

# The Costs of Buyer Counterparty Risk in Long-Term Contracts\*

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## Abstract

This paper examines how buyer counterparty risk—arising from the possibility that buyers renegotiate long-term contracts under the threat of default—distorts market efficiency. We develop a theoretical model showing that the prospect of renegotiation raises contract prices, further increasing the likelihood of renegotiation, and depresses investment. We then assess several policy interventions to promote contract liquidity in the presence of buyer counterparty risk, including public subsidies, financial guarantees, and collateral requirements. While these tools can mitigate price distortions and stimulate investment, they also introduce trade-offs such as moral hazard, demand reductions, or the reliance on costly public funds. These insights are particularly relevant in sectors with capital-intensive, long-lived assets exposed to price volatility, notably electricity markets, where underinvestment in renewable generation may slow down the energy transition and hinder decarbonization goals. Finally, we simulate the Spanish electricity contract market for solar PV to quantify the model’s predictions.

**Keywords:** Imperfect Contract Enforcement, Counterparty Risk, Renegotiations, Renewable Investments, Bilateral Contracts, Vertical Integration, Dynamic Incentives.

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# 1 Introduction

Investment in capital-intensive, long-lived assets often relies on long-term contracts to reduce uncertainty around cost recovery, especially when market conditions over the asset’s lifetime are highly volatile. Imperfect contract enforcement, however, opens the door to renegotiation, which can undermine contract liquidity and ultimately lead to underinvestment.

The consequences of imperfect contract enforcement have been studied in several markets and industries—including coffee (Macchiavello and Morjaria, 2020), coal (Joskow, 1990), oil (Stroebel and van Benthem, 2013), flowers (Macchiavello and Morjaria, 2015), truckload freight (Harris and Nguyen, 2025a,b), and liquefied natural gas (Zahur, 2024)—but they are especially relevant in the case of electricity markets for renewable power plants. With nearly zero variable costs, these assets retain a positive market value once the investment is sunk, making owners more willing to accept lower renegotiated prices if buyers later gain access to cheaper alternatives. Worldwide, there is ample evidence of attempts by buyers to renegotiate long-term renewable contracts downward when spot market prices fall.<sup>1</sup>

Furthermore, because renewable-energy projects are particularly capital-intensive and long-lived, financing costs are critical in determining their profitability. Yet the high volatility of electricity prices—driven by fluctuating supply and demand conditions, as well as technological and policy uncertainty (Chen, 2024)—makes these projects especially risky unless they are backed by long-term contracts.<sup>2</sup> Moreover, as widely documented (Bessembinder and Lemmon, 2002; de Maere d’Aertrycke et al., 2017; Willems and Morbee, 2010), electricity markets are inherently incomplete, and market participants cannot rely on financial markets to fully hedge against all price uncertainties, particularly those arising in the distant future over the plants’ long lifetimes.<sup>3</sup> The lack of contract liquidity can lead to underinvestment in renewable capacity, delaying the energy transition and hindering carbon-abatement goals.

Against this backdrop, energy regulators envision long-term contracts between buyers

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<sup>1</sup>A sample of selected case studies is reported in Appendix A.

<sup>2</sup>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.

<sup>3</sup>The lack of financial instruments to hedge all electricity price risks is further exacerbated by technological and regulatory uncertainty (Fan et al., 2010).

and sellers as a way to reduce these risks and foster investment in renewable power sources, contributing to the energy transition and reducing the dependency on fossil fuels.<sup>4</sup> 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 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).<sup>5</sup>

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.*”<sup>6</sup> However, beyond this concern, the implications on the performance of long-term contract markets of buyer counterparty risk have not, to the best of our knowledge, been explored in detail.

This paper proposes a framework to analyze the implications of buyer counterparty risk on equilibrium market outcomes. We show that the risk of contract renegotiation pushes equilibrium contract prices up, which in turn makes renegotiation more likely. Contract liquidity declines as a result, undermining 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—both theoretically and

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<sup>4</sup>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).

<sup>5</sup>See also Gohdes et al. (2022) and Dukan and Kitzing (2023). In the context of liquefied natural gas markets, Zahur (2024) also finds evidence consistent with long-term contracts increasing producers’ ability to obtain debt and lower the cost of financing.

<sup>6</sup>In the context of electricity markets, buyer counterparty risk –rather than seller counterparty risk—is the primary concern. The reason is that the deployment of renewable energy is expected to depress future spot prices, thereby increasing buyers’ incentives to renege on previously agreed contract prices in favor of spot market transactions. Asymmetries in opportunistic attitudes are not uncommon. For example, in shipper–carrier relationships in the U.S. trucking industry, Harris and Nguyen (2025b) find that shippers are largely unresponsive to spot market temptations, whereas carriers exhibit opportunistic behavior.

empirically, using data from the Spanish electricity market.

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,<sup>7</sup> driving equilibrium investment below the level that a social planner would choose. The possibility of signing 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, buyers may wish to renegotiate contract prices when the spot price falls below the contract price.<sup>8</sup> As a result, contracts provide only partial insurance against price volatility, and the first-best outcome is no longer attainable.<sup>9</sup> Since our focus is on buyer counterparty risk, we assume that lenders discipline sellers against default, ruling out the possibility that sellers can credibly renegotiate contract prices when spot market prices rise.<sup>10</sup>

The risk of contract renegotiation introduces two sources of distortion. First, to compensate for the renegotiation risk, the equilibrium price of long-term contracts increases. In turn, this raises the probability of renegotiation for all contracts—not just the marginal ones—as it makes spot trading relatively more attractive. Although higher contract prices compensate sellers for the renegotiation risk, there is a limit to how much they can rise. In particular, prices cannot exceed the level that would make buyers indifferent between signing the contract or buying in the spot market. This creates a second distortion by limiting investment. As the risk of contract renegotiation reduces seller profits, investment diminishes, potentially leaving contract demand unmet, and resulting in inefficient contract rationing.

Paradoxically, buyers can be harmed by an increase in the risk of renegotiation. Individually, buyers benefit from renegotiation when spot prices fall below the price agreed in

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<sup>7</sup>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).

<sup>8</sup>In our baseline model, we normalize the cost of contract default and renegotiation to zero. In Section 4, we introduce a collateral that is forfeited upon default. The collateral affects the price renegotiations by altering the two parties' outside options. We show that the model's main predictions continue to hold. Likewise, in Section 6, we introduce a renegotiation cost and show that, unless renegotiation is prohibitively costly, the distortions due to counterparty risk remain, although they become milder.

<sup>9</sup>As shown in Section 6, vertical integration does not resolve this problem when the buyer faces downstream competition from rivals that can procure the good at spot prices, as it is often the case in electricity markets.

<sup>10</sup>This is grounded by the empirically-reasonable assumption that banks require sellers to operate under fixed-price contracts to reduce the risk of cost recovery. This is particularly compelling in dynamic settings, as the one we analyze in Section 6, where contract default would expose sellers to future price volatility during the remaining contract duration.

the contract. Collectively, this behavior drives up equilibrium contract prices and might reduce investment, often leaving them worse off. Notably, the pass-through of the renegotiation risk into contract prices might insulate sellers from the cost of buyer counterparty risk, unless it also results in a reduction in investment, making them worse-off.

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, it is often inefficient to set collateral requirements high enough to eliminate the threat of default and the ensuing renegotiations. Instead, optimal collateral levels should balance out the benefits of reducing the likelihood of a renegotiation against the buyer's cost of posting collateral.

Our analysis suggests that public policies addressing buyer counterparty risk can yield welfare gains, but they are not without distortions. Several such measures have already been proposed in regulatory debates or implemented in electricity markets in Europe and the United States, including contract obligations on buyers to promote contract demand, public subsidies, and financial guarantees. We analyze their implications theoretically and, motivated by the recent boom in renewable energy investment in Spain, we also provide an empirical assessment using detailed cost data from solar plants 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 indicate that long-term power contracts stimulate investment and generate welfare gains for both buyers and sellers in the Spanish market. Relative to the no-contracts benchmark, aggregate welfare gains decline as the renegotiation-risk parameter increases. Buyer-specific gains fall more sharply, underscoring that, as the likelihood of renegotiation rises, buyers capture a progressively smaller share of the surplus created by contracting.

We also show that public guarantees and investment subsidies can raise welfare by lowering equilibrium contract prices, reducing sellers' risk premia, and facilitating investment, but they may also generate distortions through the shadow cost of public funds and inefficiently high investment. Public guarantees are most likely to be welfare-improving when counterparty risk is substantial and participation on the demand side of the contract market is limited, although the resulting gains may accrue disproportionately to

sellers. By contrast, regulators should be cautious when deploying public guarantees in settings with strong contract demand, as they can induce overinvestment, reduce welfare, and ultimately harm consumers.

Similar concerns apply to public subsidies, although the quantitative magnitudes may differ because their welfare effects are more sensitive to the cost of public funds. In particular, when public funds are costly, it is preferable not to provide positive subsidies, while the introduction of public guarantees may still be welfare-improving.

