper is organized as follows. In Section 2, we present the model. In Section 3, we characterize the contract-market equilibrium and assess its welfare properties. In Section 4, we introduce costly collateral, which serves to endogenize demand in the contract market, and assess its equilibrium consequences. In Section 5, we analyze several market interventions, including initiatives to promote contract demand, regulator-backed contracts, public subsidies, and public guarantees. In Section 6, we analyze the robustness of the model and explore several extensions. Using data from the Spanish electricity market, Section 7 simulates the effects of long-term contracts with and without supporting public policies through the lenses of our model. Section 8 concludes. Proofs are included in Appendix A.

[10]See also Dobermann et al. (2024), who argue that long-term contracts for coal plants established by the government of Pakistan have delayed the adoption of cleaner and cheaper alternatives. However, this argument does not apply to renewable energy contracts, as these are carbon-free and have near-zero marginal costs, making their utilization always efficient once the investments are sunk.

2 Model Description

Consider a market for a homogeneous product. On the demand side, there is a unit mass of buyers with a maximum willingness to pay of $v \geq 1$ for one unit of the good. On the supply side, there is a unit mass of (entrant) sellers that can build one unit of capacity at a fixed cost c. This unit of capacity allows the production of one unit of the good at a marginal cost normalized to zero. Entrants differ in their investment costs, which are independently drawn from a distribution function $G(c)$ with a positive density $g(c)$ in the interval $[0, 1]$.

Without entry, there is already enough preexisting capacity to meet total demand. The marginal cost of this capacity is denoted by p, distributed according to $\Phi(p)$, with a positive and differentiable density $\phi(p)$ over the interval $[0, 1]$. As a result, entry yields production savings equal to the expected marginal cost of the existing capacity displaced, $E(p)$, minus the entrants' investment cost.[11]

The timing of the game is as follows. First, at the investment stage, sellers decide whether to enter after observing their investment cost c but before knowing the realization of the marginal cost of the preexisting capacity, p. Second, at the production stage, once p is observed, buyers and sellers trade the good in a perfectly competitive spot market, where the equilibrium market price is given by p.[12] Since entrants have zero marginal cost, they produce at full capacity, earning expected spot market revenues $E(p)$.

For sellers, exposure to volatile spot-market prices creates uncertainty over cost recovery, originating an extra cost $r \in [0, E(p)]$. This can be interpreted as a higher cost of capital, microfounded in a setting with asymmetric information between the seller and its lender *à la* Gale and Hellwig (1985).[13] Alternatively, it might capture a risk premium when sellers have mean-variance preferences, in the spirit of Laffont and Tirole (1986) (section VI). In this case, $r = r_0 Var(p)$, with $r_0 \leq \frac{E(p)}{Var(p)}$. In contrast, buyers do not

[11] Positive or negative externalities derived from investment could be easily accommodated as an additive effect to the cost savings.

[12] We implicitly assume that the scale of entry is small enough. If the scale of entry covered total demand, prices would drop to the entrants' marginal costs, making investment unprofitable. Hence, in equilibrium, entry at such scale would not be observed.

[13] In their model of borrowing and lending, the optimal contract takes the form of standard debt: the seller commits to repaying a fixed amount, and in case of default, the lender incurs a costly verification of the seller's income to ensure incentive compatibility. In perfectly competitive capital markets, this verification cost is fully passed on to the seller, raising the cost of capital. As we explain later, this distress cost is absent under perfectly enforceable fixed-price contracts between buyer and seller, which effectively imply perfect observability of the seller's income.

incur in any investment and are assumed to be risk-neutral.

The expected profits of buyers (B) and sellers (S) at the investment stage can be formulated as

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

Therefore, profitable entry requires that the expected spot-market revenue, $E(p)$, covers the seller's investment cost and premium r, $c \leq c^0 \equiv E(p) - r$, so investment in equilibrium is $q^0 \equiv G(c_0)$.

If sellers were isolated from uncertain spot prices, they would invest until the marginal cost savings equaled the investment cost, $c \leq c^{FB} \equiv E(p)$, or $q^{FB} \equiv G(c^{FB})$. Hence, due to sellers' extra cost $r > 0$, the market solution is characterized by underinvestment relative to the First Best. In the next section, we analyze how fixed-price contracts, by reducing price volatility, could help reduce this inefficiency.

3 Fixed-price Contracts

Suppose that buyers and sellers are allowed to sign a fixed-price contract prior to investment, enabling them to hedge their spot-market transactions. However, only a proportion $\theta \in (q^0, 1]$ of buyers participate in the contract market,[14] with the rest always procuring the good in the spot market. The contract requires the seller to compensate the buyer for the difference between the spot price p and the contract price, denoted by f, if $p > f$, and vice versa if $f > p$.

When the spot market price p falls below the fixed price f, a proportion $\gamma \in [0, 1]$ of buyers default on the contract, introducing counterparty risk. We refer to these buyers as opportunistic (O), in contrast to the proportion $1 - \gamma$ of buyers who are trustworthy (T) and always honor the contract. Buyer profits, given by

$$\Pi_B^T(f) = v - f,$$
$$\Pi_B^O(f) = v - \int_0^f p\phi(p)\,dp - f\,(1 - \Phi(f))\,,$$

are always decreasing in the contract price f.

Sellers do not observe the buyers' trustworthiness when signing contracts but hold correct expectations regarding the probability of a buyer being opportunistic, denoted as

[14] In Section 4, we endogenize the participation rate θ by introducing (costly) collateral requirement.

z. Seller profits from signing the contract are

$$\Pi_S(f,z,c) = z\int_0^f p\phi(p)dp + f\left[1-\Phi(f)z\right] - R(f,z) - c. \tag{1}$$

Sellers receive the contract price f when buyers are trustworthy or when the realized spot price is above f, i.e., with probability $1-\Phi(f)z$. Otherwise, they receive the realized spot price p.[15] Additionally, they incur a premium $R(f,z)$ because of the possibility of contract default, which is a function of the contract price f and the probability of facing an opportunistic buyer, z. We place the following assumptions on $R(f,z)$:

Assumption 1. *The function $R(f,z)$ is continuously differentiable with $\frac{\partial R}{\partial f} \in [0, 1-z\Phi(f)]$, $R(0,z) = R(f,0) = 0$, and $R(1,1) = r$.*

Under the interpretation of r as arising from financial frictions, this assumption reflects the idea that an increase in f raises the probability of contract default by opportunistic buyers, thereby increasing the likelihood that the lender must incur in costly income verification. Alternatively, this assumption is also consistent with managers having mean-variance preferences, as captured in the following example.[16]

Example 1. *Suppose that managers have mean-variance preferences:*

$$U_S(x) = E(x) - r_0 Var(x),$$

where x is a random variable representing seller payoffs. In the spot market, x is distributed according to $\Phi(x)$. Under a fixed-price contract, x is a mixture of two distributions. With probability $1-z$, x is degenerate at f, whereas with probability z the seller receives a random return $\tilde{p}$, distributed as the minimum of p and f. Letting $r \equiv r_0 Var(p)$, the risk premium is

$$R(f,z) = r\frac{Var(x)}{Var(p)} = rz\frac{Var(\tilde{p}) + (1-z)(f-E(\tilde{p}))^2}{Var(p)}.$$

It satisfies $R(0,z) = R(f,0) = 0$ and $R(1,1) = r$. Furthermore, a necessary and sufficient condition for $\frac{\partial R}{\partial f} \in [0, 1-z\Phi(f)]$ is that

$$r \leq \frac{1}{2z}\frac{Var(p)}{1-E(p)}.$$

It follows that the mean-variance framework satisfies Assumption 1 if r is sufficiently low.

[15] Analytically, this profit function would seem to correspond to that of sellers subject to a call option with a z fraction of buyers. Crucially, however, note that the contract price f will be mispriced given that sellers have asymmetric information about whether buyers are opportunistic.

[16] More generally, in Section 6, we show that our assumption on the premium is also consistent with sellers having standard concave utility functions.

The assumption that $R(f,z)$ increases in f captures the fact that higher fixed prices increase the probability of contract default and, thus, the degree of spot-market exposure. The other assumptions imply that r is low enough so that the direct effect on profits from increasing f outweighs the costs of the corresponding increase in the premium.

As it is natural, we also assume that seller profits are decreasing in the proportion of opportunistic buyers.[17]

Assumption 2. *Seller profits,* $\Pi_S(f,z,c)$*, are decreasing in* z*.*

To characterize the equilibrium, we build on the following two results, which provide an upper and lower bound on equilibrium prices.

First, note that the probability that a seller faces an opportunistic buyer, z, depends on the contract price. Since a fixed-price contract must provide higher profits than the spot market, trustworthy buyers only sign contracts if $f \leq E(p)$. In contrast, opportunistic buyers are willing to sign contracts at any price $f \leq 1$ since they default if the spot price falls below the contract price.[18] Hence, for contract prices $f > E(p)$, in equilibrium $z^* = 1$. Likewise, assuming that all buyers are rationed symmetrically, for contract prices $f \leq E(p)$, in equilibrium $z^* = \gamma$.

Second, note that sellers benefit from fixed-price contracts by reducing the premium but, in return, they forgo the potential gains from spot prices exceeding the contract price. Hence, contract prices must be above a threshold $\underline{f}(\gamma)$ at which sellers are indifferent between signing the contract or directly trading in the spot market, i.e.,

$$\Pi_S(\underline{f},\gamma,c) = \Pi_S^0(c). \tag{2}$$

Since the profits that sellers obtain from the contract are lower the more opportunistic buyers there are, $\underline{f}(\gamma)$ is increasing in γ. Hence, $\underline{f}(\gamma)$ is greater than or equal to $E(p) - r$, which is the minimum contract price sellers are willing to accept in the absence of opportunistic buyers, $\gamma = 0$.

These two results have important implications for the equilibrium characterization, as shown next.

[17] As it is shown in Appendix A, this assumption is also satisfied by the mean-variance framework under the condition on r characterized in the previous example.

[18] Note that if $\gamma > 0$, the profits of a seller with investment cost c are strictly below $E(p) - c$. This gap will be important for the welfare analysis, as it implies that the presence of opportunistic buyers prevents sellers from fully capturing the social value generated by their investment.

Lemma 1. *In equilibrium,* $f^* \in [\underline{f}(\gamma), E(p)]$.

Adverse selection implies that $f^* \leq E(p)$. Setting prices above $E(p)$ would only attract opportunistic buyers, in which case (by Assumption 1) profits would be maximized at $f = 1$. At that price, however, sellers would be fully exposed to the spot market price, as default would occur with probability one. Since $R(1,1) = r$, seller profits would be the same as in the no-contract case for $f = 1$ and strictly lower for $f \in (E(p), 1)$. Hence, contract prices $f > E(p)$ will not be observed in equilibrium.

For contracting to be feasible, the minimum price sellers are willing to accept must not exceed the maximum price that trustworthy buyers are willing to pay. As the next result summarizes, the market for fixed-price contracts collapses if the share of opportunistic buyers is too large.

Corollary 1. *Let* $\overline{\gamma} \in (0,1)$ *be implicitly defined by* $\underline{f}(\overline{\gamma}) = E(p)$. *The contract market is active if and only if* $\gamma \leq \overline{\gamma}$.

When the contract market is active, the equilibrium price is determined by the intersection between the demand and supply for contracts. As already argued, contract demand is θ for prices $f \leq E(p)$, whereas it is $\gamma\theta$ for prices above $E(p)$.

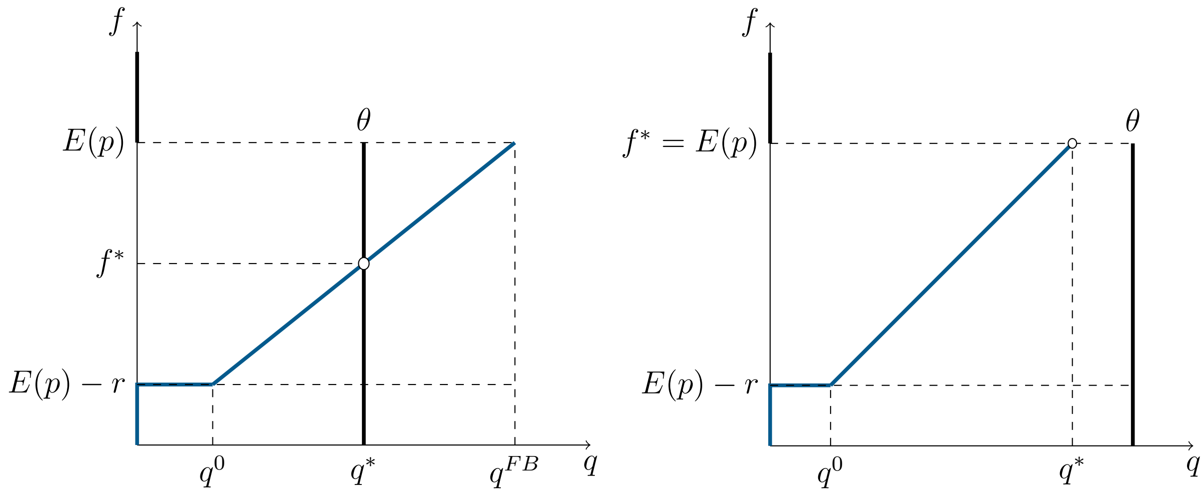
The supply of contracts can be constructed by considering three regions as a function of the investment cost. First, if $c \leq E(p) - r$, then $\Pi_S^0(c) \geq 0$, i.e., the seller invests regardless of whether a contract is signed or not. In that case, the contract is accepted by the seller as long as it is at least as profitable as the spot market, i.e., if $f \geq \underline{f}(\gamma)$.

Otherwise, sellers invest only if the contract price allows for the recovery of the investment cost, which requires signing a contract at or above the investors' break-even price $\tilde{f}(\gamma, c)$, implicitly defined by

$$\Pi_S(\tilde{f}, \gamma, c) = 0. \tag{3}$$

Finally, entry does not occur for values of c for which the seller cannot break even at the profit-maximizing price, $\Pi_S(E(p), \gamma, c) < 0$. We use $\bar{q}(\gamma)$ to denote the mass of sellers that can break even at the highest possible price, $f = E(p)$. This quantity is decreasing in γ as seller profits decrease with the proportion of opportunistic buyers.

To fix ideas, let us start by supposing that contracts are perfectly enforceable so that opportunistic buyers never default. In this case, the supply of contracts is given by the



(a) The no-rationing case **(b)** The efficient demand-rationing case

Figure 1: The contract market equilibrium under perfect contract enforceability.

Notes: In panel (a), the market clears at f^*, which is given by the cost of the marginal investor c^*. In panel (b), the equilibrium price is given by the highest price buyers are willing to pay, $E(p)$. There is demand rationing, but it is efficient since the contribution to welfare of the marginal investor, $c^* = E(p)$, is zero. In this and all subsequent figures, $G(c)$ is assumed to be $U[0, 1]$.

mass of entrants who break even at each contract price, $G(f)$, for $f \in [E(p) - r, E(p)]$, and zero otherwise.

Two cases must be considered. First, when contract demand is low, i.e., $\theta \leq G(E(p))$, there is market clearing at a quantity $q^* = \theta$ and price $f^* = G^{-1}(\theta)$ (Figure 1a). Contracts make both buyers and sellers better off, enabling investments that would not have occurred otherwise. Relative to the First Best, the only inefficiency stems from contract demand being inefficiently low, preventing some cost-saving investments from being made. Letting W^{FB} and $W^*(\gamma)$ measure welfare under the First Best and with fixed-price contracts and perfect enforcement (equivalent to the case with no opportunistic buyers, $\gamma = 0$), respectively, we have

$$W^{FB} - W^*(0) = \int_{G^{-1}(\theta)}^{E(p)} (E(p) - c)\, g(c)\, dc > 0. \tag{4}$$

Hence, an increase in contract demand θ up to $G(E(p))$ would increase social welfare.

Second, when demand is high, $\theta > G(E(p))$, there is rationing as only part of the contract demand, $q^* = G(E(p))$, is satisfied at the highest possible equilibrium price, $f^* = E(p)$ (Figure 1b). Importantly, rationing is efficient in this case as further investment would involve a cost c exceeding the marginal cost savings, $E(p)$. Since the contract solution achieves the First Best, $W^*(0) = W^{FB}$.