We have intentionally kept our setup simple to highlight the main mechanisms, but the implications of our analysis are robust to alternative specifications. Although we focus on contract renegotiation as the manifestation of poor contract enforcement, the results are more general. Our model can be easily reinterpreted to accommodate actual default if the renegotiations fail, possibly due to the presence of asymmetric information regarding the buyer's true willingness to default. 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 explore the dynamic incentives that arise under long-term contracts when spot prices are time-varying. We show that, at the beginning of the contract, the buyer has more incentives to honor it because it provides a hedge value for later periods. However, when spot prices are sufficiently low, the buyer still has incentives to renege on the contract, giving raise to the same qualitative implications as in the main model. Interestingly, in the dynamic game, the scope for renegotiation is limited and default is more likely.

**Related Literature** This paper contributes to the literature on contracting with imperfect enforcement (e.g., Baker et al. (2002), Hart (1995, 2009), and Klein (1996)) by highlighting the interaction between bilateral relationships and market-wide equilibrium outcomes. In our framework, the probability of contract renegotiation under the threat

of default is endogenous, as it depends on the equilibrium contract price. As a result, counterparty risk becomes self-defeating for buyers: while renegotiation may be individually profitable ex-post, it raises equilibrium contract prices ex-ante, worsening buyers' terms and eroding contract liquidity.

In recent years, the effects of imperfect enforcement have been empirically documented in a variety of 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 contracts 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. Harris and Nguyen (2025a) and Harris and Nguyen (2025b) study shipper–carrier relationships in the U.S. trucking industry, documenting the contractual mechanisms used to mitigate carriers' opportunistic behavior and characterizing the optimal mix of long-term contracting and spot-market transactions. Our paper provides a theoretical framework for some of the empirical findings reported in these papers.

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 to investors. 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.<sup>11</sup> 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. While our focus is on long-term contracts between private parties, we also relate to this body of work by examining the design of public policies aimed at supporting the liquidity of private contracts.

Our model also captures salient features of liquefied natural gas (LNG) markets,

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<sup>11</sup>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.

providing a theoretical framework consistent with the empirical findings in Zahur (2024). As with renewable generation, LNG exporters incur large upfront, sunk investments in liquefaction terminals and typically rely on long-term contracts with buyers who may enjoy substantial ex-post bargaining power. In these markets, as documented by Zahur (2024), ex-ante contracting facilitates investment by lowering financing costs, yet buyers' ex-post bargaining power weakens sellers' incentives to invest. A key difference relative to our setting, however, is that LNG contracts can generate ex-post inflexibilities—most notably, contracted cargoes may not be easily redirected toward destinations with higher realized demand—whereas such physical reallocation constraints are absent from our framework.<sup>12</sup>

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 under perfect and imperfect contract enforcement, 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, 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 B.

## 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 who 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  $[0, 1]$ .

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<sup>12</sup>In electricity markets, electricity production must be sold in the electricity system where the facilities are located. Prices across electricity systems converge in the absence of congestion constraints; if these exist, selling to another more profitable market is not feasible. Moreover, long-term contracts in electricity markets often involve financial commitments that are settled according to the price differences, not physical ones.

Without entry, there is enough pre-existing 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  $[0, 1]$ .<sup>13</sup> 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.<sup>14</sup>

The timing of the game is as follows. First, at the investment stage, potential sellers observe their investment cost  $c$  and then decide whether to enter, before knowing the realization of the marginal cost of the pre-existing capacity,  $p$ . Second, at the production stage, once  $p$  is realized, buyers and sellers trade in a perfectly competitive spot market. The equilibrium price is zero if the new capacity fully covers total demand, and  $p$  otherwise.<sup>15</sup> Thus, in any subgame-perfect Nash equilibrium, the pre-existing capacity sets the market price at  $p$ . Anticipating this, potential entrants at the investment stage expect to operate at full capacity and to sell at the expected spot price  $E(p)$ .

For sellers, exposure to volatile spot-market prices creates uncertainty over cost recovery, resulting in an extra cost  $r \in [0, E(p)]$ . We offer two potential interpretations for this cost premium: (i) 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);<sup>16</sup> or (ii) as 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  $r_0 \leq E(p)/Var(p)$ . In contrast, buyers, who do not make any investment, are unaffected by the spot price volatility.

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

$$\begin{aligned}\Pi_B^0 &= v - E(p), \\ \Pi_S^0(c) &= E(p) - r - c.\end{aligned}$$

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<sup>13</sup>In Section 6.4, we argue that results would be qualitatively unchanged under an increasing marginal cost curve.

<sup>14</sup>Positive or negative externalities derived from investment could be easily accommodated as an additive effect to the cost savings.

<sup>15</sup>The former case, however, will not arise in equilibrium, since entrants would then fail to recover their investment costs.

<sup>16</sup>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 buyers and sellers, which effectively implies perfect observability of the seller's income.

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

If sellers were isolated from volatile spot prices, they would invest until the marginal cost savings equaled the investment cost,  $c \leq c^{FB} \equiv E(p)$ , or  $q^{FB} \equiv G(E(p))$ . Hence, due to the seller's cost premium  $r > 0$ , the market solution is characterized by underinvestment relative to the First Best. In this paper, fixed-price contracts increase efficiency through a reduction in the sellers' exposure to volatile prices, as shown next.

### 3 Fixed-price Contracts

In the rest of the paper, we allow for buyers and sellers to sign a fixed-price contract prior to investment, enabling them to hedge their spot-market transactions.<sup>17</sup> However, only a fraction  $\theta \leq 1$  of buyers participates in the contract market, while the remaining buyers always procure the good in the spot market.<sup>18</sup> To make the analysis non-trivial, we assume that this contracting mass exceeds the investment that would take place in the absence of contracts, i.e.,  $\theta > G(E(p) - r)$ . 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  $f > p$ .

We begin by presenting a benchmark setting with perfect contract enforceability. The main analysis of the paper will then consider a richer environment where buyers can credibly renegotiate the contract after low spot prices are realized, under the threat of default.

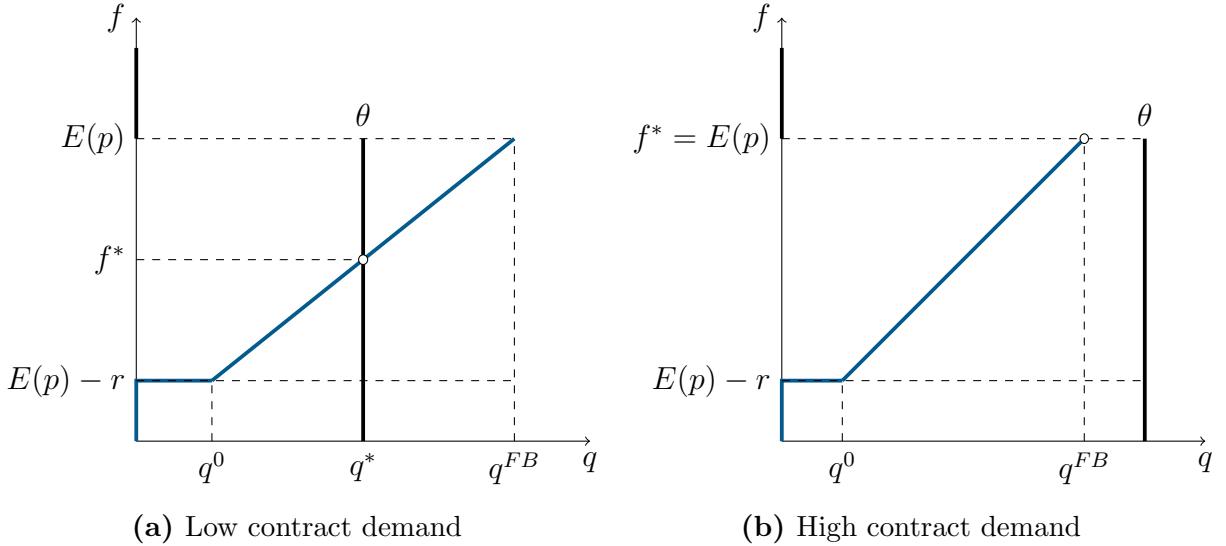
#### 3.1 Perfect Contract Enforceability

A perfectly enforceable contract at a price  $f$  implies that all uncertainty is removed from the seller's payoff and, as a result, the cost premium  $r$  is eliminated. The buyer's

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<sup>17</sup>Contracts could also incorporate some degree of price exposure or partial indexation to spot prices. However, doing so would introduce additional risks, raising issues similar to those analyzed in Section 3.2. See Fabra and Llobet (2025) for an analysis of the optimal degree of price exposure as a function of the characteristics of the production technologies.

<sup>18</sup>In practice, participation in the contract market is more likely for energy-intensive consumers; typically, large corporations in the IT and manufacturing sectors (see Appendix A). In Section 4, we endogenize buyers' participation rate  $\theta$  by introducing a (costly) collateral requirement, which might be less onerous for these types of buyers.