Our first proposition summarizes the equilibrium characterization under perfect contract enforceability, which serves as a benchmark to assess the impact of counterparty risk.

Proposition 1. *Under perfect contract enforceability, fixed-price contracts eliminate sellers' risk premia, leading to market clearing with* $q^* = \theta$ *at* $f^* = G^{-1}(\theta)$ *if* $\theta \leq G(E(p))$, *and to demand rationing with* $q^* = G(E(p)) < \theta$ *at* $f^* = E(p)$, *otherwise. Underinvestment arises in equilibrium if* $\theta < G(E(p))$. *Otherwise, investment is efficient, with* $c^* = c^{FB} = E(p)$.

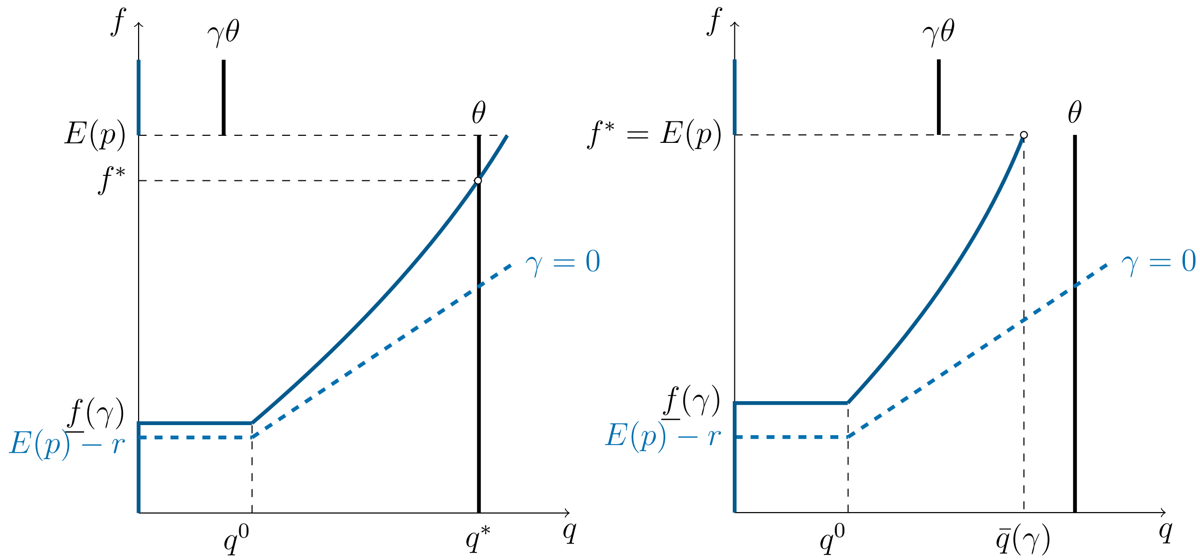
We next analyze the consequences of imperfect contract enforceability. Throughout the rest of the paper, we will focus on the case where demand is not rationed under perfect contract enforceability. This ensures that, whenever demand rationing occurs, it is only due to counterparty risk.

Assumption 3. *Let* $\theta \leq G(E(p))$.

Figure 2 depicts contract supply under imperfect enforceability. Consistent with the properties of the seller's profit function, contract supply is weakly increasing in the contract price f and shifts inward as γ increases. In Figure 2a, γ is low enough so that $\theta \leq \bar{q}(\gamma)$, allowing for market clearing, $q^* = G(c^*) = \theta$, at a contract price $\tilde{f}(\gamma, c^*)$, defined by the entrant's break-even condition (3). When γ is sufficiently high, the inward shift of the supply function gives rise to inefficient demand rationing even at the highest feasible price, $f^* = E(p)$ and the equilibrium quantity is $q^* = G(c^*) = \bar{q}(\gamma) < \theta$. This case is illustrated in Figure 2b.

Our second proposition summarizes the equilibrium characterization under imperfect contract enforceability, when the share of opportunistic buyers is small enough so that the market does not collapse (Corollary 1).

Proposition 2. *When* $\gamma \in (0, \overline{\gamma}]$, *relative to the no-contract case, fixed-price contracts reduce sellers' risk premia and mitigate underinvestment. There exists a threshold* $\hat{\gamma} \in (0, \overline{\gamma}]$ *such that when* $\gamma < \hat{\gamma}$, *the market clears at* $q^* = \theta$ *and equilibrium prices are higher than in the absence of counterparty risk,* $f^* = \tilde{f}(\gamma, c^*) > G^{-1}(\theta)$. *Otherwise, when* $\gamma \in (\hat{\gamma}, \overline{\gamma}]$, *counterparty risk gives rise to inefficient demand rationing,* $q^* = \overline{q}(\gamma) < \theta$, *and higher prices,* $f^* = E(p)$.



(a) The no-rationing case **(b)** The inefficient demand-rationing case

Figure 2: The contract market equilibrium under imperfect contract enforceability.

Notes: In panel (a), $\gamma < \hat{\gamma}$ so the equilibrium price is given by the break-even price of the marginal investor, with investment cost c^*. In subfigure (b), $\gamma > \hat{\gamma}$, which shifts the supply curve inwards. This implies that demand θ is now above the mass of sellers $\bar{q}(\gamma)$ that can break even at that price. Demand rationing leads to inefficient investment, with $\bar{c}(\gamma) < E(p)$. The dashed line represents the supply curve with perfect contract enforcement.

Using these results, we now turn to the welfare analysis.

3.1 Welfare Analysis under Imperfect Contract Enforceability

We first compare the welfare contribution of fixed-price contracts relative to the no-contract case. If $\gamma > \overline{\gamma}$, the contract market collapses, so welfare is the same in the two cases. Otherwise, if the share of opportunistic buyers is small enough, the contribution of contracts to social welfare relative to the no-contracts case is

$$W^*(\gamma) - W^*(1) = (r - R(f^*, \gamma))G(E(p) - r) + \int_{E(p)-r}^{c^*} \left[E(p) - R(f^*, \gamma) - c\right] g(c)\, dc > 0, \tag{5}$$

where $W^*(1)$ measures social welfare when all buyers are opportunistic and, therefore, only the spot market exists. The first term shows that all sellers that would invest even without contracts (those with $c \leq E(p) - r$) are better off with contracts thanks to the reduced price exposure. The second term measures the social welfare contribution of additional entry, $E(p) - c$, net of the losses due to counterparty risk. Since these two terms are positive, fixed-price contracts contribute positively to welfare.

Second, we assess the welfare losses arising from imperfect contract enforceability. This welfare difference can be written as

$$W^*(0) - W^*(\gamma) = R(f^*, \gamma)G(c^*) + \int_{c^*}^{G^{-1}(\theta)} (E(p) - c)\, g\,(c)\, dc. \tag{6}$$

The first term in (6) represents the welfare reduction caused by counterparty risk, $R(f^*, \gamma)$. This welfare cost rises with γ, both directly and indirectly through an increase in f^* and, hence, the higher premium. Notably, although f^* is determined by the marginal entrant with investment cost c^*, counterparty risk affects the mass of investors, $G(c^*)$, including inframarginal ones. This distortion does not arise when all buyers are trustworthy, as contract prices affect only the division of surplus between buyers and sellers without directly impacting efficiency. The second term in (6) captures the distortion caused by underinvestment.

The next result shows how the burden due to counterparty risk is split between buyers and sellers.

Proposition 3. *Assume* $\gamma > 0$.

(i) Sellers obtain the same profits compared to the case with perfect contract enforceability if and only if the market clears, i.e., if $\gamma \in (0, \hat{\gamma}]$. *Otherwise, they are strictly worse off.*

(ii) Imperfect contract enforceability always makes trustworthy buyers worse off. There exists $\gamma_O \in (\hat{\gamma}, \overline{\gamma})$ *such that opportunistic buyers are also worse off if and only if* $\gamma > \gamma_O$.

Imperfect contract enforceability always makes trustworthy buyers worse off, as it leads to higher contract prices and (possibly) lower investment. The effect on sellers and opportunistic buyers depends on their fraction γ.

Consider first the impact of counterparty risk on sellers when there are few opportunistic buyers, i.e., $\gamma \in (0, \hat{\gamma}]$. Since the market always clears, the second term in the welfare comparison (6) vanishes. A seller with cost c makes the same profits in equilibrium regardless of whether the contract is perfectly enforced or not,

$$\Pi_S(f^*, \gamma, c) = G^{-1}(\theta) - c.$$

The reason is that, with inelastic demand, investment is constant, and sellers fully pass on the cost of counterparty risk to buyers. Indeed, buyers, as a group, suffer the full welfare loss, $R(f^*, \gamma)$. However, opportunistic buyers may be better off, as they face a higher contract price but have the option to default if spot prices turn out to be lower. Thus, trustworthy buyers bear a proportionally larger share of the welfare loss, as opportunistic buyers impose a negative externality on them.

With a higher share of opportunistic buyers, counterparty risk also affects equilibrium investment, as captured in the second term of (6). This makes sellers worse off, as they cannot fully capture the gains from their investment.

In turn, when γ is high, opportunistic buyers face an additional negative effect, as with demand rationing they are less likely to secure a contract. If they are rationed, they must buy in the spot market at expected prices $E(p)$ without benefiting from the possibility of contract default. Indeed, when γ approaches the threshold $\overline{\gamma}$ beyond which the contract market collapses, opportunistic buyers are harmed by counterparty risk. Since the profits of opportunistic buyers decrease when they become more prevalent, there exists a threshold $\gamma_O \in (0, \overline{\gamma})$ such that, for higher values of γ, even opportunistic buyers prefer perfect contract enforceability.

This result highlights the importance of the equilibrium effects of counterparty risk. When the proportion of opportunistic buyers is large, counterparty risk exposes them to a prisoner's dilemma. While individually, they prefer to default on the contract when spot market prices are low, in equilibrium they are harmed by the reduction in investment and the ensuing price increase.

In sum, our model uncovers the effects of counterparty risk as a market failure, leading to high contract prices, excessive risks, and underinvestment. It stands to reason that measures aimed at reducing counterparty risk should increase contract liquidity and reduce underinvestment. We now turn to the study of this issue.

4 Pledging Collateral

Our previous analysis assumed that opportunistic buyers could default without penalty. While this simplification was useful, contracts typically include provisions that penalize parties who breach their obligations. In particular, buyers must pledge collateral $k > 0$, which is forfeited and transferred to the seller in cases of default.

It is straightforward to see that a sufficiently large collateral completely eliminates counterparty risk. However, such a collateral level is uncommon in practice due to the financial burden it imposes on the buyer. To explicitly account for this friction, we now assume that collateral is onerous, with a per-unit cost, ρ, which is heterogeneously distributed among buyers, with $\rho \in U[0,1]$. Different values of ρ might reflect heterogeneity in the buyers' cost of financing the collateral, which in turn could capture differences in the buyers' trustworthiness.[19]

To abstract from other dimensions of demand heterogeneity, in this section we assume that all buyers are opportunistic, $\gamma = 1$, and, for this reason, we drop the buyer subscript. Note that in the absence of collateral, by Corollary 1, the contract market would collapse. We also replace Assumption 3 by setting $\theta = 1$, so that market participation is endogenously determined by the cost of the collateral.

The value of the collateral affects the profits of buyers and sellers', thus changing their optimal decisions. If the value of the collateral exceeds the contract price, $k \geq f$, buyers never find it optimal to default. Hence, the utility of buyers and sellers simplifies in this case to

$$\Pi_B(f, k; , rho) = v - f - \rho k,$$
$$\Pi_S(f, k, c) = f - c.$$

For lower collateral levels, $k < f$, buyers still find it optimal to default when $p < f - k$. In that case, expected profits become

$$\Pi_B(f, k, \rho) = v - f\,(1 - \Phi(f-k)) - \int_0^{f-k} (p+k)\phi(p)\,dp - \rho k, \tag{7}$$
$$\Pi_S(f, k, c) = f\,(1 - \Phi(f-k)) + \int_0^{f-k} (p+k)\phi(p)\,dp - R(f-k, 1) - c. \tag{8}$$

Note that the premium is now a function of $f - k$ as it determines the probability of default.

The level of collateral affects the range of prices at which buyers and sellers are willing to trade. Consider sellers first. Since their profits increase with k, participation in the contract becomes more profitable the more collateral has been pledged. As a result, the new minimum price a seller is willing to accept is $\underline{f}(k)$, which, with some abuse of notation, is now denoted as a decreasing function of k. Additionally, by Assumption 1, seller profits are increasing in f and k. More collateral shifts the supply curve outward.

[19]For instance, in electricity markets, the main determinants of this heterogeneity are firm size and firm leverage. The cost of pledging collateral is much smaller for large technological companies and large utilities compared to small buyers.

This stands in contrast with the effect of a collateral on buyers. Their participation constraint when $k \geq f$ is now given by

$$\Pi_B(f, k, \rho) - \Pi_B^0 = E(p) - f - \rho k \geq 0, \tag{9}$$

whereas when $k < f$, buyers participate if

$$\Pi_B(f, k, \rho) - \Pi_B^0 = \int_{f-k}^{1} (p - f)\phi(p)\, dp - k\Phi(f - k) - \rho k \geq 0. \tag{10}$$

This means that opportunistic buyers no longer accept contracts regardless of their price, and the maximum price they are willing to pay, denoted as $\bar{f}(k, \rho)$, is decreasing in the collateral requirement k and its cost ρ.

These results are summarized next.

Lemma 2. *Under imperfect enforceability and with collateral $k > 0$,*

(i) The lowest contract price a seller is willing to accept, $\underline{f}(k)$, decreases with k.

(ii) The highest contract price a buyer with collateral cost ρ is willing to accept, $\bar{f}(k, \rho)$, decreases in k and ρ, ranging from $E(p) - \rho$ for $k = 1$ to 1 for $k = 0$.

The heterogeneity of ρ between 0 and 1 implies that there is always some scope for trade. Without collateral and all buyers being opportunistic, sellers would always obtain lower profits in the contract market compared to the spot market. With $k > 0$ a price $\bar{f}(k, 0)$ makes a buyer with no collateral cost indifferent between signing the contract and participating in the spot market. At this price, the contract market yields a higher social value than the spot market as it reduces the premium from r to $R(\bar{f}(k, 0) - k, 1)$. This welfare gain always accrues to the seller at the price $\bar{f}(k, 0)$. Since seller profits are increasing in f the buyer is willing to accept some $f < \bar{f}(k, 0)$.

The demand curve for contracts with collateral k and a fixed-price f is composed of the mass of buyers with $\rho \leq \hat{\rho}(f, k)$, a threshold implicitly defined by (9) and (10). Since collateral costs are uniformly distributed, the demand for fixed-price contracts is also $\hat{\rho}(f, k)$. Using previous arguments, demand for contracts is decreasing in f and k. Even though we have assumed full access to the contract market for all buyers, i.e., $\theta = 1$, the variation in collateral costs, ρ, results in endogenous market participation.

When the required k is low, the cost of collateral does not reduce demand or expand supply significantly. In contrast, a sufficiently large k gives rise to market clearing at the intersection between demand and supply,

$$\hat{\rho}(f^*(k), k) = G(c^*), \tag{11}$$

where, as before, c^* is related to $f^*(k)$ through the zero-profit condition $\Pi_S(f^*, k, c^*) = 0$. This solution is depicted in Figure 3.

Since a higher k shifts the supply curve out and the demand curve in, the equilibrium contract price is decreasing in k. Hence, starting from an equilibrium with high $f^*(k)$ and low k such that $f^*(k) > k$, an increase in k reduces $f^*(k)$ up to a threshold $\hat{k}$, at which point the probability of default becomes zero. Further increases in k lead to $f^*(k) < k$, maintaining a zero probability of default.

Lemma 3. *There exists a unique $\hat{k}$ for which $f^*(\hat{k}) = \hat{k}$, so that $\Phi(f^*(k) - k) = 0$ if and only if $k \geq \hat{k}$. If $r \leq E(p) - \hat{k}$, eliminating counterparty risk is not feasible.*

Hence, setting $k = \hat{k}$ is sufficient to fully eliminate the probability of default but only when r is not too small. Intuitively, asking for a high collateral reduces the demand for contracts, pushing contract prices down. Since $\hat{k}$ does not depend on r when this is low enough, the candidate equilibrium contract price would fall below the minimum price that makes sellers indifferent between hedging through contracts or selling their output in the spot market, $\underline{f}(k)$. In such a case, and as shown in the proposition below, even if setting $k = \hat{k}$ were feasible, sellers would be better off with lower collateral requirements and a higher price.