**Figure 1:** The Contract Market Equilibrium under Perfect Contract Enforceability

Notes: In panel (a),  $\theta \leq G(E(p))$  and the market clears at  $f^*$ , which is given by the cost of the marginal investor  $c^*$ . In panel (b),  $\theta > G(E(p))$  and 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  $U[0, 1]$ .

and seller's profits become

$$\Pi_B(f) = v - f,$$

$$\Pi_S(f, c) = f - c.$$

Since trading in the spot market is the outside option, buyers are only willing to accept contracts with  $f \leq E(p)$ . In turn, contract prices must allow sellers to break even,  $f \geq c$ , and to earn at least as much as in the spot market,  $f \geq E(p) - r$ .

Two cases must be considered. First, as shown in Figure 1(a), when contract demand is low,  $\theta \leq G(E(p))$ , there is market clearing at a quantity  $q^* = \theta$  and price  $f^* = G^{-1}(\theta)$ , covering the cost of the marginal investor. 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 carried out.

Second, when contract demand is high,  $\theta > G(E(p))$ , Figure 1(b) shows that there is demand rationing; only  $q^* = G(E(p)) < \theta$ , is satisfied at the highest possible equilibrium price,  $f^* = E(p)$ , supporting all the socially-efficient investments. Importantly, rationing is efficient in this case, as further investment would involve an investment cost  $c$  exceeding

the marginal cost savings,  $E(p)$ .

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 the sellers' cost premium  $r$ , leading to market clearing with  $q^* = \theta$  at  $f^* = G^{-1}(\theta)$  if  $\theta \leq G(E(p))$ , and to efficient 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.*

As it is clear from this simple discussion, under perfect contract enforceability, policies aimed at fostering the demand for fixed-price contracts would always increase social welfare and, when sufficiently high, the First Best will be attained.

### 3.2 Imperfect Enforcement and Renegotiation

We now turn to the case in which contracts cannot be perfectly enforced. Specifically, after the spot price  $p$  is realized, the buyer can renegotiate the contract price with probability  $\gamma \in [0, 1]$  by making a take-it-or-leave-it offer to the seller under the threat of default. We refer to  $\gamma$  as the renegotiation risk parameter.<sup>19</sup> Since our focus is on buyer counterparty risk, we assume that sellers face prohibitively high costs from renegotiating the contract, stemming from the fact that financing contracts are often related to the signing of long-term contracts. Hence, sellers have no credible scope to renegotiate.

Renegotiation occurs after investment decisions have been made, and the investment cost is sunk. The seller's outside option at that stage is therefore to sell its output on the spot market at the realized price  $p$ . Consequently, when  $p < f$  and the buyer makes a take-it-or-leave-it offer, the contract price is renegotiated down to  $p$ .

The previous arguments allow us to write the profits of a buyer with a contract price  $f$ , that can be renegotiated with probability  $\gamma$  whenever it is in the buyer's interest to

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<sup>19</sup>All buyers are assumed to be equally likely to renegotiate the terms of the contract. In Section 6, we consider an adverse selection environment in which buyers can be of two types: opportunistic, with probability  $\gamma$ , or trustworthy, with probability  $1 - \gamma$ . Opportunistic buyers always renegotiate whenever it is in their interest to do so, whereas trustworthy buyers never renegotiate. We show that adverse selection enlarges the distortions uncovered in the baseline model.

do so, as

$$\Pi_B(f, \gamma) = v - \gamma \int_0^f p\phi(p) dp - f [1 - \gamma\Phi(f)]. \quad (1)$$

As it is intuitive, buyer profits are decreasing in  $f$  and increasing in  $\gamma$ .

In turn, sellers receive the contract price  $f$  whenever buyers do not renegotiate, i.e., an event that occurs with probability  $1 - \gamma\Phi(f)$ ; otherwise, sellers receive the realized spot price  $p$ .<sup>20</sup> Their profits become

$$\Pi_S(f, \gamma, c) = \gamma \int_0^f p\phi(p) dp + f [1 - \gamma\Phi(f)] - R(f, \gamma) - c. \quad (2)$$

The term  $R(f, \gamma)$  is a cost premium, analogous to  $r$  under spot trading, but now reflecting the fact that the seller is exposed to spot-market prices only if renegotiation occurs. The cost premium plays a central role in the model, insofar as it determines the gains from trade between buyers and sellers (i.e., the sum of (1) and (2)).

Rather than imposing a specific functional form for the cost premium, we assume it satisfies a set of properties outlined below.

**Assumption 1.** *The function  $R(f, \gamma)$  is continuously differentiable, strictly increasing in  $f$  and  $\gamma$ , and such that  $\Pi_S(f, \gamma)$  is increasing in  $f$ . Furthermore,  $R(0, \gamma) = R(f, 0) = 0$ , and  $R(1, 1) = r$ .*

The cost premium is  $R(f, \gamma)$  is strictly lower than  $r$ , unless the contract is always renegotiated, which occurs when the contract is priced at the highest possible spot price,  $f = 1$ , and  $\gamma = 1$ . Likewise, the cost premium disappears if contracts are never renegotiated, which occurs either when contracts are priced at the lowest possible spot price,  $f = 0$ , or when  $\gamma = 0$ .

The fact that  $R(f, \gamma)$  increases in both  $f$  and  $\gamma$  can be rationalized under the interpretations of the cost premium proposed earlier. If the premium arises from financial frictions, a higher probability of renegotiation (which increases in  $f$  and  $\gamma$ ) makes costly income verification by the lender more likely, and this expected cost is passed through to the seller as a higher cost of capital. Alternatively, the premium can be rationalized by managers having mean-variance preferences, in which case renegotiation raises the

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<sup>20</sup>Analytically, this profit function is equivalent to the payoff of a call option that buyers exercise with probability  $\gamma$ . Since such options do not insulate sellers from price volatility, the use of call options generates effects analogous to those described in this paper.

volatility of seller returns and, therefore, the required premium. Under this interpretation, compliance with Assumption 1 amounts to  $r$  being sufficiently low.<sup>21</sup>

Since the premium increases in  $f$ , our assumption guarantees that this effect is not so strong as to overturn the direct positive impact of  $f$  on returns, which would imply that seller profits decrease in  $f$ , making contracts are such prices irrelevant.

Equations (1) and (2) determine the scope for trade as they establish the maximum contract price that buyers are willing to pay, and the minimum contract price that sellers are willing to receive. First, a buyer will not accept a contract price yielding expected payments above the expected spot market price. In particular, the maximum price that a buyer is willing to pay,  $\bar{f}(\gamma)$ , is implicitly defined by  $\Pi_B(\bar{f}, \gamma) = v - E(p)$ , increasing in  $\gamma$  and above  $E(p)$ .

Second, sellers benefit from fixed-price contracts by reducing the cost premium, but in return, they forgo potential gains from spot prices exceeding the contract price. Hence, contract prices must make sellers at least indifferent between signing the contract or directly trading in the spot market. Additionally, contract prices must also make the investment profitable. These two conditions imply that the minimum price that sellers are willing to accept,  $\underline{f}(\gamma, c)$ , is implicitly defined by

$$\Pi_S(\underline{f}, \gamma, c) = \max \{ \Pi_S^0(c), 0 \}. \quad (3)$$

Since contract profits are lower the higher the likelihood of renegotiation,  $\underline{f}(\gamma, c)$  is strictly increasing in  $\gamma$ . Hence,  $\underline{f}(\gamma, c)$  is greater than or equal to  $E(p) - r$ , which is the minimum contract price in the absence of renegotiation,  $\gamma = 0$ . Likewise, since the break-even constraint is more demanding for higher cost sellers,  $\underline{f}(\gamma, c)$  is (weakly) increasing in  $c$ .

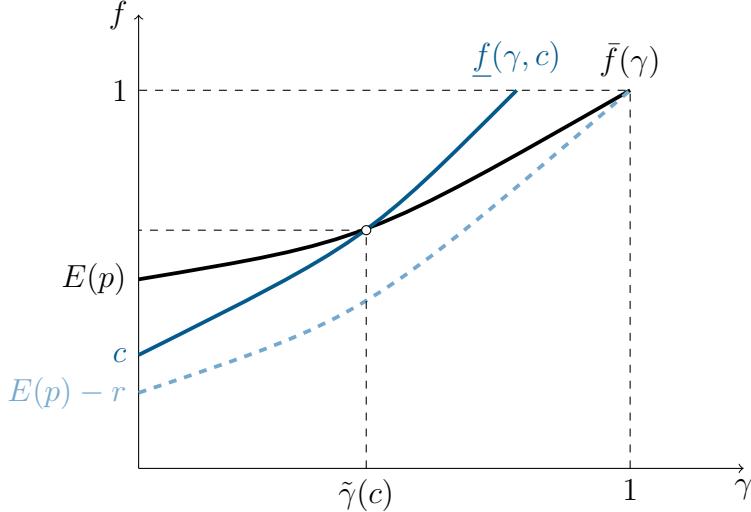
Our first lemma characterizes the properties of these price thresholds, which are illustrated in Figure 2.

**Lemma 1.** *The threshold prices for buyers and sellers to accept a fixed-price contract have the following properties:*

- (i)  $\bar{f}(\gamma)$ , is increasing in  $\gamma$ , with  $\bar{f}(0) = E(p)$  and  $\bar{f}(1) = 1$ .
- (ii)  $\underline{f}(\gamma, c)$ , is increasing in  $\gamma$  and weakly increasing in  $c$ . In particular,  $\underline{f}(0, c) \geq E(p) - r$  and  $\underline{f}(1, c) \geq 1$ , satisfied with equality for all  $c \leq E(p) - r$ , and with strict

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<sup>21</sup>See Appendix C for details. More generally, we also show that our assumption on the premium is also consistent with sellers having standard concave utility functions.



**Figure 2:** The Scope for Contracting

Notes: This figure depicts the highest price that buyers are willing to accept (solid black line) and the lowest price that sellers are willing to accept (solid blue line for sellers with cost  $c > E(p) - r$ , and dashed blue line for  $c \leq E(p) - r$ ) as a function of the renegotiation risk parameter,  $\gamma$ . Whereas there is always scope for trading with seller types  $c \leq E(p) - r$ , the higher cost sellers require  $\gamma$  to be below  $\tilde{\gamma}(c)$ .

*inequality for all higher costs.*

Furthermore,  $\underline{f}(\gamma, c)$  is steeper in  $\gamma$  than  $\bar{f}(\gamma)$ , for all  $\gamma$  and  $c$ .

In the absence of renegotiation,  $\gamma = 0$ , and consistent with the perfect-enforcement case discussed above, both buyers and sellers are willing to accept any contract price that delivers higher profits than spot-market trading, provided that the investment is profitable, i.e.,  $\bar{f}(0) = E(p) > \underline{f}(0, c) = \max\{E(p) - r, c\}$ , supporting investments with  $c > E(p) - r$  that would not occur without the contract. At the opposite extreme, when  $\gamma = 1$ , the contract offers no upside to the seller who anticipates that the price will always be renegotiated to  $p$  whenever it falls below  $f$ . Consequently, the only feasible contract price is  $f = 1$ . As this price delivers the same outcome as the spot market, it is acceptable only for sellers who would invest even without a contract, i.e.,  $\bar{f}(1) = \underline{f}(1, c) = 1$  for  $c \leq E(p) - r$ , and  $\bar{f}(1) = 1 < \underline{f}(1, c)$  for higher cost types.

A direct implication of this result is that if buyers are very likely to renegotiate, contracts cannot induce investment beyond what would occur in the absence of contracting. This is a classical instance of hold-up.

**Corollary 1.** *For any  $c > E(p) - r$ , there exists a unique threshold  $\tilde{\gamma}(c) \in (0, 1)$  such*

that there is scope for contracting with a seller with cost  $c$  if and only if  $\gamma \leq \tilde{\gamma}(c)$ , with  $\tilde{\gamma}(c)$  decreasing in  $c$ .

Combining the previous results, we can derive the lower and upper bounds for equilibrium prices in the contract market, given the cost of the marginal investor,  $c^*$ .

**Lemma 2.** *For all  $\gamma \in [0, 1]$ , the equilibrium contract price must be such that  $f^* \in [\underline{f}(\gamma, c^*), \bar{f}(\gamma)]$ , where the cost of the marginal investor satisfies  $c^* > E(p) - r$ .*

This result, which relies on the assumption that  $\theta > G(E(p) - r)$ , implies that for any  $\gamma < 1$ , long-term contracts foster investment above and beyond the level induced by the spot market. Hence, in equilibrium,  $\Pi_S^0(c^*) < 0$ , and the cost of the marginal investor can be defined from (3) as

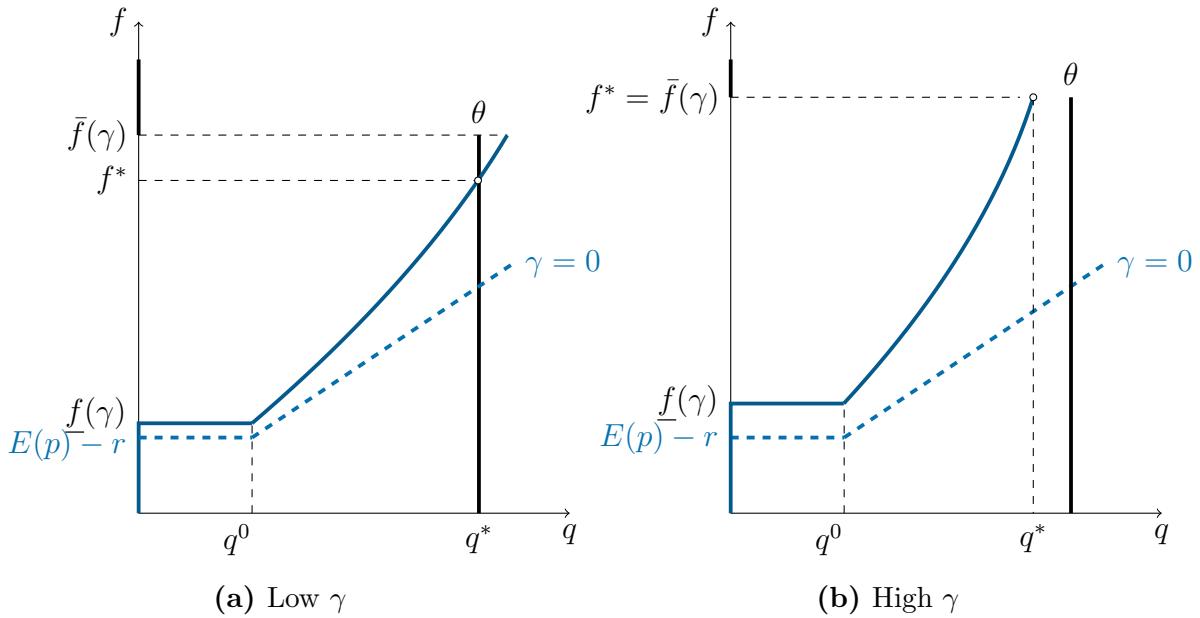
$$\Pi_S(\underline{f}, \gamma, c^*) = 0. \quad (4)$$

Figure 3 illustrates the two possible equilibrium configurations depending on the renegotiation risk parameter,  $\gamma$ . As shown in panel (a), for low values of  $\gamma$  (formally, for  $\gamma \leq \tilde{\gamma}(c^*)$ ), all demand is satisfied, implying that  $f^* < \bar{f}(\gamma)$  and  $q^* = \theta$ . For higher values of  $\gamma$ , because the supply curve shifts further up, demand is rationed. As shown in panel (b), this implies that the equilibrium price reaches its highest level, extracting all buyers' surplus. The equilibrium level of investment,  $q^* = G(c^*)$ —where  $c^*$  is implicitly defined in (4)—involves inefficient rationing: some of the contract demand that would be efficiently served under perfect contract enforcement is left unmet.

The next proposition summarizes the effects of imperfectly enforceable contracts, both relative to the no-contract benchmark and relative to the case of perfect enforceability.

**Proposition 2.** *Relative to the no-contract case, fixed-price contracts reduce sellers' cost premia and mitigate underinvestment. Relative to the perfect-enforceability benchmark, the effect of contracts depends on the renegotiation risk parameter. There exists a threshold  $\hat{\gamma}$ , implicitly defined by  $\pi_S(\bar{f}(\hat{\gamma}), \hat{\gamma}, G^{-1}(\theta)) = 0$ , such that:*

- (i) *If  $\gamma \leq \hat{\gamma}$ , the market clears at  $q^* = \theta$  and equilibrium prices are higher than in the absence of counterparty risk,  $f^* > G^{-1}(\theta)$ . A reduction in the buyers' renegotiation power  $\gamma$  decreases the equilibrium price  $f^*$  without affecting investment  $q^*$ .*
- (ii) *If  $\gamma > \hat{\gamma}$ , counterparty risk gives rise to inefficient demand rationing,  $q^* < \theta$ , and to the highest feasible contract prices,  $f^* = \bar{f}(\gamma)$ . In this case, a higher renegotiation*



**Figure 3:** 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. In subfigure (b),  $\gamma > \hat{\gamma}$ , which shifts the supply curve inwards. This implies that demand  $\theta$  is now above the mass of sellers  $q^*$  that can break even at that price. Demand rationing leads to inefficient investment. The dashed line represents the supply curve with perfect contract enforcement.

risk parameter  $\gamma$  increases the equilibrium price  $f^*$  and reduces the equilibrium quantity  $q^*$ .

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

### 3.3 Welfare Effects of Imperfectly Enforceable Contracts

Define  $W^*(\gamma)$  as the level of total welfare when the renegotiation risk parameter is  $\gamma$ . Notice that  $\gamma = 0$  corresponds to the perfect enforcement case, while  $\gamma = 1$  is equivalent to a situation where long-term markets do not exist.

We first compare the welfare contribution of fixed-price contracts relative to the no-contract case:

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

where, as defined in Proposition 2,  $f^*$  is the equilibrium contract price, and  $c^*$  is the investment cost of the marginal seller. The first term shows that all sellers who would otherwise invest in the spot market (those with  $c \leq E(p) - r$ ) benefit from the reduced

price exposure that contracts provide. The second term measures the social welfare contribution of the additional entry net of the cost premium caused by counterparty risk,  $R(f^*, \gamma)$ . 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

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

The first term in (6) represents the increased cost of price exposure caused by counterparty risk,  $R(f^*, \gamma)$ . This welfare cost rises with  $\gamma$ , both directly, as a higher  $\gamma$  increases the contract price, and indirectly, as the price increase weakly raises the cost premium. Notably, this increase in the cost premium affects the mass of all investors,  $G(c^*)$ , including the inframarginal ones. The second term in (6) captures the potential distortion caused by underinvestment.