From a social-welfare perspective, while setting $k > \hat{k}$ is certainly dominated, $k = \hat{k}$ may not be optimal either. The net welfare effect of increasing collateral depends on the balance between the costs of counterparty risk and of the collateral itself. When the premium does not increase much with the probability of default, the social cost of counterparty risk is relatively small compared to the social cost of collateral. In that case, it is welfare enhancing to allow in equilibrium for a positive probability of default.

Proposition 4. *Under imperfect enforceability and with collateral $k > 0$:*

(i) There exists a unique r_S^0 such that seller profits are higher at some $k < \hat{k}$ than at $k = \hat{k}$ if and only if $\frac{\partial R}{\partial f}(0, 1) < r_S^0$.

(ii) There exists a unique $r_W^0 < r_S^0$ such that social welfare is higher at some $k < \hat{k}$ than at $k = \hat{k}$ if and only if $\frac{\partial R}{\partial f}(0, 1) < r_W^0$.

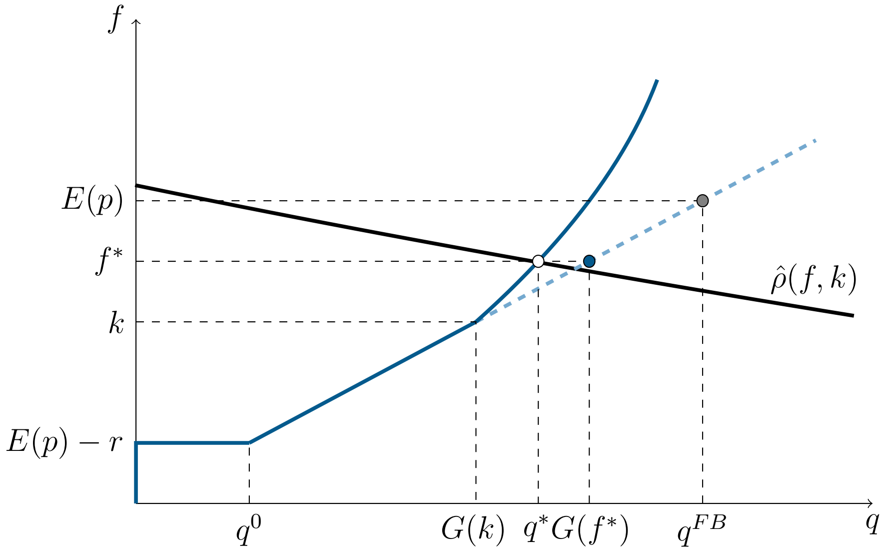


Figure 3: Market clearing when buyers pledge collateral.

Notes: Contract demand is downward sloping because of the cost of collateral. Demand and supply intersect at $f^* > k$, so there is a positive probability of default. Without counterparty risk, the equilibrium would be at $(f^*, G(f^*))$ (blue dot). With costless collateral, the equilibrium would be at $(E(p), G(E(p))$ (gray dot).

Interestingly, there are cases where eliminating counterparty risk is optimal for society, but not necessarily for sellers. The reason is that it also benefits buyers. Although for a given price f buyers individually benefit from the possibility of defaulting on the contract, the equilibrium effect of counterparty risk is a decrease in supply, raising the price of the contract.

To interpret this result, we can measure the welfare loss from setting $k < \hat{k}$ compared to the First Best as

$$W^{FB} - W^*(k) = G(c^*) R(f^* - k, 1) + \int_{c^*}^{E(p)} (E(p) - c) \phi(p) \, dp + \frac{\hat{\rho}(f^*)^2}{2} k. \tag{12}$$

The effect of counterparty risk is captured by the first and second terms, representing the costs incurred by sellers and the social cost due to underinvestment, respectively.[20] The last term captures the total cost of the collateral.

Hence, while setting $k = \hat{k}$ eliminates the costs of counterparty risk, it does not achieve the First Best due to the cost of the collateral and the underinvestment it engenders. This loss can be significant if $\hat{k}$ is large, such as when $E(p)$ is high.[21]

[20]The costs of underinvestment can be further decomposed: without counterparty risk, the marginal investor would have had an investment cost $f^* > c^*$, and with costless collateral, the cost of the marginal investor would have shifted from f^* to $E(p)$. This decomposition can be observed in Figure 3, where the solid dots indicate the allocation without counterparty risk and with costless collateral.

[21]Note that $\hat{k}$ only depends on $E(p)$. In particular, it is the same for all mean-preserving price

In sum, adding costly collateral does not eliminate the market failures associated with counterparty risk. Even when the optimal collateral eliminates the probability of default, the cost of collateral remains, leading to reduced demand and underinvestment. Furthermore, when the social cost of default is sufficiently low, the optimal collateral also involves a positive probability of contract default, exposing sellers to costly risk. The resulting inefficiencies open the door to welfare-improving market interventions, as we discuss next.

5 Market Interventions

In this section, we consider several market interventions aimed at addressing the previous market failures. For simplicity, we base our analysis on the benchmark model, with exogenous contract demand θ and no collateral, $k = 0$.[22] We also assume a sufficiently small fraction of opportunistic buyers so that the market for long-term contracts remains relevant.

5.1 Promoting Contract Demand

Our previous analysis has highlighted a weak demand for fixed-price contracts as a key determinant of underinvestment. Specifically, cases where $\theta < q^{FB}$ result in inefficient investment, even in the absence of counterparty risk. An increase in demand, θ, could be endogenously achieved through policies aimed at reducing participation costs (e.g., contract standardization),[23] or exogenously, through mandates to purchase energy in long-term markets (Mays et al., 2022). While Proposition 1 indicates that a higher θ would always increase efficiency under perfect contract enforcement, we now analyze to which extent this result extends to cases with counterparty risk.

First, consider high values of γ such that $\bar{q}(\gamma) \leq \theta$. In this case, demand is rationed, rendering increases in contract demand ineffective. For lower values of γ, when demand is not rationed, raising contract demand boosts investment but also increases the

distributions.

[22]Our previous analysis suggests that the results would remain qualitatively unchanged under the optimal costly collateral, provided that the cost premium is sufficiently low so that some meaningful counterparty risk persists in equilibrium.

[23]In the context of electricity markets, contract standardization is often recommended to promote long-term contracting. In line with this view, the European energy regulator is currently exploring whether "standardized PPAs will promote transparency, efficiency, and integration of the European internal energy market."(ACER, 2024)

equilibrium contract price, thereby raising the default probability for all inframarginal contracts.

This trade-off underscores the limitations of promoting contract demand without addressing the root cause of weak contract liquidity. Promoting contract demand to stimulate investment leads to increasing default risk, particularly as the share of opportunistic buyers in the market grows.[24]

5.2 Regulator-backed Contracts

An alternative way to address the market failures caused by buyers' counterparty risk is for the regulator to demand fixed-price contracts, which are then passed on to final buyers.[25] Since the regulator has the authority to enforce payment even if spot prices fall below the contract price, counterparty risk is eliminated.[26]

We denote the amount of regulator-backed contracts as θ_R and, in line with Assumption 3, we set $\theta_R \leq G(E(p))$. On the demand side, these contracts are uniformly allocated among the unit mass of buyers, i.e., the regulator allocates a proportion θ of these contracts to buyers who would have participated in the private-contract market anyway, while the remaining contracts are distributed to buyers who would otherwise trade in the spot market. Therefore, the remaining demand for private contracts is reduced to $\theta(1-\theta_R)$, of which a fraction γ corresponds to opportunistic buyers.[27]

On the supply side, and consistent with common practice, regulator-backed contracts are allocated through an auction among sellers. This auction occurs before private contracts are signed and prior to any investment decisions. Sellers bid on the fixed price at which they are willing to produce under the contract, and the auctioneer selects them in ascending price order. Buyers and sellers who do not secure a regulator-backed contract can subsequently trade in the private-contract market.

[24] Our simulations in section 7 provide instances where demand expansions might indeed reduce welfare.

[25] In the US, public utility companies often play this role, as they are required to ensure that a certain percentage of their total electricity generation comes from renewable sources under the Renewable Portfolio Standards (RPS) (Kim and Samano, 2024). Since public utility companies can pass on their costs to final consumers, these contracts can be considered risk-free. In Europe, regulators assume this role by auctioning regulator-backed contracts, often referred to as Contracts for Differences (CfDs) (Fabra and Montero, 2020).

[26] In many cases, especially in developing countries, regulator-backed contracts typically involve less risk compared to contracts with private parties, but they are not entirely risk-free. Instances of default or contract renegotiation have been reported in countries such as India, Mexico, Turkey, Pakistan, and South Africa. See, for example, Ryan (2024) and Dobermann et al. (2024).

[27] Since the new buyers would not have participated in the private market otherwise, their trustworthiness is inconsequential for the analysis.

The equilibrium market outcome critically depends on the share of opportunistic buyers, γ. First, suppose that γ is sufficiently high so that the mass of sellers able to profitably trade in the private contract market is smaller than the volume of regulator-backed contracts, $\bar{q}(\gamma) \leq \theta_R$. This means that private contracts are completely crowded out. As sellers compete for regulator-backed contracts, they bid a price that makes them indifferent with their outside option. Specifically, for investors with costs $c \leq E(p) - r$, the alternative is trading in the spot market, while for higher-cost investors, the outside option is not investing at all. Since $\bar{q}(\gamma) \leq \theta_R$, the auction price is set by these higher-cost investors at $f_R^* = G^{-1}(\theta_R)$. Because regulator-backed contracts eliminate counterparty risk altogether, the resulting equilibrium outcome is analogous to Proposition 1, with θ replaced by θ_R. This situation is illustrated in Figure 4b.

Matters change for lower values of γ such that $\bar{q}(\gamma) > \theta_R$ as, in that case, the excess demand for regulator-backed contracts can be profitably met in the private market. This situation is illustrated in Figure 4a. Since total demand for contracts, $\theta_R + \theta(1 - \theta_R)$, is increasing in θ_R, investment (weakly) increases and private contracts are sold at (weakly) higher prices as compared to the case without regulator-backed contracts.

Crowding-out is partial because investors still have the alternative to trade in the private-contracts market, which affects their opportunity cost of signing a regulator-backed contract. This means that, when competing for these contracts, the highest bid of a seller with cost c, f_R, is determined by

$$f_R - c = \max\left\{\Pi_S(f^*, \gamma, c), 0\right\}.$$

All sellers for whom participation in the private-contracts market is profitable place the same bid, regardless of c.[28]

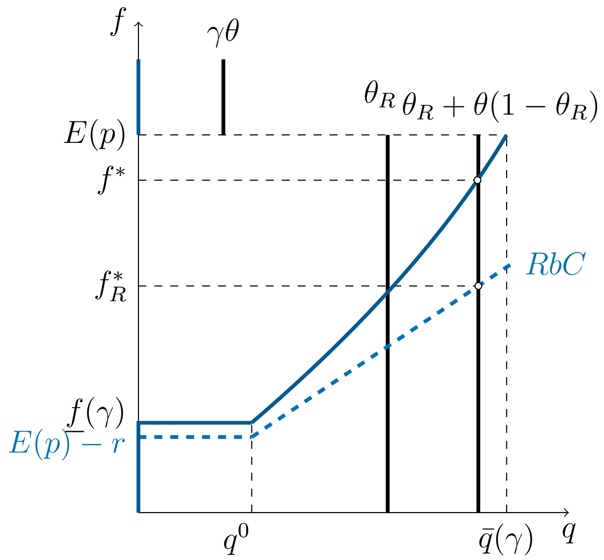
In equilibrium, all sellers must be indifferent between contracting with the regulator or a private buyer. It follows that the equilibrium price for regulator-backed contracts is

$$f_R^* = \int_0^{f^*} p\phi(p)dp + f^*(1 - \Phi(f^*)\gamma) - R(f^*, \gamma) < f^*. \tag{13}$$

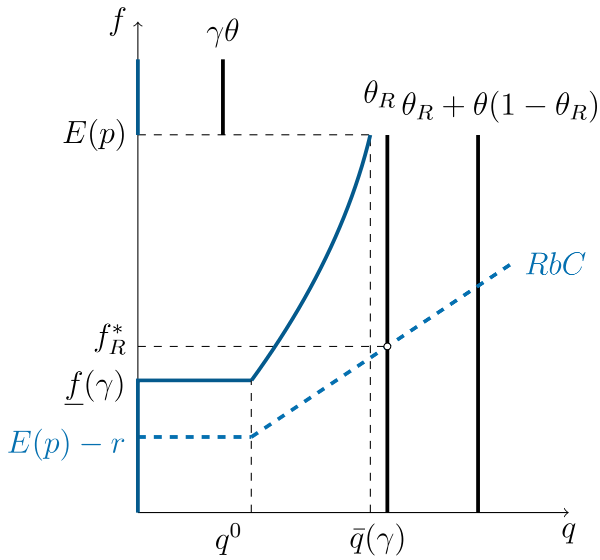
The price in the private-contract market, f^*, includes a premium required to attract sellers. This premium is increasing in the proportion of opportunistic buyers.

The following proposition summarizes the previous results.

[28] This implies that the allocation of regulator-backed contracts among the winning sellers does not affect the equilibrium outcome.



(a) Partial crowd-out (low γ)



(b) Full crowd-out (high γ)

Figure 4: Market clearing under Regulator-backed Contracts.

Notes: In panel (a) γ is small and $\theta_R + \theta(1-\theta_R) < \bar{q}(\gamma)$ so the private-contract market operates. Private contracts are sold at prices f^* above the price of the regulator-backed contracts f_R^*. In panel (b) γ is high, and regulator-backed contracts crowd out the private market, resulting in all contracts being sold at f_R^*.

Proposition 5. *When an amount θ^R of regulator-backed contracts is auctioned off among sellers, private contracts are*

(i) completely crowded out when γ is high enough so that $\bar{q}(\gamma) \leq \theta^R$. The equilibrium price for regulator-backed contracts is $f_R^* = G^{-1}(\theta_R)$, resulting in total investment $q^* = \theta_R$.

(ii) partially crowded out when γ is low so that $\bar{q}(\gamma) > \theta^R$. The equilibrium in the private-contract market is the same as in Proposition 2, with θ replaced by $\theta_R + \theta(1-\theta_R)$. The equilibrium price for regulator-backed contracts f_R^*, defined in (13), is lower than the equilibrium price for private contracts, f^*.

Using this equilibrium characterization, the following proposition compares welfare with and without regulator-backed contracts.

Proposition 6. *If γ is high enough so that $\bar{q}(\gamma) \leq \max(\theta, \theta^R)$, regulator-backed contracts unambiguously increase welfare.*

First, consider case (i) in Proposition 5, where $\bar{q}(\gamma) \leq \theta^R$, and private contracts are fully crowded out. Because counterparty risk is eliminated, the social gains are equivalent to those discussed in (6), with θ replaced with θ_R. Regulator-backed contracts eliminate the cost premium and foster investment.

Now consider case (ii), where $\bar{q}(\gamma) > \theta_R$, so that some contracts are privately traded. If $\bar{q}(\gamma) \leq \theta$, the welfare contribution of regulator-backed contracts is simply $\theta_R \gamma R(E(p))$, as with or without them, the equilibrium price in the private contract market is $E(p)$, resulting in the same investment level. Thus, in this scenario, regulator-backed contracts contribute to welfare only by reducing the cost premium.

In the remaining cases, where γ is low enough so that $\bar{q}(\gamma) > \max(\theta, \theta^R)$, introducing regulator-backed contracts introduces a trade-off similar to that encountered when promoting contract demand. On the one hand, regulator-backed contracts are risk-free but, through the demand expansion effect, they increase the price and, hence, the risk premia of private contracts. On the other hand, the welfare contribution of regulator-backed contracts to reducing underinvestment remains present. As a result, the overall welfare effect of regulator-backed contracts depends on the relative magnitude of these effects.