The next result shows how an increase in  $\gamma$  affects buyers and sellers.

**Proposition 3.** *In equilibrium, if the renegotiation risk parameter  $\gamma$  increases,*

- (i) *Sellers' profits remain unchanged when  $\gamma < \hat{\gamma}$ , and decrease otherwise.*
- (ii) *Buyers' profits remain unchanged when  $\gamma \geq \hat{\gamma}$ , and decrease otherwise.*

When the  $\gamma$  is low (Figure 3(a)), the market always clears. Thus, as  $\gamma$  increases, sellers can fully pass on the higher expected costs associated with counterparty risk to contract prices without affecting investment or their profits. Since the welfare loss (6) increases in  $\gamma$ , buyer profits decrease due to the price increase, despite their higher ability to renegotiate contract prices.

When  $\gamma$  is high (Figure 3(b)), the equilibrium price extracts all the surplus from buyers,  $f^* = \bar{f}(\gamma)$ . As a result, sellers can no longer fully pass on the additional cost of counterparty risk. Thus, in this region, an increase in  $\gamma$  reduces investment, making sellers worse off while buyers' surplus remains constant at 0.

So far, our analysis has highlighted the importance of the equilibrium effects of counterparty risk, as it leads to high contract prices, excessive risks, and underinvestment. It stands to reason that measures aimed at reducing the scope for renegotiation should increase contract liquidity and reduce underinvestment. We next turn to the study of this issue.

## 4 Pledging Collateral

Our previous analysis assumed that buyers could threaten to default at no cost, thereby granting them the possibility to renegotiate the contract price down to the spot price. Although this assumption is analytically convenient, penalties for contract breach are common in practice. We accommodate this feature by supposing that buyers must pledge a collateral  $k > 0$ , which is forfeited and transferred to the seller in the event of default. The presence of collateral both reduces the incidence of renegotiation and strengthens the seller's outside option, limiting the buyer's ability to force the contract price all the way down to the spot price.

It is straightforward to see that a sufficiently high collateral can prevent renegotiation altogether. Such levels, however, are rarely observed in practice because they would impose a substantial financial burden on buyers. To capture this friction explicitly, we assume that posting collateral is costly: each buyer faces a per-unit cost of posting collateral  $\rho$ , which is heterogeneous and distributed uniformly on  $[0, 1]$ , i.e.,  $\rho \sim U[0, 1]$ . Variation in  $\rho$  can be interpreted as differences in buyers' financing costs for collateral, and more broadly, as heterogeneity in buyer trustworthiness.<sup>22</sup>

For simplicity, we assume in this section that buyers can always renegotiate contract prices,  $\gamma = 1$ . Note that, in this case, in the absence of collateral, by Lemma 1, the contract market would not induce any additional investment. We also set  $\theta = 1$ , so that market participation is determined only by the cost of posting collateral.

When the value of the collateral exceeds the contract price,  $k \geq f$ , buyers never find it optimal to renegotiate the contract. Hence, the utility of buyers and sellers simplifies to

$$\begin{aligned}\Pi_B(f, k; , \rho) &= v - f - \rho k, \\ \Pi_S(f, k, c) &= f - c.\end{aligned}$$

For lower collateral levels,  $k < f$ , buyers still find it optimal to renegotiate whenever

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<sup>22</sup>For example, in electricity markets, this heterogeneity is largely driven by firm size and leverage. The cost of pledging collateral is much lower for large technology firms and large utilities than for smaller buyers.

$p < f - k$ . In that case, expected profits become

$$\Pi_B(f, k, \rho) = v - f(1 - \Phi(f - k)) - \int_0^{f-k} (p + k)\phi(p) dp - \rho k, \quad (7)$$

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

Note that the cost premium is now a function of  $f - k$ , which determines the probability of renegotiation.

The level of collateral affects the range of prices at which buyers and sellers are willing to contract. Consider sellers first. Since their profits increase with  $k$ , participation in the contract becomes more profitable the more collateral is pledged. With some abuse of notation, we now denote the minimum price that a seller is willing to accept as  $\underline{f}(k, c)$ , which is a decreasing function of  $k$ . Additionally, by Assumption 1, seller profits are increasing in  $f$  and, by extension,  $k$ . Hence, more collateral shifts the supply curve outwards.

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

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

whereas when  $k < f$ , buyers participate if

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

The maximum price that buyers are willing to pay, denoted as  $\bar{f}(k, \rho)$ , is decreasing in the collateral requirement  $k$  and its cost  $\rho$ .

These results are summarized next.

**Lemma 3.** *Under imperfect enforceability and with collateral  $k > 0$ ,*

- (i) *The lowest contract price a seller with investment cost  $c$  is willing to accept,  $\underline{f}(k, c)$ , decreases with  $k$ .*
- (ii) *The highest contract price a buyer with collateral cost  $\rho$  is willing to accept,  $\bar{f}(k, \rho)$ , decreases in  $k$  and  $\rho$ , ranging from 1 when  $k = 0$  to  $E(p) - \rho$  when  $k = 1$ .*

The heterogeneity of  $\rho$  between 0 and 1 implies that there is always some scope for trade. Without collateral and with  $\gamma = 1$ , sellers would always obtain lower profits in

the contract market compared to the spot market. With  $k > 0$ , a contract price  $\bar{f}(k, 0)$  makes a buyer with no cost of collateral 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 cost 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  $f$ , buyers are willing to accept some  $f < \bar{f}(k, 0)$ .

The demand curve for contracts with collateral  $k$  and a contract 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,  $\rho$ , results in endogenous market participation.

When  $k$  is sufficiently high it gives rise to market clearing at the intersection between demand and supply,

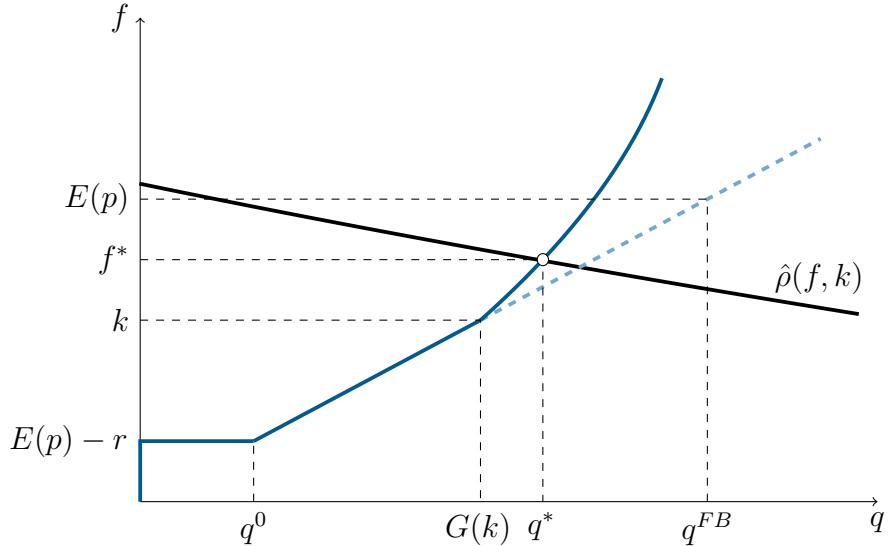
$$\hat{\rho}(f^*(k), k) = G(c^*), \quad (11)$$

where, as before,  $c^*$  is related to the equilibrium price  $f^*(k)$  through the zero-profit condition  $\Pi_S(f^*, k, c^*) = 0$ . This solution is depicted in Figure 4.

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 renegotiation becomes zero. Further increases in  $k$  lead to  $f^*(k) < k$ , maintaining a zero probability of contract renegotiation.

**Lemma 4.** *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.



**Figure 4:** 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 renegotiation

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 cost premium does not increase much with the probability of renegotiation, 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 for a positive probability of renegotiation.

**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  $\frac{\partial R}{\partial f}(0, 1) < r_W^0$ .*

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.

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 public policies aimed at improving market performance, as we discuss next.

## 5 Public Policies

In this section, we consider several public policies aimed at addressing the previous market failures. For simplicity, we base our analysis on the benchmark model, with exogenous contract demand  $\theta$  and no collateral,  $k = 0$ .<sup>23</sup> We also assume that the renegotiation risk parameter is sufficiently small so that the market for long-term contracts may effectively support additional investment.

### 5.1 Promoting Contract Demand

Our previous analysis identifies weak demand for fixed-price contracts as a key driver of underinvestment (Proposition 1). In particular, whenever  $\theta < G(E(p)) = q^{FB}$ , investment is inefficient even under perfect contract enforceability. Policies that raise contract demand,  $\theta$ , can do so endogenously by lowering participation costs (e.g., through contract standardization)<sup>24</sup> or exogenously through mandates to procure energy in long-term markets (Mays et al., 2022). While Proposition 1 implies that higher  $\theta$  always improves efficiency under perfect enforcement, we now argue that this conclusion may change in the presence of counterparty risk.

Consider first the case with  $\gamma \leq \hat{\gamma}$ , so that the market clears (Figure 3(a)). In this region, raising  $\theta$  increases contracting and stimulates investment. However, it also raises the equilibrium contract price, which increases the probability of renegotiation and, hence, the cost premium borne by all sellers, including the inframarginal ones. This second channel weakens the welfare gains from promoting contract demand. In particular, the closer  $\gamma$  is to  $\hat{\gamma}$ , the stronger the price effect and the smaller the net welfare gain.

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<sup>23</sup>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 remains in equilibrium.

<sup>24</sup>In 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).

If the renegotiation risk parameter is even higher,  $\gamma > \hat{\gamma}$  (Figure 3(b)), contract demand is rationed in equilibrium and increases in  $\theta$  become ineffective.

The trade-off between higher investment and the increase in the risk premium highlights the limits of promoting contract demand in isolation. If weak contract liquidity is ultimately driven by counterparty risk, then expanding contract demand to stimulate investment can increase renegotiation risk, potentially overturning the positive welfare effects of fostering demand.<sup>25</sup>

## 5.2 Public Subsidies

Public subsidies are a common policy instrument for addressing inefficiencies caused by underinvestment. In this section, we show that subsidies can also reduce the costs of counterparty risk—even in cases where they do not stimulate investment. At the same time, if set too large, they can induce inefficient over-investment.

Unconditional subsidies—i.e., transfers paid to all investors regardless of whether they sign a fixed-price contract or not—encourage investment, but they do not directly improve contract liquidity nor they address the distortions generated by counterparty risk.<sup>26</sup> For this reason, we focus on *uniform and conditional* subsidies  $T \geq 0$ , paid only to sellers who sign a fixed-price contract. In the spirit of the market-regulation literature, we assume that financing this policy entails a per-unit social cost of public funds,  $\lambda \geq 0$ .

Subsidies affect contract supply through two channels. First, a seller prefers a fixed-price contract to spot-market trading whenever

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

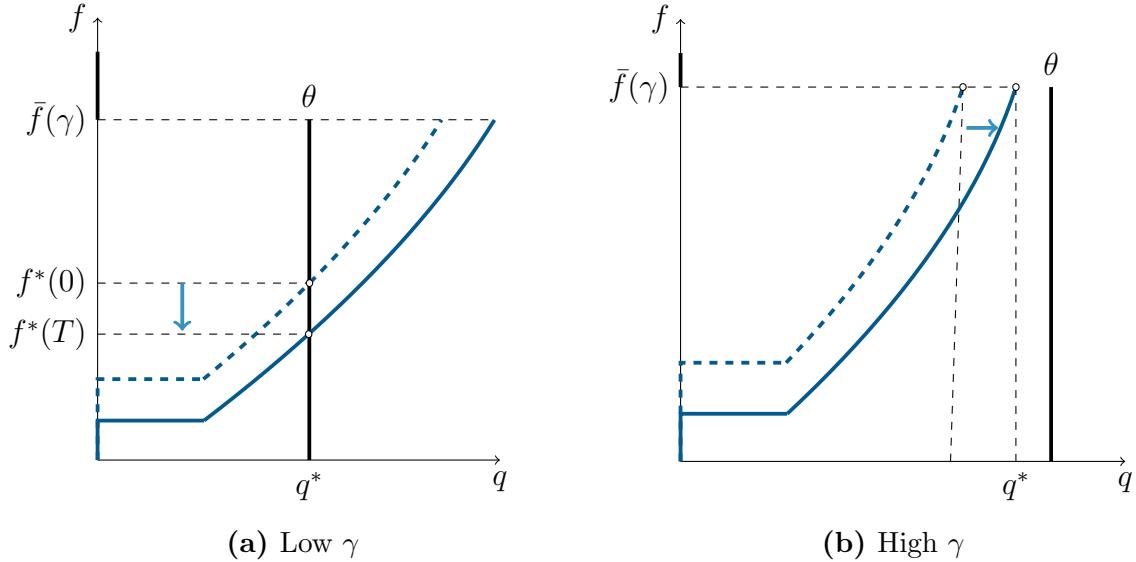
From this condition, we obtain that the minimum contract price acceptable to sellers,  $\underline{f}(\gamma, c, T)$ , which decreases with  $T$ . Second, a higher subsidy relaxes the break-even condition, so that more sellers can profitably break even, expanding contract supply.

Since subsidies strengthen the incentives to invest, the threshold probability of renegotiation when the market clears is an increasing function of  $T$ ,  $\hat{\gamma}(T)$ . As a result, when  $\gamma \leq \hat{\gamma}(T)$ , the equilibrium contract price  $f^*(\gamma, T)$  is pinned down by the new break-even

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<sup>25</sup>Our simulations in Section 7 provide instances in which demand expansions reduce welfare.

<sup>26</sup>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 output is backed by long-term contracts (Aldy et al., 2023; Chen, 2024).



**Figure 5:** The Effect of Public Subsidies.

Notes: In panel (a)  $\gamma \leq \hat{\gamma}(T)$ , so that the market clears and subsidies reduce the contract price without affecting investment. In panel (b)  $\gamma > \hat{\gamma}(T)$  is high, so that there is demand rationing. Subsidies increase investment while contract prices remain at the maximum price that buyers are willing to pay,  $\bar{f}(\gamma)$ .

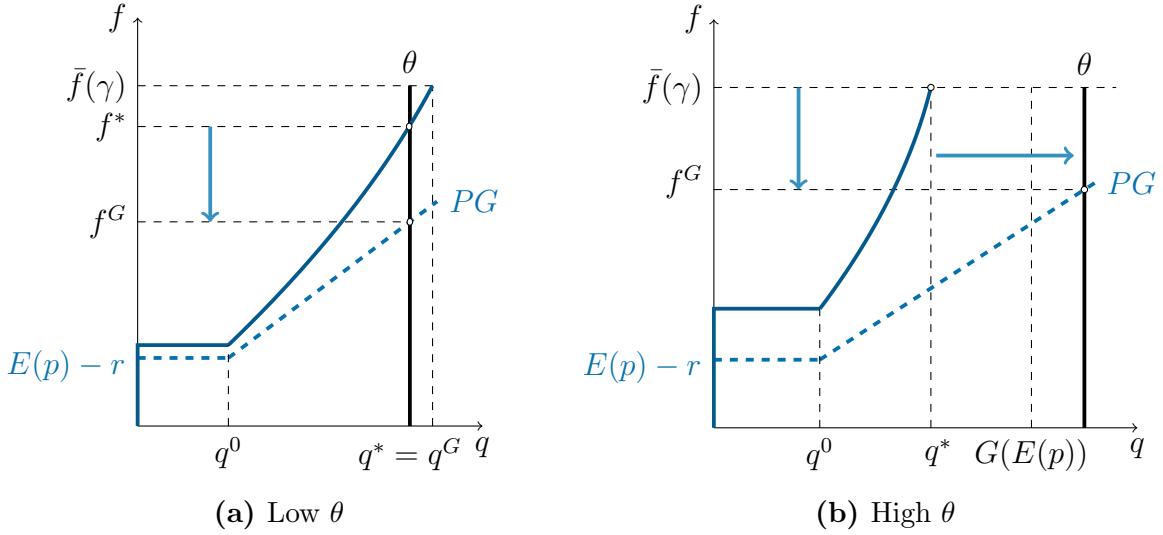
condition of the marginal seller,

$$\Pi_S(f^*, \gamma, c^*) + T = 0. \quad (12)$$

By contrast, when  $\gamma > \hat{\gamma}(T)$ , demand is rationed, and the equilibrium contract price extracts all the buyers' surplus. In this region, subsidies foster investment because they relax the marginal investor's participation constraint, even though they do not reduce the equilibrium contract price.

As illustrated in Figure 5, for low  $\gamma$ , a marginal increase in  $T$  lowers equilibrium contract prices while leaving investment unchanged. For high  $\gamma$ , subsidies increase investment without reducing prices. If  $T$  is sufficiently high, this boost could potentially lead to overinvestment if  $\theta > G(E(p))$  and  $c^* > E(p)$ .

In sum, subsidies are a second-best policy: although they mitigate underinvestment, they do not address the fundamental source of inefficiency, namely counterparty risk. With subsidies, the first-best outcome can be attained only if public funds are costless and regulators have sufficiently precise information to avoid setting subsidies so high that they induce overinvestment.



**Figure 6:** The Effects of Public Guarantees

Notes: In panel (a)  $\theta$  is low, so that the market clears, and public guarantees reduce the contract price without affecting investment. In panel (b)  $\theta > G(E(p))$  is high, so that without guarantees there is demand rationing. Public guarantees reduce prices and induce over-investment.

### 5.3 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  $f$  to sellers, who are compensated for the shortfall  $f - p$  in the event of contract default. As in the previous case, the disbursement of public funds is subject to a social cost  $\lambda \geq 0$ .