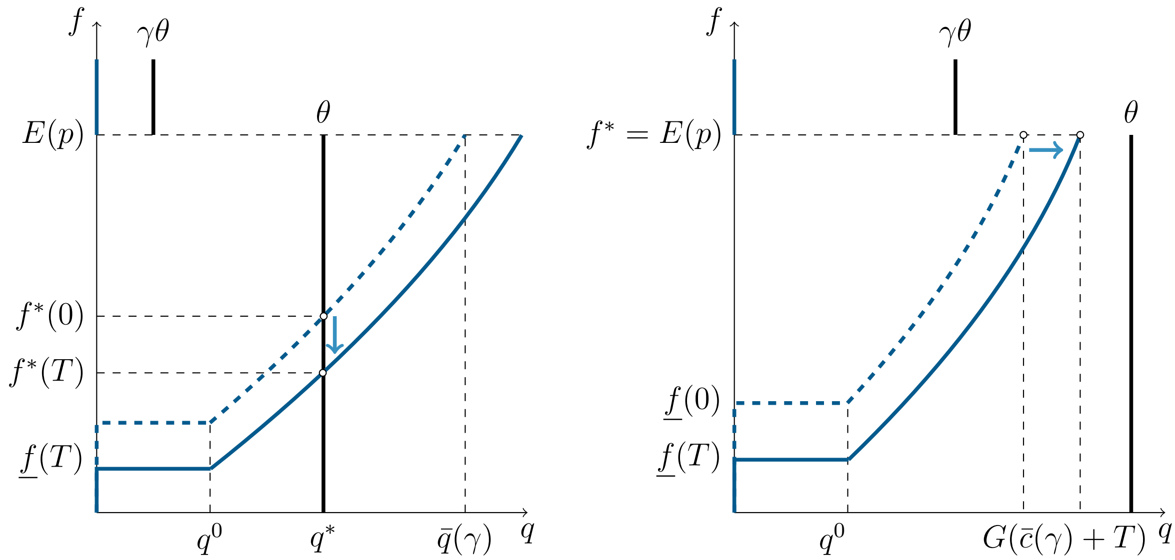
In any event, increases in θ_R have a more positive impact on welfare than equivalent increases in θ (i.e., promoting contract demand, as analyzed in the previous section). The reason is that both policies have the same impact on prices in the private-contract market, but the former eliminates the premium of all trade that takes place through regulator-backed contracts.

5.3 Public Subsidies

Public subsidies are a common policy instrument to mitigate inefficiencies arising from underinvestment. In this section, we show that they also contribute to mitigate counterparty risk, even when they do not foster investment.

Unconditional subsidies, i.e., those provided to all investors regardless of whether they sign a fixed-price contract, encourage investment but do not effectively promote contract liquidity or mitigate the distortions caused by counterparty risk.[29] For this reason, we focus on uniform and conditional subsidies, $T \geq 0$, paid specifically to sellers who sign a fixed-price contract. In the spirit of the market-regulation literature, we assume that such a subsidy carries a per-unit social cost of funds, $\lambda \geq 0$.

[29]Unconditional subsidies are widespread. For example, in the US, renewable producers receive a Production Tax Credit (PTC) per unit of renewable output or investment subsidies, regardless of whether the output is backed by long-term contracts (Aldy et al., 2023; Chen, 2024).



(a) The low γ case.

(b) The high γ case.

Figure 5: The Effect of Public Subsidies.

Notes: In panel (a) γ is low, so that the market clears and subsidies reduce the contract price without affecting investment. In panel (b) γ is high, so that there is demand rationing. Subsidies increase investment while contract prices remain at $E(p)$.

Subsidies affect the supply of contracts through two channels. First, sellers prefer a fixed-price contract to trading in the spot market if

$$\Pi_S(f, \gamma, c) + T \geq \Pi_S^0 = E(p) - r - c.$$

As a result, the minimum contract price, $\underline{f}$, is decreasing in T. Second, supply expands as more sellers can break even at every contract price. When γ is low so that $q^* = \theta < \bar{q}(\gamma)$, the equilibrium price, $f^*(T)$, is equal to $\tilde{f}(\gamma, c)$, now implicitly defined as the solution to the new break-even constraint for the marginal seller,

$$\Pi_S(\tilde{f}, \gamma, c^*) + T = 0. \tag{14}$$

When γ is high enough so that $q^*\bar{q}(\gamma) < \theta$, the equilibrium price maximizes seller profits, $f^* = E(p)$. Yet, public subsidies help in expanding investment to $G(\bar{c}(\gamma) + T)$.

In sum, as illustrated in Figure 5, for low γ, a marginal increase in the subsidy reduces prices but leaves investment unchanged. In contrast, for high γ, subsidies increase investment without reducing prices.

The optimal subsidy weights the price or investment effects against the social cost of the subsidy. Formally, the regulator selects the level of the subsidy T to maximize the contribution of contracts to social welfare, accounting for the effect on the equilibrium price, f^*, and on investment, $G(c^*(T))$, minus the social cost of the subsidy.

In this case, the welfare losses arising from imperfect contract enforceability become

$$W^*(0) - W^T(\gamma) = R(f^*(T), \gamma)G(c^*(T)) + \int_{c^*(T)}^{G^{-1}(\theta)} (E(p) - c)g(c)dc + \lambda G(c^*(T))T. \quad (15)$$

The next result characterizes the subsidy that minimizes welfare distortions.

Proposition 7. *Assume that $g(c)/G(c)$ is weakly decreasing in c. The optimal subsidy $T^*(\lambda)$ is (weakly) decreasing and $f^*(\lambda)$ (weakly) increasing in λ. Furthermore,*

(i) When γ is small so that $\bar{q}(\gamma) \geq \theta$, investment is $q^* = \theta$ and the equilibrium fixed-price contract is a continuous function of λ,

$$f^*(\lambda) = \begin{cases} 0 & \text{if } \lambda \leq \underline{\lambda}, \\ \tilde{f}(G^{-1}(\theta), T^*(\lambda)) & \text{if } \lambda \in (\underline{\lambda}, \overline{\lambda}), \\ \tilde{f}(G^{-1}(\theta), 0) & \text{if } \lambda \geq \overline{\lambda}, \end{cases}$$

where $\tilde{f}(c, T)$ is defined in (14) and $\underline{\lambda} < \overline{\lambda}$.

(ii) When γ is high so that $\bar{q}(\gamma) < \theta$, there exists $\hat{\lambda}$ such that for $\lambda > \hat{\lambda}$, $q^* = G(c^*(T))$ and $f^*(\lambda) = E(p)$. If $\lambda \leq \hat{\lambda}$ then $q^* = \theta$ and

$$f^*(\lambda) = \begin{cases} 0 & \text{if } \lambda \leq \underline{\lambda}, \\ \tilde{f}(G^{-1}(\theta), T^*(\lambda)) & \text{if } \lambda \in (\underline{\lambda}, \hat{\lambda}), \end{cases}$$

where $f^*(\hat{\lambda}) < \bar{f}$.

The optimal solution reflects two different trade-offs. When the market clears, the optimal T arises from a *rent-counterparty-risk trade-off*. Increasing T lowers the equilibrium contract price, thus reducing counterparty risk for all contracts. However, raising T also engenders a social cost due to the usage of public funds, implying that the subsidy should decrease as λ increases. If λ is sufficiently close to zero, social welfare always increases with T until $f^* = 0$, fully eliminating counterparty risk and achieving efficient investment when $\lambda = 0$.

In contrast, if there is rationing in equilibrium, the optimal T addresses a *rent-investment* trade-off. The subsidy enables some investments but at the cost of increasing inframarginal rents. In this case, the equilibrium price remains unchanged at $E(p)$.

In sum, subsidies represent a second-best policy because, while they mitigate under-investment, they do not address the root cause of inefficiency: counterparty risk. With subsidies, the first-best outcome can only be achieved if public funds are costless. One source of costless funds is the proceeds from auctions of regulator-backed contracts, which generate efficiency gains by effectively reducing counterparty risk. When the volume of regulator-backed contracts is limited and the first-best cannot be attained, combining both instruments may improve welfare through the supply expansion promoted by subsidies.

5.4 Public Guarantees

Suppose now that, instead of offering a conditional subsidy, the regulator can provide public guarantees. These guarantees are designed to secure a revenue f for the seller even if the buyer defaults on the contract. In other words, public guarantees act as a payment to the seller that compensates for the revenue shortfall $f-p$ in the event of a default. As in the previous case, the disbursement of public funds is subject to a social cost $\lambda \geq 0$.

Because the seller no longer faces counterparty risk, profits under the fixed-price contract become $\Pi_S(f,c) = f - c$, regardless of the value of $f \in [0,1]$. Buyer's profits remain unchanged. The immediate implication of this result is that sellers will demand the highest possible price contingent on not being undercut by a competitor. This price is $f^G = G^{-1}(\theta) \leq E(p)$ and the total investment becomes $q^G = \theta$.

Suppose that γ is low enough so that, without guarantees, there is no demand rationing, $G(\bar{c}(\gamma)) \geq \theta$. The market outcome in this case coincides with the situation without counterparty risk in Section 3, as described in Figure 1a. The effect of these guarantees on social welfare can be computed as

$$W^G(\gamma) - W^*(\gamma) = \theta \left[R(f^*, \gamma) - \lambda\gamma \int_0^{G^{-1}(\theta)} (G^{-1}(\theta) - p)\phi(p)dp \right] \lessgtr 0.$$

This expression means that for public guarantees to be socially optimal, the gains from completely removing counterparty risk must compensate the social cost of providing them. Clearly, this will be the case if λ is sufficiently low.

Alternatively, when γ is high so that $G(\bar{c}(\gamma)) < \theta$, public guarantees foster investment, $q^G > q^*$. Interestingly, this case implies a new trade-off, as shown in the expression below for the social gain from the guarantee,

$$W^G(\gamma) - W^*(\gamma) = G(\bar{c}(\gamma))R(E(p), \gamma) + \int_{\bar{c}(\gamma)}^{G^{-1}(\theta)} (E(p) - c)g(c)dc$$
$$- \lambda\theta\gamma \int_0^{G^{-1}(\theta)} (G^{-1}(\theta) - p)\phi(p)dp \lesseqgtr 0.$$

The first two terms represent the benefits of reducing counterparty risk and the third measures the cost of the corresponding use of public funds, as discussed in the previous scenario. The key distinction in this case is that counterparty risk is eliminated for sellers who would have participated even without public guarantees, represented by $G(\bar{c}(\gamma))$. However, the cost of public funds applies to the guarantees provided to all sellers, denoted by θ, including those who would not have entered the market otherwise.

Additionally, public guarantees could give raise to moral hazard problems. Protected from the risk of default, sellers would be willing to sell at prices above $E(p)$, giving rise to overinvestment when $\theta > G(E(p))$. This distortion is ruled out in our model due to Assumption 3, but relaxing this assumption would introduce an additional negative effect in the above welfare equation.

6 Robustness and Extensions

This section briefly examines the robustness of the paper's main results under alternative specifications and explores several extensions.

6.1 Risk Aversion

In the baseline model, we captured the costs of price volatility through a premium $R(f, z)$ which satisfied Assumption 1, and which is consistent with mean-variance preferences. In this section, we show that this reduced-form approach approximates the behavior of sellers with a standard utility function $u(w)$, where w denotes income and $u' > 0$ and $u'' < 0$. Investment occurs in a first period, and returns are obtained in a second period.

For prices $f > E(p)$, only opportunistic buyers are willing to accept the contract. Hence, the expected utility of a seller in the second period can be written as

$$U_S(f, 1) = \int_0^f u(p)\phi(p)dp + (1 - \Phi(f))u(f). \tag{16}$$

For lower prices, the buyer is opportunistic with probability γ, giving rise to an expected utility equal to

$$U_S(f,\gamma) = \gamma\left[\int_0^f u(p)\phi(p)dp + (1-\Phi(f))u(f)\right] + (1-\gamma)u(f). \tag{17}$$

Both expressions (16) and (17) are increasing in f, achieving local maxima at $f^* = 1$ and $f^* = E(p)$, respectively. Moreover, (17) is decreasing in γ. These results are consistent with our baseline model under Assumption 1.

Letting $R^u(f, z^*)$ denote the risk premium under a contract price f, these expressions can be respectively re-written as

$$U_S(f,z^*) = \begin{cases} u\left(\int_0^f p\phi(p)dp + f(1-\Phi(f)) - R^u(f,1)\right) & \text{if } f > E(p), \\ u\left(\gamma\int_0^f p\phi(p)dp + f(1-\Phi(f)\gamma) - R^u(f,\gamma)\right) & \text{if } f \leq E(p). \end{cases}$$

Likewise, the expected utility for sellers when trading in the spot market during the second period is given by

$$U_S^0 = u\left(\int_0^1 pdp - R^u(1,1)\right).$$

The following lemma shows that the risk premium derived from this model satisfies the basic properties assumed in Assumption 1.

Lemma 4. *The risk premium $R^u(f,z)$ satisfies the following properties: $R^u(0,\gamma) = R^u(f,0) = 0$ and $R^u(1,1) = r$. Furthermore, $U_S^0 \geq U_S(f,\gamma)$ for all $f > E(p)$.*

Hence, our reduced-form specification captures the relevant features of a model incorporating sellers' risk aversion via a concave utility function. To make this equivalence explicit, consider:

$$\Pi_S(f,\gamma,c) = u^{-1}\left(U_S(f,\gamma)\right) - c,$$

where $\Pi_S(f,\gamma,c)$ is defined in (1). Since the risk premium $R^u(f,\gamma)$ satisfies similar properties to $R^u(f,\gamma)$, we can approximate $U_S(f,\gamma,c)$ with the profit function $\Pi_S(f,\gamma,c)$. Figure 6 provides an example.

6.2 Renegotiation and Limited Liability

In the baseline model, we assumed that when the spot market price drops below the contract price, opportunistic buyers default, creating counterparty risk. However, there

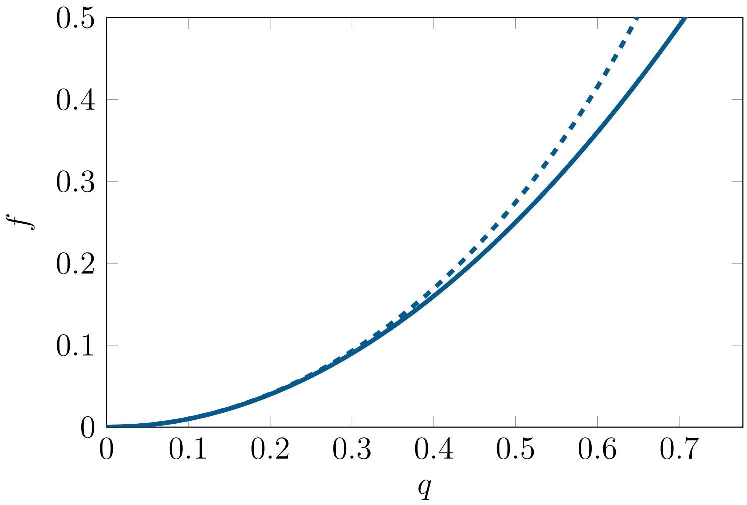


Figure 6: Contract Supply when Sellers have a Concave Utility Function.

Notes: The utility function is $u(p) = \frac{1}{2}\frac{p^{1-\sigma}}{1-\sigma}$ for $\sigma = 0.5$ and $\Phi(p) = p$. The figure represents the cases when all buyers are trustworthy (solid) and when a proportion $\gamma = \frac{1}{2}$ are opportunistic (dashed line).

are alternative manifestations of counterparty risk that would result in similar profit expressions for both buyers and sellers.

Consider, for example, the possibility of contract renegotiation. Specifically, when the realized spot price p falls below f, buyers may propose a renegotiation with probability $\gamma \leq 1$, making a take-it-or-leave-it offer to reset the contract price to p. The seller accepts it, as it makes it indifferent between staying in the contract at p or selling in the spot market. Analytically, the resulting profit expressions would coincide with those of the baseline model.

Results also remain unchanged if contract default arises not from the buyer's opportunistic behavior but from limited liability and downstream market competition. Suppose that the buyer is an intermediary that purchases the input to resell it to final consumers in a downstream market. With probability γ, a Bertrand competitor offering a homogeneous good enters the downstream market, purchasing the input in the spot market at a price p. Consequently, whenever $p < f$, the buyer is priced out of the downstream market and, due to limited liability, it cannot fulfill its contract obligations. As a result, the seller is forced to offer its output in the spot market at p rather than at the contract price f. Interestingly, this formulation implies that greater downstream market power reduces counterparty risk, leading to lower contract prices and increased investment, notwithstanding the potential adverse effects on final consumers.