Because sellers no longer face counterparty risk, their profits under a fixed-price contract are  $\Pi_S(f, c) = f - c$  for any contract price  $f \in [0, 1]$ , regardless of the realization of the spot price  $p$ . This means that there is no scope for renegotiation. Whenever  $p < f$  sellers will not accept a renegotiated price lower than  $f$ , making default on the contract optimal for the buyer. Buyers' expected profits are still determined by (1) as in the baseline model. As a result of this default, with probability  $\gamma$  the government needs to incur in a cost equal to the price difference,  $f - p$ .

An immediate implication of the usage of public guarantees is that the supply of contracts coincides with that under perfect enforcement. By contrast, the demand for contracts remains as under the imperfect enforcement case: buyers are willing to pay at most  $\bar{f}(\gamma)$ , which, unlike in the perfect-enforcement benchmark, exceeds  $E(p)$ .

Consider first the case in which weak contract demand prevents the attainment of the First Best under perfect contract enforcement, i.e.,  $\theta < G(E(p))$ . If  $\gamma \leq \hat{\gamma}$  (as shown in

Figure 6(a)), the supply effect implies a lower equilibrium contract price,  $f^G = G^{-1}(\theta)$  and no effect on equilibrium investment,  $q^G = \theta$ . Interestingly, by inducing a reduction in the contract price, public guarantees also mitigate the likelihood of contract default and thus reduce the expected fiscal cost associated with compensating sellers in the event of default. The welfare gains from guarantees can be measured as

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

This expression implies that public guarantees are socially optimal whenever the cost of public funds  $\lambda$  is sufficiently low. In that case, the gains from eliminating counterparty risk outweigh their social cost.

If  $\gamma > \hat{\gamma}$ , public guarantees additionally stimulate new investment, raising it from  $q^* < \theta$  to  $q^G = \theta$ . They also reduce the contract price, from  $f^* = \bar{f}(\gamma) > E(p)$  to  $f^G = G^{-1}(\theta) < E(p)$ . The welfare gains from introducing public guarantees can now be written as

$$\begin{aligned} W^G(\gamma) - W^*(\gamma) &= q^* R(\bar{f}(\gamma), \gamma) + \int_{G^{-1}(q^*)}^{G^{-1}(\theta)} (E(p) - c) g(c) dc \\ &\quad - \lambda \theta \gamma \int_0^{G^{-1}(\theta)} (G^{-1}(\theta) - p) \phi(p) dp \leq 0. \end{aligned}$$

The new investment expansion effect increases the social value of public guarantees (second term of the above equation), making them welfare-improving even for higher values of  $\lambda$ .

However, if  $\theta > G(E(p))$ , public guarantees run the risk of generating over-investment, as illustrated in Figure 6(b). The reason is that contract prices may exceed  $E(p)$  despite sellers being protected from the risk of renegotiation. The new equilibrium price is either  $f^G = G^{-1}(\theta)$ , if this does not reach the maximum willingness to pay of buyers, or  $f^G = \bar{f}(\gamma)$ , otherwise. The welfare effect of public guarantees now becomes

$$\begin{aligned} W^G(\gamma) - W^*(\gamma) &= q^* R(\bar{f}(\gamma), \gamma) + \int_{G^{-1}(q^*)}^{E(p)} (E(p) - c) g(c) dc \\ &\quad + \int_{E(p)}^{f^G} (E(p) - c) g(c) dc - \lambda \theta \gamma \int_0^{f^G} (f^G - p) \phi(p) dp \leq 0. \end{aligned}$$

Notice that the third term in the expression above reflects the social cost of moral hazard: guarantees induce overinvestment. Some investors with a cost higher than the

savings in expected production costs,  $c > E(p)$ , might find it optimal to enter. Overinvestment is more likely the higher is the risk of renegotiation, since the highest price that sellers might obtain,  $\bar{f}(\gamma)$ , is increasing in  $\gamma$ .

A remedy to this inefficiency is to impose a cap at  $E(p)$  on the contract prices eligible for public guarantees. This regulation would implement the first best allocation when  $\lambda = 0$ .

## 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 Renegotiation Cost

In our baseline model, we assumed that buyers could renegotiate the contract at no cost. We now relax that assumption by introducing a renegotiation cost  $z > 0$ . As we show below, such a cost helps align the incentives of buyers and sellers, thereby reducing the incidence of counterparty risk. It is easy to see that, when the renegotiation cost is sufficiently high, the equilibrium outcome converges to the case of perfectly enforceable contracts.<sup>27</sup>

If  $z \geq f$ , buyers never find it optimal to renegotiate as the cost of doing so exceeds any potential price saving. Hence, buyers' and sellers' profits coincide with the case of perfect contract enforcement.

For  $z < f$ , buyers only renegotiate the contract if  $p < f - z$ , in which case they incur the additional cost  $z$ . Their profits become

$$\Pi_B(f, \gamma) = v - \gamma \int_0^{f-z} (p + z) \phi(p) dp - f [1 - \gamma \Phi(f - z)].$$

As buyers' profits decrease in  $z$ , the maximum contract price they are willing to pay also decreases in  $z$ , and equals  $E(p)$  when  $z = E(p)$ .

For sellers, profits become

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

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<sup>27</sup>Similar results would emerge if, instead, we allowed buyers to derive a direct benefit from long-term contracts arising, for instance, when the seller produces clean energy that helps buyers meet regulatory requirements or attain Corporate Social Responsibility targets.

Since sellers' contract profits are increasing in  $z$ , the contract-supply curve shifts downward as  $z$  rises.

Combining these demand and supply effects, the increase in the renegotiation cost  $z$  drives the equilibrium outcome closer to the perfect-enforcement benchmark. In particular, depending on the value of  $\gamma$ , equilibrium prices go down and investment (weakly) goes up. The intuition is that higher renegotiation costs better align the incentives of buyers and sellers, thereby mitigating the inefficiencies associated with imperfect contract enforcement. In the limit, as  $z$  approaches  $E(p)$  and renegotiation becomes prohibitively costly, contracts are effectively perfectly enforceable.

## 6.2 Buyer Default and Vertical Integration

In the baseline model, we assumed that when the spot market price falls below the contract price, buyers renegotiate contract prices with probability  $\gamma$ . However, there are alternative forms of counterparty risk that lead to analogous profit expressions for both buyers and sellers.

Suppose, for example, that the buyer does not renegotiate opportunistically but out of necessity, i.e., because of limited liability in the presence of downstream competition. In particular, with probability  $\gamma$ , a Bertrand competitor offering a homogeneous good enters the downstream market and acquires the input in the spot market at a price  $p$ . Whenever  $p < f$ , the original buyer is priced out of the downstream market and, due to limited liability, doesn't honor its contractual obligations. As a result, the seller is forced to sell 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: by making it less likely that the buyer is undercut in the downstream market, it lowers the probability of default, thereby supporting lower contract prices and higher investment, albeit potentially at the expense of final consumers.

This result has implications for the standard solutions proposed to deal with counterparty risk. For example, one might expect vertical integration to restore efficiency by aligning the incentives of buyers and sellers and eliminate hold-up (Hart, 1995). However, in settings where the buyer faces downstream competition with probability  $\gamma$ , the vertically integrated firm remains exposed to spot price volatility and profits are given

by

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

Thus, only when  $\gamma = 0$  does the integrated structure capture the full value of the investment. When  $\gamma > 0$ , the underinvestment problem persists, as the integrated firm remains partially exposed to spot market prices through the competitive pressure exerted by its downstream rival. In the extreme case where  $\gamma = 1$ , the integrated firm's profits coincide with those in the no-contract scenario.

In sum, when downstream competition is the source of price exposure, vertical integration does not eliminate a market failure analogous to that caused by buyer counterparty risk.

### 6.3 Adverse Selection

In our baseline model, we have assumed that all buyers are equally likely to renegotiate the terms of the contract once the spot price is realized. Alternatively, we can consider an adverse selection problem where buyers can be of two types, either opportunistic with probability  $\gamma$  or trustworthy with probability  $1 - \gamma$ . The former always renegotiate the contract when  $p < f$ , whereas the latter always honor it. Sellers do not observe the buyers' type when signing contracts but hold correct expectations regarding the probability of a buyer being opportunistic.

The results in this case are qualitatively unchanged, and most of our previous findings go through without modification. An interesting difference arises, however. In the baseline model, buyers accept prices  $f \leq \bar{f}(\gamma)$ . In the adverse selection framework, opportunistic buyers accept any price  $f \leq 1$ , since they default if the spot price falls below the contract price. In contrast, trustworthy buyers only accept contracts with  $f \leq E(p)$ . This implies that a price  $f > E(p)$  will only attract opportunistic buyers, leading to adverse selection à la Stiglitz and Weiss (1981). Under mild assumptions, this implies that, in the adverse selection paradigm, equilibrium prices will not exceed  $E(p)$ , which is lower than the upper-bound price  $\bar{f}(\gamma)$  in our baseline model. Hence, investment incentives are reduced even further, illustrating the additional distortions that adverse selection can generate.