6.3 Vertical Integration

In our baseline model, counterparty risk arises because the incentives of buyers and sellers are misaligned. Thus, one might expect vertical integration to eliminate counterparty risk (Hart, 1995), allowing the resulting firm to capture the full value of the investment, as in Proposition 1.

However, this prediction does not hold in situations as those discussed in the previous subsection, where the buyer acts as an intermediary between the seller and final consumers. If, as in the previous case, we suppose there is a downstream competitor (with probability γ), the vertically-integrated firm remains exposed to spot market price volatility. Profits for the integrated structure are given by

$$\Pi_I(c) = (1 - \gamma)(E(p) - c) + \gamma(E(p) - c - r).$$

Consequently, only when $\gamma = 0$, the integrated structure captures the full value of the investment. When $\gamma > 0$ vertical integration does not fully resolve the underinvestment problem because the firm is still partially exposed to spot market prices through the competitive pressure from its downstream competitor. Indeed, in the extreme case where $\gamma = 1$, the profits of the integrated firm are reduced to those in the no-contract scenario, leading to a welfare loss relative to the case of contracts among stand-alone firms, as captured in (4).

6.4 A Buyer's Positive Premium

In the baseline model, we assumed that the buyer views a long-term contract as beneficial only insofar as it provides access to lower prices. However, buyers might directly benefit from long-term contracts when, for example, the seller produces clean energy helping to fulfill regulatory requirements or Corporate Social Responsibility considerations. In this section, we analyze the effects of considering this premium on market outcomes.

Suppose that whenever the buyer honors the contract, it obtains an additional premium $r_B > 0$. This assumption has two important implications for the model. First, an opportunistic buyer will now default on the contract if $f > p + r_B$. Second, a trustworthy buyer will now be interested in signing the contract if $f \leq E(p) + r_B$.

By continuity with the baseline model, when the buyer premium is small, choosing a price that only attracts opportunistic buyers is dominated by a lower price that also attracts trustworthy buyers, $f \leq E(p) + r_B$. Consequently, seller profits can now be expressed as

$$\Pi_S(f, c) = \gamma \int_0^{f - r_B} p\phi\,(p)\,dp + f(1 - \gamma\Phi(f - r_B)) - \gamma R(f - r_B) - c,$$

increasing in r_B. Intuitively, when the buyer faces a premium associated with a long-term contract, the default probability decreases for a given f, thereby increasing the seller's profits. Indeed, for a sufficiently large r_B, default is entirely averted.

The minimum contract price that fosters participation for the seller, $\underline{f}$, can now be obtained from

$$\Pi_S(\underline{f}(\gamma, r_B), c) - \Pi_S^0 = 0.$$

Since seller profits are increasing in r_B, it follows that $\underline{f}(\gamma, r_B)$ is decreasing in r_B. As a result, the range of prices under which a long-term contract will emerge, $f \in [\underline{f}(\gamma, r_B), E(p) + r_B]$ expands with r_B.

Combining the previous results, a small buyer premium shifts the contract supply curve downwards. Depending on the share of opportunistic buyers, this results in either lower prices or higher investment. Compared to the perfect enforcement case, the welfare loss due to counterparty risk decreases, as a buyer's premium aligns the incentives of buyers and sellers, thereby reducing the cost of imperfect contract enforcement.

However, when the buyer premium is sufficiently large, opportunistic buyers no longer pose a significant risk, as their incentives to default are substantially reduced. As a result, the profit-maximizing choice of f involves a trade-off: either a low price that attracts both buyer types and hence has a low probability of default, or a higher price that, by only attracting opportunistic buyers, increases the probability of default but to a lower extent than in the baseline model. The higher r_B, the more likely it is that the second option will dominate.

6.5 Dynamic Interactions and Time-Varying Prices

Our analysis has relied on a static model despite the long-term nature of contracts. Our conclusions extend to situations where price realizations throughout the contract's duration are highly correlated over time, reflecting the idea that the primary source of uncertainty is the future average price level rather than its short-run variations. Under this setup, an opportunistic buyer's decision to honor the contract hinges entirely on the initial price realization, allowing us to collapse the dynamic interaction in a single stage. However, when future prices are not highly correlated over time, the incentives of an opportunistic buyer to default would depend on the price realization in each period and the remaining contract duration.

In this section, we show that when prices are weakly correlated over time, the probability of default decreases due to the continuation value of staying in the contract. Contracts shield buyers from future high prices, which in turn lowers the probability of early default. In turn, reducing the default probability during early periods also decreases the sellers' future risk premia.

To illustrate these ideas, in this section we assume that all buyers are opportunistic ($\gamma = 1$). This means that in the static setting, or when prices are perfectly correlated over time, the contract market would collapse (Corollary 1). However, as we show next, under time-varying prices, the contract market may still operate due to the dynamic incentives that long-term contracts engender.

Consider a simple dynamic game where price realizations are *i.i.d.* over time, following the same distribution $\Phi(p)$. Contracts span two periods, with second-period payoffs discounted by buyers and sellers at rates $\delta_B \leq 1$ and $\delta_S \leq 1$, respectively. After observing the price realization in each period, each buyer decides whether to default on the contract. If default occurs, all future transactions remain unhedged and both firms rely on the spot market.

The game is solved by backward induction. At $t = 2$, if the buyer honored the contract at $t = 1$, the problem simplifies to our static model. Conversely, if the buyer defaulted on the contract, both the seller and buyer are exposed to spot prices. This means that at $t = 1$, the buyer's net present value profits from honoring the contract are given by $v - f + \delta_B \Pi_B(f)$, while the profits from defaulting are $v - p + \delta_B(v - E(p))$.

Consequently, the buyer defaults at $t = 1$ if and only if p falls below $\hat{p}$, defined as

$$\hat{p} \equiv f - \delta_B \int_f^1 (p - f)\phi(p)\, dp < f. \tag{18}$$

The second term in the above expression represents the option value of honoring the contract in the first period, as it allows the buyer to hedge against high prices in the second period. This option value decreases with higher f and lower δ_B, increasing the default probability.[30] In the second period, the buyer defaults whenever p falls below f. Since $\hat{p} < f$, the probability of default increases over time. Notably, when $\delta_B = 0$, the continuation value falls to zero and the trigger price for defaults remains f, as in the static model.

The change in the buyer's behavior may influence the sellers' optimal price, even when sellers are myopic or fully discount the future ($\delta_S = 0$). In this case, the seller's profit expression is the same as in the static model but must be evaluated at a lower trigger price, $\hat{p}$:

$$V_S(f, c) = \int_0^{\hat{p}} p\phi(p)dp + (1 - \Phi(\hat{p}))f + R(\hat{p}, 1) - c.$$

The first derivative of the seller's profit with respect to f is now

$$\frac{\partial V_S}{\partial f} = 1 - \Phi(\hat{p}) - \frac{\partial \hat{p}}{\partial f} R'(\hat{p}, 1) = [1 - \Phi(\hat{p}) - R'(\hat{p}, 1)] - \delta_B(1 - \Phi(f))R'(\hat{p}, 1). \tag{19}$$

By Assumption 1, the term in square brackets is positive, fostering a high f by the seller. However, when $\delta_B > 0$, the buyer's dynamic incentives operate in the opposite direction, as lowering f reduces the probability of default more than proportionally. If the premium is sufficiently sensitive to the trigger price, the seller will optimally choose $f^* < 1$. This lower contract price, in turn, reduces the default probability, potentially preventing the collapse of the contract market even when all buyers are opportunistic. We illustrate this possibility with the following example.

Example 2. *Suppose $\delta_S = 0 < \delta_B$, $\Phi(f) = f$, and $R(f, 1) = \int_0^f (1 - p)dp$. In this case, $E(p) = \frac{1}{2} = R(1, 1) = r$ and $R'(f, 1) = 1 - \Phi(p)$, satisfying Assumption 1.*

Under these assumptions, the derivative of seller profits becomes

$$\frac{\partial V_S}{\partial f} = -\delta_B(1 - \Phi(f))R'(\hat{p}, 1) < 0.$$

In the static framework ($\delta_B = 0$), the marginal effect of increasing f on revenue and the premium balance out, resulting in constant profits equal to participating in the spot market. However, with dynamic incentives ($\delta_B > 0$), a decrease in f increases seller profits due to the reduced probability of default. Consequently, the optimal fixed price results from the solution to $\hat{p} = 0$ in (18). *This choice eliminates default in the first period while ensuring a positive risk-free return,*

$$f^* = \frac{1 + \delta_B - \sqrt{1 + 2\delta_B}}{2} > 0, \tag{20}$$

[30] For sufficiently low f and/or sufficiently high δ_B, the trigger price becomes negative, implying that the default probability in the first period becomes zero.

which exceeds the spot-market return of $E(p) - r = 0$.

Let's now consider forward-looking (or patient) sellers ($\delta_S > 0$). Their present value of profits can be expressed as

$$V_S(f, c) = \int_0^{\hat{p}} p\phi(p)dp + (1 - \Phi(\hat{p}))f + R(\hat{p}, 1) \\ + \delta_S \left[\Phi(\hat{p})(E(p) - r) + (1 - \Phi(\hat{p}))\Pi_S(f, 1, 0)\right] - c.$$

When sellers are patient, profits reflect the fact that default in the first period exposes the seller to spot-market risk in the second period, as captured by the first term in square brackets. Conversely, when buyers honor the contract, second-period profits are those in the static case, as indicated by the second term in square brackets.

The derivative with respect to f shows that seller dynamic incentives introduce a new trade-off,

$$\frac{\partial V_S}{\partial f} = 1 - \Phi(\hat{p}) - \frac{\partial \hat{p}}{\partial f} R'(\hat{p}, 1) + \delta_S \left[-(r - R(f, 1))\phi(\hat{p}) \frac{\partial \hat{p}}{\partial f} + \frac{\partial \Pi_S}{\partial f} \right].$$

Compared to the derivative when $\delta_S = 0$ in (19), the sign of the new term in brackets is ambiguous. The first effect is negative: increasing f raises the probability of incurring in a spot-market premium $r > R(f, 1)$ in the second period. The second effect is positive, as static profits increase with f (Assumption 2). However, if the premium is highly sensitive to the price, the second effect becomes small, allowing the first effect to dominate. Additionally, the first-period effect is also likely to be negative, suggesting that $f^* < 1$ could be optimal in this scenario.

Example 2 (cont'd)**.** *In the previous example, let* $\delta_S > 0$. *The derivative of the profit function now becomes*

$$\frac{\partial V_S}{\partial f} = -\delta_B(1 - \Phi(f))R'(\hat{p}, 1) - \delta_S(r - R(f))\Phi(\hat{p}, 1)\frac{\partial \hat{p}}{\partial f} < 0.$$

Compared to the case with $\delta_S = 0$, *the incentives to reduce the price are now stronger, as the second term in the above derivative is also negative. Thus, it remains optimal to set a fixed price that induces no default in the first period* ($\hat{p} = 0$)*, while ensuring a positive return for* f^* *defined in* (20).

Finally, forward-looking sellers can prevent the collapse of the contract market even when buyers are myopic. Specifically, suppose $\delta_B = 0$, so the buyer's trigger price is

$\hat{p} = f$. For a given contract price f, seller profits are lower in the dynamic framework compared to the static one. This is because the probability of facing the spot-market price in the second period is higher, $\Phi(f) + (1 - \Phi(f))\Phi(f) > \Phi(f)$, as a first-period default automatically leaves the seller unhedged in the second period. Lowering the contract price reduces the probability of default more than in the static model, which in turn decreases the premium by $r - R(f, 1)$. This result is evident in the previous example, where the profit derivative remains negative even when $\delta_B = 0$.

Beyond the fact that dynamic incentives increase the likelihood of the contract market existing for higher values of γ, the qualitative implications of our baseline model remain valid in this more complex dynamic version. Specifically, in both formulations, counterparty risk persists, resulting in inefficiently high prices and underinvestment.

7 Simulations

In this section, we illustrate how our theoretical framework can be used to inform policy analysis, using data from the Spanish electricity market. In particular, we simulate the equilibrium outcomes and welfare effects of long-term contracts and the supporting public policies.

We assess the effect on prices, investment, and welfare of promoting long-term power contracts between potential renewable investors and energy-intensive buyers, from the perspective of 2021.[31] To address this question, we compile detailed data on solar and wind projects that became operational one year later (corresponding to the average construction timeline), allowing us to estimate the average production cost for each plant. Using future prices for electricity available at the time, along with reasonable values for the remaining model parameters, we compute the equilibrium in the contract market under the assumption that all these projects compete for long-term contracts.[32]

We also evaluate several policy scenarios with the implementation of public subsidy schemes, public guarantees, or regulator-backed contracts. This allows us to quantify how different policy designs influence pricing, investment decisions, and overall welfare relative to the baseline no-policy intervention case.

Before turning to the simulations, it is important to highlight key extensions of the

[31] For context, the volume of disclosed PPA deals in Spain in 2022, 2023 were 3.9GW, 4.67 GW, respectively (Pexapark, 2024).

[32] See Appendix B for details on the methodology and parameter values.

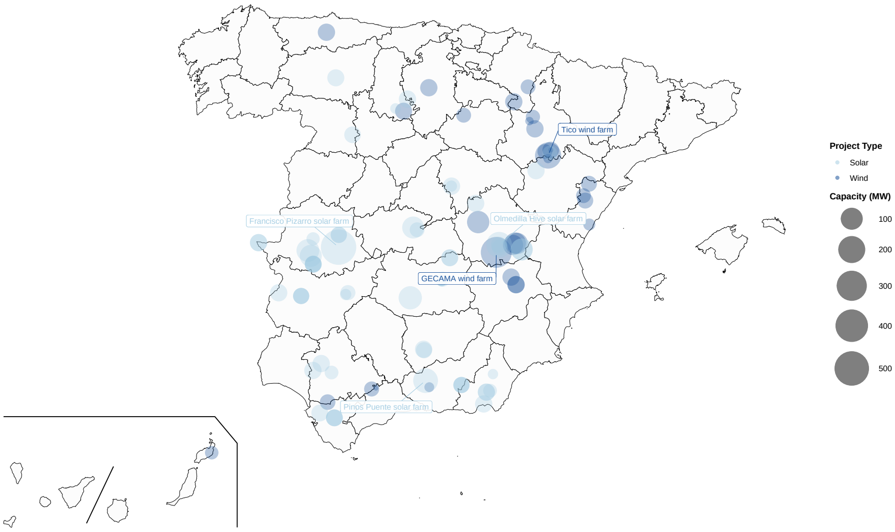


Figure 7: Map of the New Spanish Renewable Power Plants (2022)

Notes: This map shows the location and size of the wind (dark blue) or solar (light blue) power plants that started operating in Spain in 2022. The size of the circle is proportional to the plant's capacity.

theoretical model that better reflect real-world complexities. In the model, all plants differ only in their per-unit investment cost, with capacities and output normalized to one. This simplification yields identical premia for a given contract price for all plants. In reality, however, plants differ in multiple dimensions, including their size and technology (e.g., wind or solar), which, combined with location-specific resource availability, lead to differences in expected production across plants. As a result, average costs and spot-market premia may vary significantly at the plant level. Consequently, the aggregate contract supply function is not linear but step-wise, reflecting the discrete sizes, average costs and premia of the various renewable power plants. The simulations below extend the model to accommodate this richer structure.

7.1 Estimating Contract Supply

The analysis proceeds in three steps. First, we estimate each plant's average cost. Second, we estimate the expected utility that each plant obtains in the spot market and under a fixed-price contract. Third, we compute the contract price that would induce each plant to participate in the contract market, satisfying its break-even constraint and yielding expected profits at least as high as in the spot market.

Estimating plants' average costs We use data from the official registry of renewable power plants in Spain (PRETOR) to obtain the characteristics of all renewable investment projects that began operating in 2022, including their technology (solar or wind), maximum production capacity, and location. Using resource availability data at each specific location, we compute the expected lifetime production of each project, as illustrated in Figure 7.

Fixed investment costs are derived using estimates for each technology in Spain for 2021 from IRENA (2023), incorporating mild economies of scale based on plant size. A plant's long-run average cost is then calculated as the ratio of its investment cost to its expected lifetime production. Variation in location-specific resource availability and plant size leads to heterogeneity in average costs across projects, ranging from €19/MWh to €44/MWh.[33] Wind plants typically have higher average costs than solar plants.

Estimating spot and contract profits We assume that spot prices fluctuate between €0/MWh and €60/MWh, with an expected price of €40/MWh that has been calibrated to reflect the average value at which electricity futures for the period 2022–2027 were trading in Spain as of 2021.[34] A plant operating in the spot market earns a revenue equal to this price multiplied by its production. Only a small mass of plants (representing 3% of the total capacity) earn strictly positive profits in the spot market, and only those can profitably invest in the absence of contracts.[35]

Given the spot price distribution, we compute the expected revenues of sellers under fixed-price contracts for any contract price f and a share of opportunistic buyers $\gamma \in [0, 0.5]$, which guarantees that the market does not collapse (Corollary 1). To compute sellers' risk premia, we assume that investors have mean-variance preferences. Since price volatility affects plants through their output, risk premia are increasing in expected production. More productive plants are therefore more exposed to price risk and more sensitive to increases in the share of opportunistic buyers.

We follow similar steps under each policy scenario considered, adjusting the compu-

[33] This price range is in line with the winning bids in the renewable energy auction that was held by the Spanish regulator in 2021.

[34] For future horizons, this market was not sufficiently liquid.

[35] This aligns with anecdotal evidence from industry practitioners. For example, *"Having a PPA with a client committed to purchasing the plant's output in advance is a necessary condition to obtain a credit loan."* (EL MUNDO, España, ante el frenazo solar: Van a caer muchos proyectos, solo sobrevivirán los mejores, April 7, 2025.)

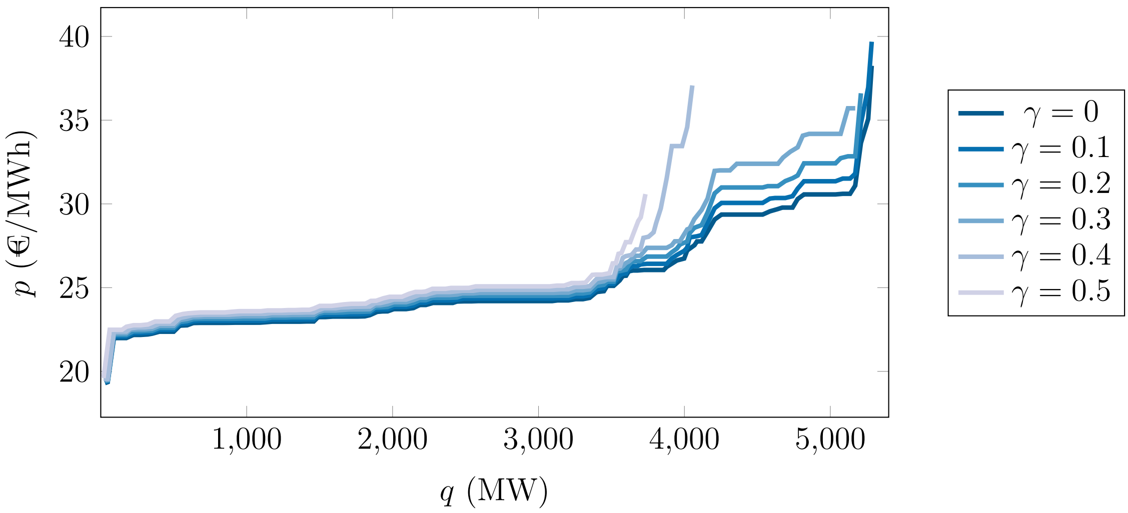


Figure 8: Contract Supply Curves for Various γ Values

Notes: This figure shows the contract supply curves for different values of $\gamma \in [0, 0.5]$. The case with $\gamma = 0$ corresponds to perfect contract enforceability. As γ goes up, the supply curves shift inwards, leading to higher prices and potentially constrained investment in equilibrium.

tation of contract profits according to the public support measure in place.

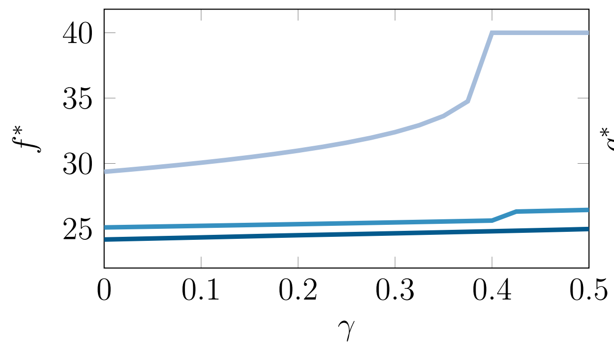
Figure 8 presents the baseline contract supply curves assuming no policy intervention, for different values of γ. Consistent with the model, the contract supply curves shift inward as γ increases, reflecting both the higher prices required to induce sellers to sign contracts and the reduced scale of feasible investment.

7.2 Simulation Results

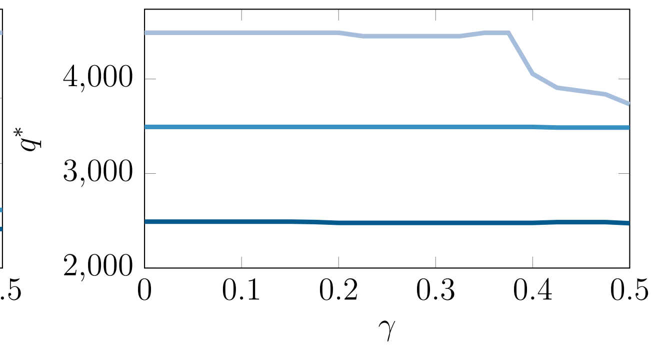
For each of the three contract demand levels considered (2,500 MW, 3,500 MW, and 4,500 MW), we compute the equilibrium outcomes, including prices, investment, and welfare, decomposed between sellers' and buyers' surplus.

Figure 9 presents the baseline results in the absence of policy intervention. As shown in Figure 9a, when contract demand is 2,500 MW, equilibrium contract prices increase from €24.2/MWh under perfect enforceability to €25.0/MWh when half of the buyers are opportunistic. Contract prices become more sensitive to counterparty risk at higher demand levels, as the supply curves steepen. At a demand of 4,500 MW and $\gamma = 0.5$, the market fails to clear: prices jump to the expected spot price of €40/MWh, and only 83% of contract demand gets fulfilled, as shown in Figure 9b.

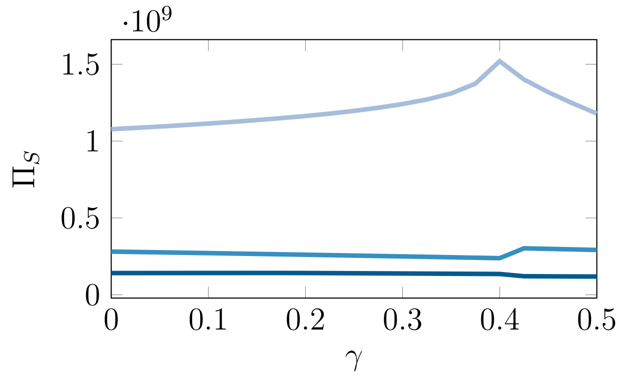
Figure 9e illustrates how the increase in contract prices reduces welfare as γ rises.



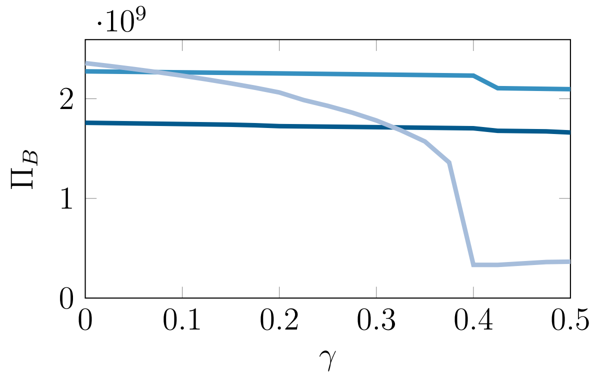
(a) Contract Prices



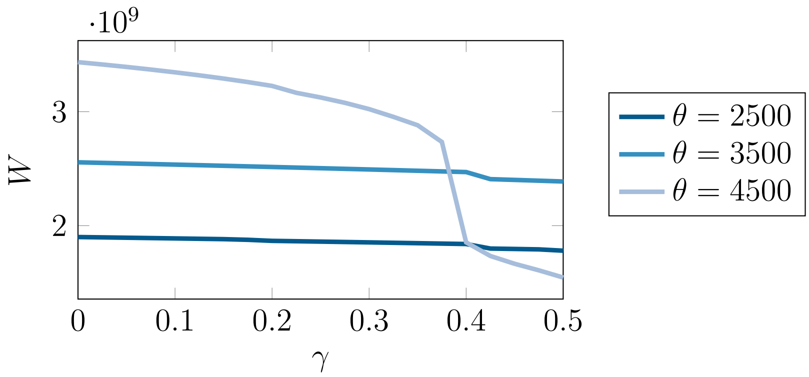
(b) Investment



(c) Seller Profit



(d) Buyer Profit



(e) Welfare

Figure 9: The Contract Market Equilibrium under the No-Intervention Scenario

Notes: These figures show the equilibrium outcomes in the no-intervention scenario for three levels of contract demand (2,500MW, 3,500MW, and 4,500MW), across values of $\gamma \in [0, 0.5]$. The case $\gamma = 0$ corresponds to perfect contract enforceability. As γ increases, contract prices in panel (a) weakly rise, while investment in panel (b) weakly declines. Seller profits in panel (c) increase with γ, except when contracts are rationed. The opposite is true for Buyer profits in panel (d). Welfare in panel (e) declines with γ and exhibits a non-monotonic relationship with contract demand.

The effect is most pronounced under high contract demand, where the welfare loss is amplified not only by higher prices but also by reduced investment. When contract demand is 2,500MW, welfare decreases by 6% as the share of opportunistic buyers rises from $\gamma = 0$ to $\gamma = 0.5$. In contrast, with a demand of 4,500MW, welfare drops by 55% over the same range. This suggests that the contraction in investment has a stronger impact on welfare than the price increase itself.[36]

Interestingly, welfare results also indicate that promoting contract demand is welfare-improving when counterparty risk is low, but it may reduce welfare at higher levels of γ. This is particularly evident for the cases with $\gamma = 0.4$ and $\gamma = 0.5$, where welfare under the low and intermediate demand levels exceeds that of the high-demand scenario.

Despite these frictions, welfare under all scenarios remains substantially higher than in the absence of contracts. Specifically, each MW of capacity added due to contracts (i.e., capacity that would not be installed under spot-only trading) contributes between €0.68 million and €0.77 million in lifetime welfare gains. These figures drop to €0.41 million and €0.34 million when contract demand is high and $\gamma = 0.4$ or $\gamma = 0.5$, respectively.

As can be seen in Figure 9c, sellers capture a varying share of total welfare, which tends to be higher when counterparty risk is most severe, i.e., under high contract demand and high γ. This occurs because counterparty risk is passed through to higher contract prices, which in turn generate substantial inframarginal rents for sellers (Proposition 3). For instance, when contract demand is high and there is no counterparty risk, the seller captures about 30% of total welfare but when $\gamma = 0.3$, the share increase to 40%. This highlights how buyer counterparty risk makes buyers collectively worse off: not only does overall welfare decline, but they also capture a shrinking share of it, particularly when counterparty risk is more problematic, as shown in Figure 9d. Nonetheless, sellers are also harmed by counterparty risk when it limits the scale of investments (Proposition 3), as can be seen from the figure when demand is high and $\gamma > 0.4$.

Public Policies Both public guarantees and public subsidies result in lower contract prices and higher investment compared to the no-intervention baseline. In the case of public guarantees, the impact is more pronounced as, once all risk is transferred to the

[36] Recall that we are abstracting from positive externalities arising from renewable investment. To the extent that the increase in γ reduces investment, the welfare reduction would be stronger in the presence of these externalities.

regulator, the new equilibrium prices and investment levels correspond to those under $\gamma = 0$. As shown Table 1, this risk reallocation is welfare improving, as the price decline contributes to further reducing the overall cost of risk. Since this benefit outweighs the fiscal cost of public funds, welfare increases relative to the baseline. The effect is especially significant when counterparty risk is high. For example, under high contract demand and $\gamma = 0.5$, welfare more than doubles as contract prices fall by 27% and investment rises by 20%. The same table also shows that buyers benefit from public guarantees, despite the fiscal burden, as their surplus increases significantly, particularly in the high-demand scenario.

Table 1: Effects of Public Guarantees on Buyer Profit and Welfare

	Buyer Profit (%)			**Welfare** (%)		
γ	*2,500 MW*	*3,500 MW*	*4,500 MW*	*2,500 MW*	*3,500 MW*	*4,500 MW*
0	100.0	100.0	100.0	100.0	100.0	100.0
0.1	100.6	100.3	105.3	100.6	100.7	102.5
0.2	100.9	100.7	113.5	100.8	101.4	106.1
0.3	101.4	101.1	127.4	101.4	102.2	111.1
0.4	102.0	101.5	708.7	102.1	103.0	185.5
0.5	105.4	107.9	644.1	106.3	106.5	222.1

Notes: This table shows, for $\gamma \in [0, 0.5]$, the effects of public guarantees on buyer profit and welfare relative to the no-intervention benchmark. In all tables, buyer profit includes the cost of subsidies and guarantees.

Matters differ when assessing the welfare effects of public subsidies. Since all production under a contract receives the subsidy with certainty, yet counterparty risk remains, the fiscal burden tends to outweigh the modest welfare gains from slightly lowering prices and increasing investment. As a result, the net effect of public subsidies is less favorable and can become negative at high subsidy levels.

In order to compare the welfare effects of public guarantees and public support, we compute the value of the subsidy that equates the level of public expenditure across instruments. As illustrated in Figure 10, the comparison shows that public guarantees dominate public subsidies from a welfare perspective. This difference becomes more pronounced as counterparty risk increases, particularly when both contract demand and γ are high.

The comparison between regulator-backed contracts and public guarantees hinges

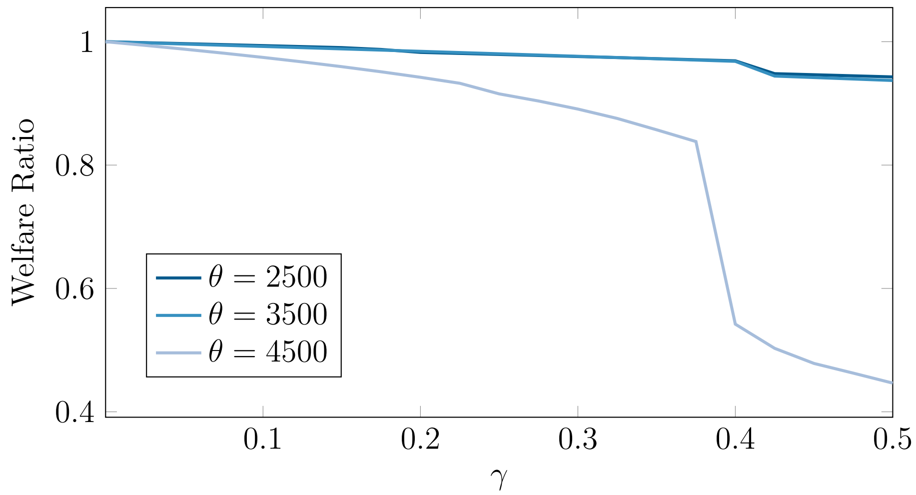


Figure 10: Welfare comparison: public subsidies versus public guarantees

Notes: This figure shows, for the three demand levels considered, Welfare under public subsidies relative to public guarantees for the value of the public subsidy that equates public expenditure under the two instruments. The ratio is always below 100%, and it is decreasing in $\gamma \in [0, 0.5]$.

on the relative amounts that regulators are willing to commit via guarantees or direct contracts. As an illustration, let's assume that they are equal, i.e., $\theta_R = \theta$. For the low-demand case (2,500 MW), Tables 2 and 3 present equilibrium prices for private and public contracts, total investment, and welfare relative to the no-intervention baseline.[37]

While regulator-backed contracts partially crowd out private contracts, total investment increases due to the induced demand-expansion effect. The wedge between public and private contract prices reflects the value sellers place on reducing counterparty risk, which translates into higher welfare gains. For low values of γ, both buyers and sellers are better off. However, for high values of γ, buyers can be worse off given that the demand expansion effect pushes up the price of private contracts, leading to higher prices for the regulator-backed contracts.

The welfare comparison between the scenarios with regulator-backed contracts and public guarantees captures both this demand expansion effect and the reduction in the fiscal cost associated with financing public guarantees. Together, these effects explain the superior welfare performance of regulator-backed contracts under equivalent commitments (see Figure 11).

[37]Our simulations do not capture cases where private contracts are fully crowded out. In this case buyers are unambiguously better off compared to the non-intervention case as the price of public contracts corresponds to those under perfect enforceability, while the contracted quantity remains unchanged.

Table 2: Equilibrium Outcomes with Regulator-backed Contracts relative to the No-Intervention Case

	Prices (€/MWh)			**Investment** (MW)		
γ	f_R^*	f^*	f_B	q_R	q^*	q_B
0.0	30.6	30.6	24.2	2,491	2,501	2,491
0.1	30.7	31.4	24.3	2,480	2,512	2,491
0.2	31.0	32.4	24.5	2,480	2,512	2,478
0.3	31.4	34.2	24.7	2,472	2,512	2,478
0.4	32.4	40.0	24.8	2,488	1,566	2,478
0.5	30.8	40.0	25.0	2,488	1,245	2,474

Notes: This table shows, for $\gamma \in [0, 0.5]$, the equilibrium price and quantity for regulator-backed contracts (f_R^*, q_R^*) and private contracts (f^*, q^*) relative to the equilibrium price of price contracts in the no-intervention baseline (f_B, q_B).

Table 3: Welfare Effects of Regulator-backed Contracts relative to the No-Intervention Case

γ	**Welfare** (%)	**Seller Profit** (%)	**Buyer Profit**(%)
0.0	198	963	137
0.1	197	995	132
0.2	196	1,044	127
0.3	192	1,149	115
0.4	146	1,205	62
0.5	135	1,062	69

Notes: This table shows, for $\gamma \in [0, 0.5]$, welfare, seller profit and buyer profit in the equilibrium with regulator-backed contracts relative to the no-intervention case. Regulator-backed contracts are welfare improving, leading to significant gains to sellers. Buyers benefit from regulator-backed contract only for $\gamma \leq 0.3$.

8 Concluding Remarks

In this paper, we uncover the implications of buyer counterparty risk, a market failure in long-term contracting that leads to inefficiently high prices, excessive risks, and underinvestment — even in the absence of other commonly studied failures like market power or environmental externalities. We also show that adding costly collateral does not always resolve this market failure and may even harm both sellers and buyers. Our analysis is robust across alternative specifications while remaining tractable enough to support meaningful extensions.

Although counterparty risk may appear in various settings, we argue it is especially

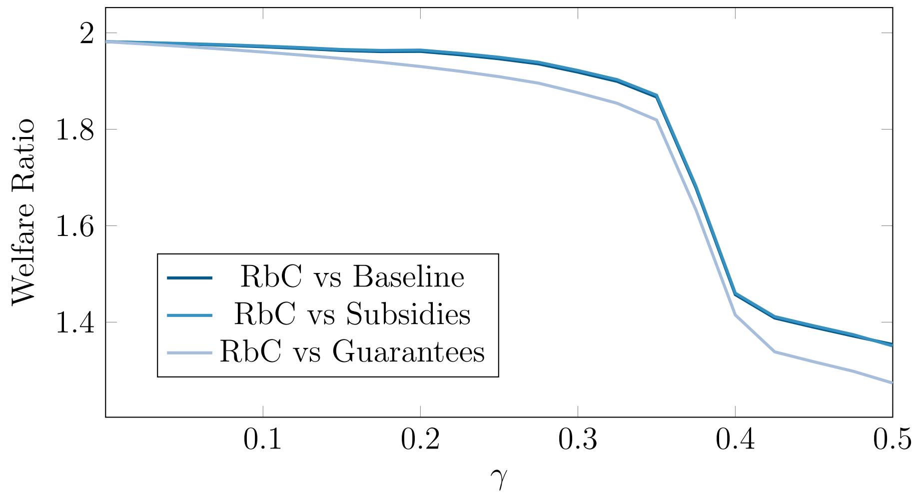


Figure 11: Welfare Ratio between regulator-backed contracts and the baseline, public subsidies, and public guarantees case.

Notes: This figure assumes $\theta = \theta_R = 2,500$. Welfare under the baseline and public subsidies is almost identical and the two corresponding curves overlap.

problematic for capital-intensive, long-term investments in sectors with highly volatile spot prices, where financing costs are particularly sensitive to price uncertainties. Renewable energy is a notable example, as underinvestment in low-carbon assets can impose severe social costs by delaying carbon abatement.

These inefficiencies highlight the potential for welfare-improving interventions, some of which have been implemented or discussed in policy circles, though their effects remain under-explored. Our paper aims to fill this gap, offering a flexible framework to analyze the impacts of policies that provide public guarantees or public subsidies, and encourage regulatory bodies to serve as contract counterparties. Overall, our findings suggest that policies need to address the root cause of counterparty risk; without mitigating this risk, countervailing measures may incur high costs — whether from public funds or from increased default risk driven by excessive contract prices.

Our simulations of long-term contracting in the Spanish market suggest a clear ranking of policy effectiveness: regulator-backed contracts yield the highest welfare gains, followed by public guarantees, with public subsidies performing least well. The key reason is that, unlike public subsidies, both regulator-backed contracts and public guarantees eliminate counterparty risk — though only the former does so without incurring fiscal costs. These results are likely to generalize beyond the specific case studied, as the underlying mechanisms are not tied to particular parameter values.

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A Proofs

Here we include the proofs of the results in the main sections of the paper.

Details on Example 1: Define $\tilde{p} = \min\{p, f\}$. Under a fixed-price contract, x is distributed according to a mixture of two distributions and the variance of x is

$$Var(x) = zVar(\tilde{p}) + (1-z)z(f - E(\tilde{p}))^2.$$

This implies that

$$R(f,z) = r\frac{Var(x)}{Var(p)} = rz\frac{Var(\tilde{p}) + (1-z)(f - E(\tilde{p}))^2}{Var(p)}.$$

We compute the variance of $\tilde{p}$, as

$$\sigma^2(f) \equiv Var(\tilde{p}) = E(\tilde{p}^2) - E(\tilde{p})^2.$$

The derivative of this expression with respect to f is

$$\frac{d\sigma^2}{df} = 2(f - E(\tilde{p}))(1 - \Phi(f)).$$

As a result,

$$\frac{\partial R}{\partial f}(f,z) = 2zr\frac{f - E(\tilde{p})}{Var(p)}(1 - z\Phi(f)),$$

which is always non-negative, and lower than $1 - z\Phi(f)$ if and only if

$$r \leq \frac{1}{2z}\frac{Var(p)}{f - E(\tilde{p})}. \tag{21}$$

Since the denominator in the right-hand side is increasing in f, it follows that the most stringent condition arises when $f = 1$, as indicated in the main text.

Finally, we now show that seller profits are decreasing in z. Notice that,

$$\frac{\partial \Pi_S}{\partial z} = -\int_0^f (f-p)\phi(p)dp - \frac{\partial R}{\partial z}(f,z),$$

where

$$\frac{\partial R}{\partial z} = r\frac{Var(\tilde{p}) + (1-2z)(f - E(\tilde{p}))^2}{Var(p)} > -r\frac{(2z-1)(f - E(\tilde{p}))^2}{Var(p)} > -\frac{(2z-1)(f - E(\tilde{p}))}{2z},$$

where we have used (21) to obtain a lower bound on this derivative. As $f - E(\tilde{p}) = \int_0^f (f-p)\phi(p)dp$, this implies that

$$\frac{\partial \Pi_S}{\partial z} < -\frac{f - E(\tilde{p})}{2z} < 0.$$

Proof of Lemma 1: In the text. $\square$

Proof of Corollary 1: It follows from Assumption 2 and equation(2) that $\underline{f}(\gamma)$ is increasing in γ. When $\gamma \to 1$, by Assumption 1, profits from the contract are lower than in the spot market. The rest of the argument is in the text. $\square$

Proof of Proposition 1 and 2: In the text. $\square$

Proof of Proposition 3: Let's denote as $V_S(\gamma)$ and $V_B(\gamma)$ the sum of the equilibrium profits of sellers and buyers as a function of γ. Note that the marginal investor just breaks even regardless of the share of opportunistic buyers.

Consider first the impact on sellers. If $\gamma \le \hat{\gamma}$, the marginal investor is the same as when there is perfect contract enforceability, which is also equivalent to the case with $\gamma = 0$. As in both cases the market clears, the marginal investor has costs $G^{-1}(\theta)$. Hence, sellers' profits are

$$V_S(\gamma) = V_S(0) = \int_0^{G^{-1}(\theta)} \left(G^{-1}(\theta) - c\right) g(c)dc.$$

Otherwise, if $\gamma > \hat{\gamma}$, counterparty risk implies that the marginal investor has costs $\bar{c}(\gamma) < G^{-1}(\theta)$. Seller profits become

$$V_S(\gamma) = \int_0^{\bar{c}(\gamma)} \left(\bar{c}(\gamma) - c\right) g(c)dc,$$

which are increasing in $\bar{c}(\gamma)$, and therefore decreasing in γ as $\bar{c}(\gamma)$ falls in γ. Since $V_S(0) = V_S(\gamma)$ for all $\gamma \le \hat{\gamma}$, and $V_S(0)$ is independent of γ, it follows that $V_S(0) > V_S(\gamma)$ for all $\gamma > \hat{\gamma}$.

Consider now the impact on buyers. If $\gamma \le \hat{\gamma}$, since sellers do not lose from counterparty risk, buyers suffer the full welfare loss,

$$\Delta V_B \equiv V_B(\gamma) - V_B(0) = W(\gamma) - W(0) = -\theta R(f^*, \gamma).$$

Trustworthy buyers suffer it more than proportionally as they face the same increase in the price as the opportunistic buyers but do not benefit from the possibility of default. Indeed, trustworthy buyers always lose from counterparty risk, while opportunistic buyers may benefit from it. In particular, if $\gamma \le \hat{\gamma}$,

$$\Delta\Pi_B^T \equiv \Pi_B^T(f) - \Pi_B^0 = G^{-1}(\theta) - f^* < 0,$$
$$\Delta\Pi_B^O \equiv \Pi_B^O(f) - \Pi_B^0 = G^{-1}(\theta) - f^* + \int_0^{f^*} \left(f^* - p\right) \phi(p)dp. \tag{22}$$

Otherwise, if $\gamma > \hat{\gamma}$, buyers are affected both by the increase in the price and the reduction in contract liquidity. The impact of counterparty risk on trustworthy buyers is

$$\Delta\Pi_B^T = G^{-1}(\theta) - E(p) < 0,$$

given that, regardless of whether they get allocated a contract or buy through the spot market, they pay a price $E(p)$, which by our assumption on demand, is greater than $G^{-1}(\theta)$. For opportunistic buyers, the impact is

$$\Delta\Pi_B^O = G^{-1}(\theta) - E(p) + \frac{G(\bar{c}(\gamma))}{\theta}\int_0^{E(p)} (E(p) - p)\phi(p)dp. \tag{23}$$

To sign the impact on opportunistic buyers, first notice that $\Delta\Pi_B^O$ is decreasing in γ either through the effect on f^* in (22) or through the effect on $\bar{c}(\gamma)$ in (23). Consider next the value of $\Delta\Pi_B^O$ as $\gamma \to 0$ in (22) and $\gamma = \overline{\gamma}$ in (23). At one extreme, if $\gamma \to 0$, then $f^* \to G^{-1}(\theta)$, so $\Delta\Pi_B^O > 0$ and opportunistic buyers always benefit from the possibility of default. At the other extreme, if $\gamma = \overline{\gamma}$, the contract market collapses, forcing all buyers to buy at spot prices. This makes each opportunistic buyer worse off, as each of them loses $E(p) - G^{-1}(\theta) > 0$. It follows that there exists a unique threshold $\gamma_O \in (\hat{\gamma}, \overline{\gamma})$ such that each opportunistic buyer is made worse off by the lack of contract enforceability if and only if $\gamma > \gamma_O$. □

Proof of Lemma 2: Regarding the seller, the lowest acceptable price, $\underline{f}_S(k)$, satisfies (9) with equality. Since

$$\frac{\partial \Pi_S(f,k,c)}{\partial k} = \Phi(f-k) + \frac{\partial R}{\partial f}(f-k,1) > 0,$$

it follows that $\underline{f}(k)$ must be decreasing in k

The highest price the seller is willing to accept, $\bar{f}(k)$, is its profit maximizing price. Since

$$\frac{\partial \Pi_S(f,k,c)}{\partial f} = (1 - \Phi(f-k)) - \frac{\partial R}{\partial f}(f-k,1) > 0,$$

by Assumption 1.

The highest price a buyer with cost of collateral ρ is willing to accept, $\bar{f}(k,\rho)$, satisfies

$$\Pi_B(\bar{f}(k,\rho),k,\rho) = v - E(p).$$

Since profits are decreasing in k and f, and the right-hand side is a constant, it follows that $\bar{f}(k,\rho)$ must be decreasing in k and ρ. For $k = 0$, we revert to the baseline model, with opportunistic buyers accepting the contract regardless of the price, $\bar{f}(0,\rho)=1$ for all ρ. For $k=1$, which fully eliminates counterparty risk, $\Pi_B(\bar{f}(1,\rho),k,\rho)=v-f-\rho$. Hence, $\bar{f}(1,\rho)=E(p)-\rho$. $\square$

Proof of Lemma 3: In an interior solution, defined as an outcome with positive counterparty risk, f^* is obtained from equation (11). Since $\hat{\rho}(f,k)$ is decreasing in f and k, and c^* is increasing in k, this implies that $f^*(k)$ is strictly decreasing in k. As this function is continuous and $f^*(0)=1>0>f^*(1)-1$, we have that there is a unique value of k, denoted as $\hat{k}$, such that $f^*(\hat{k})=\hat{k}$.

For this contract to eliminate counterparty risk it must lead to $f^*(\hat{k})=\hat{k}\geq \underline{f}=E(p)-r$. When this is not the case, eliminating counterparty risk is incompatible with sellers participating in the fixed-price contract. $\square$

Proof of Proposition 4: From Lemma 3, we only need to consider thresholds that exceed $E(p)-\hat{k}$. When the thresholds for r_S and r_W computed below do not meet this constraint, the relevant one is the maximum of both.

With respect to part (i), the derivative of the seller's profits in (8) with respect to k is

$$\frac{d\Pi_S\left(f^*,k,c\right)}{dk}=\left[\Phi\left(f^*-k\right)+r\phi\left(f^*-k\right)\right]+\left[1-\Phi\left(f^*-k\right)-\frac{\partial R}{\partial f}(f^*-k,1)\right]\frac{df^*}{dk}.$$

which evaluated at $\hat{k}$, where $f^*=\widehat{k}$, simplifies to

$$\left.\frac{d\Pi_S\left(f^*,k,c\right)}{dk}\right|_{k=\widehat{k}}=\frac{\partial R}{\partial f}(0,1)+\left(1-\frac{\partial R}{\partial f}(0,1)\right)\frac{df^*}{dk}. \tag{24}$$

The first term is how much a higher collateral reduces the cost of default. The second one captures how much it reduces profits in the absence of default by lowering the equilibrium price.

We can rewrite the market clearing condition using (7) equated to the outside option Π_B^0 as

$$\Psi(f,k)\equiv kG(c^*)-\left(\int_{f-k}^{1}(p-f)\phi(p)dp-k\Phi(f-k)\right)=0,$$

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

To compute $\frac{df^*}{dk}$ we use the Implicit Function Theorem where

$$\frac{d\Psi}{dk}=G(c^*)+kg(c^*)\left[\Phi(f-k)+\frac{\partial R}{\partial f}(0,1)(f-k,1)\right]+\Phi(f-k),$$

$$\frac{d\Psi}{df}=kg(c^*)\left[1-\Phi(f-k)-\frac{\partial R}{\partial f}(f-k,1)\right]+(1-\Phi(f-k)).$$

Evaluated at $k = \hat{k} = f^*\left(\hat{k}\right)$ we can compute

$$\left.\frac{df}{dk}\right|_{k=\hat{k}} = -\frac{\left.\frac{d\Psi}{dk}\right|_{k=\hat{k}}}{\left.\frac{d\Psi}{df}\right|_{k=\hat{k}}} = -\frac{G(\hat{k}) + \hat{k}g(\hat{k})\frac{\partial R}{\partial f}(0,1)}{\hat{k}g(\hat{k})\left(1 - \frac{\partial R}{\partial f}(0,1)\right) + 1}.$$

Replacing in (24), we obtain that eliminating counterparty risk decreases seller profits if and only if

$$\frac{\partial R}{\partial f}(0,1) < r_S^0 \equiv \frac{G(\hat{k})}{1 + G(\hat{k})}.$$

Regarding part (ii), total welfare can be written as

$$W(k) = \int_0^{\Pi_S(f^*,k,c^*)} \Pi_S\left(f^*, k, c\right) g(c)dc + \int_0^{\hat{\rho}} \left(\Pi_B(f^*, k, \rho) - \Pi_B^0\right) d\rho.$$

The derivative with respect to k evaluated at $f^*(\hat{k}) = \hat{k}$ becomes

$$W'(k) = G(c^*)\frac{d\Pi_S\left(f^*, k, c\right)}{dk} + \hat{\rho}\left[-(1 - \Phi(f-k))\frac{df}{dk} - \Phi(f-k) - \frac{\hat{\rho}}{2}\right]$$

where we are using the fact that $\Pi_S\left(f^*, k, c^*\right) = 0$ and $\Pi_B(f^*, k, \hat{\rho}) - \Pi_B^0 = 0$.

When we evaluate this derivative at $k = \hat{k}$ it becomes

$$W'(\hat{k}) = G(\hat{k})\left[\left.\frac{d\Pi_S\left(f^*, k, c\right)}{dk}\right|_{k=\hat{k}} - \left.\frac{df}{dk}\right|_{k=\hat{k}} - \frac{G(\hat{k})}{2}\right].$$

Replacing from part (i) we obtain that the derivative is increasing in k if and only if

$$\frac{\partial R}{\partial f}(0,1) < r_W^0 = \frac{G(\hat{k})(1 + g(\hat{k})\hat{k})}{2 + 2g(\hat{k})\hat{k} + 2G(\hat{k}) + G(\hat{k})g(\hat{k})\hat{k}}.$$

Furthermore,

$$r_S^0 - r_W^0 = \frac{G(\hat{k})\left(1 + g(\hat{k})\hat{k} + G(\hat{k})\right)}{(1 + G(\hat{k}))(2 + 2g(\hat{k})\hat{k} + 2G(\hat{k}) + G(\hat{k})g(\hat{k})\hat{k})} > 0.$$

We can then conclude that whenever it is worthwhile for the seller to eliminate counterparty risk it is also good for society but not the other way around. □

Proof of Proposition 5 and 6: In the text. □

Proof of Proposition 7: When $\theta \leq G(\bar{c}(\gamma))$, the first-order condition of the objective function of (15), contingent on $T > 0$, can be obtained as

$$\left(\frac{\partial R}{\partial f}(f^*, \gamma)\frac{\partial f^*}{\partial T} + \lambda\right)\theta = \left(-\frac{\frac{\partial R}{\partial f}(f^*, \gamma)}{1 - \Phi(f^*) - \frac{\partial R}{\partial f}(f^*, \gamma)} + \lambda\right)\theta = 0, \quad (25)$$

where $f^* = \tilde{f}(G^{-1}(\theta), T) \in (0, E(p))$ arises from (14) so that $\frac{\partial f^*}{\partial T} = -\frac{1}{1-\Phi(f^*)-\frac{\partial R}{\partial f}(f^*,\gamma)} < 0$. Since this condition of the minimization is increasing in λ, the objective function is supermodular in T and λ, implying that T^* is (weakly) decreasing in λ. As a result, f^* is (weakly) increasing in λ.

If λ is sufficiently small, we have that $f^* = 0$. This contract price characterizes a corner solution as long as $\lambda \leq \underline{\lambda} = \frac{\frac{\partial R}{\partial f}(0,\gamma)}{1-\frac{\partial R}{\partial f}(0,\gamma)} > 0$. Similarly, when $\lambda \to \infty$ then $T^* \to 0$ and $f^*(\lambda) \to \tilde{f}(G^{-1}(\theta), 0)$, and it yields a positive first order condition if $\lambda \geq \overline{\lambda} = \frac{\frac{\partial R}{\partial f}(\tilde{f}(G^{-1}(\theta),0),\gamma)}{1-\Phi(\tilde{f}(G^{-1}(\theta),0))-\frac{\partial R}{\partial f}(\tilde{f}(G^{-1}(\theta),0),\gamma)} > \underline{\lambda}$.

When $\theta > G(\bar{c}(\gamma))$, there are two possible optimal configurations. Contingent on $T \in (0, G^{-1}(\theta) - \bar{c}(\gamma)]$, we have that $c^* = \bar{c}(\gamma) + T$ resulting in $f^* = E(p)$. As a result, the first-order condition corresponding to (15) can be written as

$$-\left[E(p) - R(E(p), \gamma) - \bar{c}(\gamma) - (1 + \lambda)T_1^*\right] g(\bar{c}(\gamma) + T_1^*) + \lambda G(\bar{c}(\gamma) + T_1^*) = 0,$$

where we have denoted the solution as T_1^* and under the decreasing hazard-rate assumption on $g(c)$ characterizes its unique minimum. As before, T_1^* is decreasing in λ due to the supermodularity of the objective function. Denote welfare in this case as $W_1(\lambda)$.

Contingent on $T > G^{-1}(\theta) - \bar{c}(\gamma)$ the solution is characterized by (25). Denote this solution T_2^* and welfare as $W_2(\lambda)$.

When $\lambda = 0$, $W_2(0) > W_1(0)$ since the second case characterizes the optimum by lowering $f^*(0) = 0$ eliminating counterparty risk and $q^* = \theta$. When $\lambda \to \infty$, $\lim_{\lambda\to\infty} W_1(\lambda) > \lim_{\lambda\to\infty} W_2(\lambda)$ since $\lim_{\lambda\to\infty} T_1(\lambda) = 0$. Furthermore,

$$\frac{dW_2}{d\lambda} = -\theta T_2^* < -G(\bar{c}(\gamma) + T_1^*)T_1^* = \frac{dW_1}{d\lambda} < 0.$$

Therefore, there exists a unique $\hat{\lambda}$ where $W_1(\hat{\lambda}) = W_2(\hat{\lambda})$ so that the solution is $T^*(\lambda) = T_1^*$ if $\lambda > \hat{\lambda}$ and $f^* = \bar{f}$ and $T^*(\lambda) = T_2^*$ otherwise. In this latter case, the fixed-price is the same as in part (i). □

Proof of Lemma 4: We can write seller's expected utility as

$$U_S(f, \gamma) = \gamma \int_0^f u(p)\, \phi(f)\, dp + u(f)(1 - \Phi(f)\gamma) \tag{26}$$

$$= u\left(\gamma \int_0^f p\phi(f)\, dp + f(1 - \Phi(f)\gamma) - R^u(f, \gamma)\right) \tag{27}$$

Solving for the premium:

$$R^u(f,\gamma) = \gamma \int_0^f p\phi(f)\,dp + f(1-\Phi(f)\gamma) \tag{28}$$
$$- u^{-1}\left(\gamma \int_0^f u(p)\,\phi(f)\,dp + u(f)(1-\Phi(f)\gamma)\right) \tag{29}$$

The premium $R^u(f,\gamma)$ is a continuous function, and it is continuously differentiable given the properties of the utility function.

Taking derivatives on both sides of (27) w.r.t. f:

$$u'\left(\gamma \int_0^f p\phi(f)\,dp + f(1-\Phi(f)\gamma) - R^u(f,\gamma)\right)\left((1-\Phi(f)\gamma) - \frac{\partial R^u(f,\gamma)}{\partial f}\right) = u'(f)(1-\Phi(f)\gamma)$$

Solving it,

$$\frac{\partial R^u(f,\gamma)}{\partial f} = (1-\Phi(f)\gamma)\left(1 - \frac{u'(f)}{u'\left(\gamma \int_0^f p\phi(f)\,dp + f(1-\Phi(f)\gamma) - R^u(f,\gamma)\right)}\right) > 0, \tag{30}$$

which is positive because of the concavity of u and

$$f > \gamma \int_0^f p\phi(f)\,dp + f(1-\Phi(f)\gamma) - R^u(f,\gamma).$$

Furthermore, since the term in parentheses in (30) is lower than one, it follows that

$$\frac{\partial R^u(f,\gamma)}{\partial f} < (1-\Phi(f)\gamma) < 1-\Phi(f).$$

Evaluating the premium (29) at $(1,1)$, we obtain the same premium as without contracts:

$$R^u(1,1) = E(p) - u^{-1}\left(\int_0^1 u(p)\,\phi(f)\,dp\right) = r.$$

Evaluating (29) at $(0,\gamma)$ and $(1,0)$, we obtain:

$$R^u(0,\gamma) = R^u(1,0) = 0.$$

Last, it is easy to see that the properties of $R^u(f,\gamma)$ imply that $U_S(f,\gamma)$ is increasing in f. Hence, for $f \in (E(1),1]$, it attains a maximum at $f=1$. It follows that

$$U_S^0 = U_S(1,\gamma) > U_S(f,\gamma).$$

□

B Further Details on the Simulations

In this Appendix we provide details about the numerical simulations. The final objective has been to quantify, in the context of the Spanish electricity market, the impact of long-term contracts and related public policies on prices, investment, and welfare.

Constructing the average cost curve We have collected the set of electricity production units (solar or wind) in Spain that began operation in 2022. Each unit i is defined by its technology t (solar or wind), its capacity k_i (kW), and its geolocation l using Global Monitor (2023*a*,*b*).

A plant's *total costs* $C(k_i)$ are given by:

$$C(k_i) = \left(c_{it}^{INV} + c_{it}^{OM} \times \text{life}\right) \times \left[k_i + (1000 - k_i)\omega\right],$$

where the cost parameters have been obtained from IRENA (2023), and converted into euros using the average US/EUR exchange rate for that year. In particular, the investment cost (EUR/MW), c_{it}^{INV}, equals 820 for solar and $1,120$ for wind. The fixed operation and maintenance cost (EUR/MW), c_{it}^{OM}, equals 7.7 for solar and 30.7 for wind. Finally, the scale economies parameter is set to $\omega = 0.01$.

The *average cost* $c(k_i)$ is computed as:

$$c(k_i) = \frac{C(k_i)}{q_i},$$

where q_i is the plant's total lifetime production, computed as:

$$q_i = h_l \times \text{life} \times k_i,$$

where h_l is the location and technology-specific capacity factor for an expected lifetime of 25 years, obtained from the webpage https://www.renewables.ninja/, and life $= 25 \times 8,760$ hours.

Once we have characterized the plants' average costs, we construct the industry average cost curve by ranking the plants from low to high average cost, with their corresponding capacity. Figure 12 illustrates the estimated average costs for all the plants in our sample.

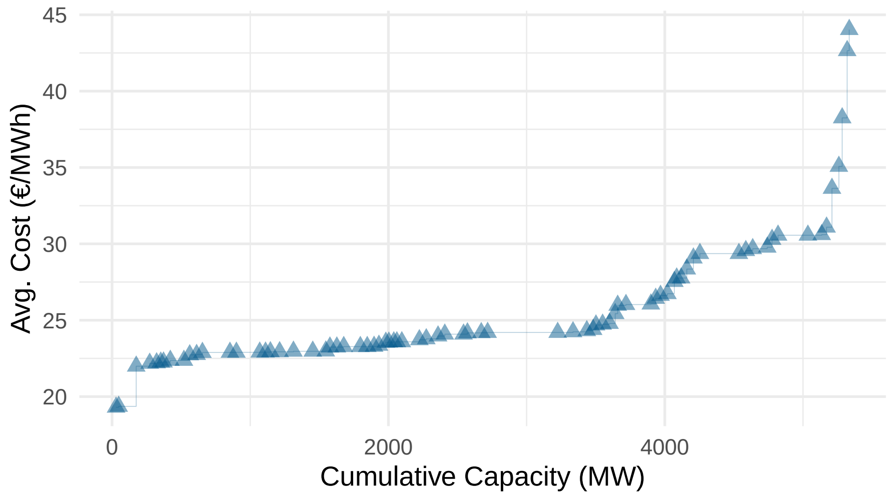

Figure 12: Average Cost Curve (€/MWh)

Constructing contract supply Sellers have to decide whether to invest, and whether to hedge through a fixed-price contract. We compute seller profits in the spot market and with fixed-price contracts.

Spot prices and contract prices are scaled to $p \times x$ and $f \times x$, respectively, where $p, f \in (0, 1)$, and $x = 60$ is a factor set so that the average spot price reflects the price at which electricity futures were trading in 2022. We assume that p follows a Beta distribution with parameters $\alpha = 4$ and $\beta = 2$. As a result,

$$E(px) = \frac{\alpha}{\alpha + \beta} x = 40, \quad \text{Var}(px) = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)} x^2 = 114.29.$$

We have adapted the profit expressions from the main text to accommodate the fact that production and capacities differ across plants and are not normalized to 1. When trading in the spot market, sellers obtain:

$$\Pi^0_{iS}(c) = q_i E(px) - C(k_i) - r_i, \tag{31}$$

where q_i is the total production of plant i in MWh and $r_i \equiv r_0(xq_i)^2 Var(p)$, where r_0 is set sufficiently low as to ensure positive spot profits for some plants, i.e., $r_0 = 1.334653 \times 10^{-7}$.

Alternatively, sellers who enter a contract at a fixed price $f \in (0, 1)$ earn profits:

$$\Pi_{iS}(f; \gamma; c) = q_i x \left[\gamma \int_0^f p\phi(p)\, dp + f \cdot \Big(1 - \gamma\Phi(f)\Big) \right] - R_i(f, \gamma) - C(k_i), \tag{32}$$

where $\phi(p)$ and $\Phi(p)$ are the PDF and CDF of the Beta distribution, respectively. The share of opportunistic buyers is in the range $\gamma \in [0, 0.5]$. The premium for each plant,

$R_i(f,\gamma)$, under mean-variance preferences, and using Assumption 1, is defined as

$$R_i(f,\gamma) = r_0\,\gamma\, q_i^2\, x^2\ \left[Var(\tilde{p}) + (1-\gamma)\times(f - E(\tilde{p}))^2\right].$$

A fixed-price contract must satisfy two constraints:

(i) **Break-even constraint**: contract profits have to be non-zero. For each plant, we compute the contract price f^c that equates contract profits to zero.

(ii) **Spot-market constraint**: the contract must be at least as profitable as trading in the spot market. For each plant, we compute the contract price f_i^{spot} that equates profits between the contract and the spot market.

Putting these together, the contract price offered by each plant is:

$$f_i = \max\{f_i^c, f_i^{spot}\}.$$

Constructing contract demand Contract demand is θ for prices at or below $xE(p)$, and zero for prices above. We use the values $\theta \in \{2500\,MW, 3500\,MW, 4500\,MW\}$.

Computing the equilibrium in the contract market The intersection between the contract supply curve and contract demand curve gives the contract price f^* that clears the market. If the two curves do not intersect, the equilibrium price is the expected spot price $xE(p)$ and the equilibrium quantity is the one that can be produced by plants with average costs below that level.

Welfare analysis We compute welfare without contracts, W^0, as the surplus generated by all plants that find it profitable to invest under spot trading only:

$$W^0 = \sum_{i\in\,\mathcal{I}_0} (x\times E(p)\times q_i - C(k_i) - r_i) \tag{33}$$

where $\mathcal{I}_0$ is the set of plants with $\Pi_S^0 \geq 0$.

When the share of opportunistic buyers is γ, welfare is computed as the surplus generated by all plants that invest in equilibrium with a fixed-price contract:

$$W(\gamma) = \sum_{i\in\mathcal{I}_\gamma} (x\cdot E(p)\cdot q_i - C(k_i) - R_i(f^*,\gamma)) \tag{34}$$

where $\mathcal{I}_\gamma$ is the set of plants i with $f_i \leq f^*$.

Seller profits in equilibrium with fixed-price contracts can be computed as

$$\Pi_S(\gamma) = \sum_{i \in \mathcal{I}_\gamma} \pi_{iS}(f^*, \gamma, c), \tag{35}$$

Buyer profits are computed as the difference between welfare and seller profit. This implies that the costs of public funds is attributed to buyers.

The simulations for the analysis of public policies follow similar steps, and are available from the authors upon request.