## 6.4 Increasing Marginal Cost of Pre-existing Capacity

In our baseline model, we assume that existing capacity has a constant marginal cost  $p$ , distributed according to  $\Phi(p)$ . This assumption greatly simplifies the analysis because, regardless of the investment in new capacity, the spot price and its distribution remain unchanged. In the context of electricity markets, however, incumbent plants typically differ in their marginal costs, generating an upward-sloping supply curve in the spot market. As a result, additional investment in zero-marginal-cost capacity—which displaces existing production—lowers spot prices on average.

Allowing for heterogeneous marginal costs would not alter the qualitative conclusions of our baseline model. The main difference is that the equilibrium condition in the contract market would have to be jointly determined with the equilibrium in the spot market. In particular, contract supply depends on the spot price distribution (and, thus, on the expected spot price), which would now be a function of equilibrium contract investment  $q^*$ . That is,  $\Phi(p; q^*)$  and  $E(p; q^*)$ , with the latter decreasing in  $q^*$ . Similarly, contract demand would change, since the maximum price buyers are willing to pay depends on their expectations about spot-market prices. Additional investment would still be welfare improving, but the marginal value of each additional unit would be decreasing, since it would displace existing generation with relatively lower marginal costs.

Interestingly, allowing for an upward-sloping spot supply curve changes the benefits of expanding contract demand. An outward shift in contract demand induces additional investment, which in turn lowers spot prices. Lower spot prices make renegotiation more likely and therefore raise the risk premium on all contracts. This reinforces the negative effects discussed above: higher contract demand increases investment at the margin, but it also makes all inframarginal investment more expensive.

## 6.5 Dynamic Interactions and Time-Varying Prices

Our analysis relies on a static model despite the long-term nature of the contracts. Nevertheless, the conclusions of the baseline framework extend naturally to environments in which price realizations are highly correlated over the life of the contract. This case captures situations where uncertainty is primarily about the future price level, rather than short-run price fluctuations.

In this section, we show that when prices are only weakly correlated over time, the

buyer is more likely to honor the contract in early periods due to its option value in the future. Interestingly, default can occur with positive probability in the early periods, as it may be preferable for the buyer to default rather than to renegotiate the contract.

To illustrate these ideas, we extend the model to two periods. To keep the model comparable to the static benchmark, we make two assumptions. First, we assume that after the contract is signed, with probability  $\gamma$  the buyer can renegotiate in both periods and with probability  $1 - \gamma$  this renegotiation is never possible. Second, we normalized first- and second-period profits according to the weights  $1 - \delta$  and  $\delta$ , with  $\delta \in [0, 1/2]$ .<sup>28</sup> Since contracts span both periods, when price realizations are perfectly correlated over time, the outcome coincides with the static setting, and investment is unaffected.

Consider now the case where price realizations are *i.i.d.* across the two periods, following the same distribution  $\Phi(p)$ . When renegotiation is possible, in each period, after observing the price realization the buyer decides whether to make a take-it-or-leave-it offer to lower the contract price under the threat of default, and the seller then decides whether to accept it. If the parties renegotiate at  $t = 1$ , the new contract price also applies at  $t = 2$ , and may be renegotiated again in the second period. If default occurs at  $t = 1$ , all future transactions remain unhedged and both buyer and seller rely on the spot market.

The game is solved by backward induction. If default occurs in the first period, the contract is terminated, and both the seller and the buyer are exposed to spot prices. Otherwise, the second-period problem reduces to the static model.

At  $t = 1$ , the buyer may attempt to renegotiate the contract price to some  $f_1 < f$ . When the spot price  $p$  falls below  $f$ , the seller is willing to accept renegotiation as long as the new price  $f_1$  is at least equal to a threshold  $\underline{f}_1$ , defined by the seller's indifference between continuing under the contract and switching to the spot market in both periods,

$$(1 - \delta)\underline{f}_1 + \delta \left[ \int_0^{\underline{f}_1} p\phi(p), dp + \underline{f}_1 \left( 1 - \Phi(\underline{f}_1) \right) \right] = (1 - \delta)p + \delta E(p). \quad (13)$$

However, this same condition also pins down the buyer's indifference between renegotiating and defaulting (and then buying at the spot price). As a result, there is no scope for mutually acceptable renegotiation: any  $f_1$  the seller would accept leaves the buyer better off defaulting, while any  $f_1$  that makes the buyer prefer renegotiation is rejected by

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<sup>28</sup>Restricting attention to  $\delta \leq 1/2$  ensures that first-period profits receive at least as much weight as second-period profits.

the seller. This is not surprising since, at this stage, the continuation game is effectively zero-sum.

The previous result, however, does not imply that the buyer will always honor the contract in the first period. On the contrary, when  $p$  is sufficiently low, the buyer may prefer to default by making an offer  $f_1 \leq \underline{f}_1$ , anticipating that the seller will reject it and default will ensue. In that case, trade in both periods takes place at spot prices, and the buyer's net present value of profits is

$$(1 - \delta)(v - p) + \delta(v - E(p)),$$

instead of the payoff from staying in the contract,

$$(1 - \delta)(v - f) + \delta\Pi_B(f).$$

Comparing these expressions implies that the buyer defaults at  $t = 1$  if and only if  $p$  falls below  $\hat{p}$ , defined as

$$\hat{p} \equiv f - \frac{\delta}{1 - \delta} \int_f^1 (p - f)\phi(p)dp \leq f. \quad (14)$$

Intuitively, the buyer trades off the first-period gain from default,  $f - \hat{p}$ , against the expected loss from forgoing hedging in the second period. When the second period receives sufficiently little weight (i.e., when  $\delta$  is small), default occurs with positive probability in equilibrium (i.e.,  $\hat{p} > 0$ ).

Hence, an important difference relative to the baseline case (or to the case in which prices are perfectly correlated over time) is that default can arise in equilibrium as a strictly preferred option for the buyer, relative to renegotiation. The reason is that renegotiation offers no upside to the seller: it lowers the price in the first period,  $f_1 < f$ , and it also lowers the effective ceiling on the contract price in the second period, when renegotiation may occur again. Default, by contrast, does not require the seller's consent and can therefore be used by the buyer to extract additional rents.

Overall, relative to the case of perfect correlation, for a given  $f$  the contract is more likely to be honored  $-(1 - \gamma\Phi(\hat{p}))$  rather than  $(1 - \gamma\Phi(f))$ —because it provides an option value to the buyer. Yet there remains a positive probability that the contract is renegotiated in the second period or not honored in the first period. Thus, as in the baseline model, contracts do not provide sellers with a perfect hedge: limited enforceability raises risk premia relative to full enforceability, which in turn depresses investment below the efficient level.

## 7 Simulations

In this section, we illustrate how our theoretical framework can be used to inform policy analysis. We calibrate the model using data from the Spanish electricity market, taking the perspective of investments in renewable energy carried out in 2021.<sup>29</sup> Our interest is in understanding the effects of long-term power contracts on investment, prices, and welfare —accounting for the profits of both producers and buyers. We also assess the impact of the public policies discussed in previous sections.

To address this question, we compile detailed data on solar projects that became operational in 2022—corresponding to the average construction timeline of one year,—to estimate the average production cost of 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.

In our simulations, we make assumptions to match the theoretical model and some relevant real-world features of the market. In the model, all plants differ only in their per-unit investment cost, with capacities and output normalized to one. This simplification implies that the risk premium of all plants is the same for a given contract price. In practice, however, plants differ in multiple dimensions, including their size and location-specific resource availability. As a result, average costs and spot-market premia may vary significantly at the plant level. We abstract from this dimension and, instead, we focus on the heterogeneity of investment cost due to differences in local irradiation for a given plant size.

### 7.1 Estimating Contract Supply

The analysis proceeds in three steps. First, we recover the average cost curve of all potential plants that could have been built. Second, we estimate the expected surplus that each plant would obtain 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.

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<sup>29</sup>For context, the volume of disclosed PPA deals in Spain in 2022 and 2023 were 3.9 GW and 4.67 GW, respectively (Pexapark, 2024).

**The supply of renewable capacity** We start by collecting data from the Spanish official registry of renewable power plants (PRETOR, 2025), which includes the characteristics of all renewable investment projects that began operating in 2022 such as their technology (in our case, solar PV), maximum production capacity, and location, shown in panel (a) of Figure 7. Using solar irradiation data at each specific geo-location (Renewables Ninja, 2025), we compute the expected lifetime production of each project (assuming an expected lifetime of 25 years).

Fixed investment costs are derived using IRENA (2023) estimates for Spain in 2021. A plant’s long-run average cost is then calculated as the ratio of its total cost (adding investment and operation and maintenance costs) to its expected lifetime production. Variation in location-specific solar irradiation leads to heterogeneity in average costs across projects, ranging from €21/MWh to €24/MWh.<sup>30</sup> We eliminate plants from the Spanish islands, as they do not belong to the same electricity network and face different revenue expectations.

The resulting average costs correspond to the plants that were actually built and, therefore, their distribution is selected, as one would expect that only investments with a positive net present value were undertaken. To recover the distribution of all potential plants, we approximate the average costs as arising from a log-normal distribution with a minimum cost of €20/MWh and a truncation at the highest average cost observed in the data, €24/MWh. The result of this estimation is shown in Panel (b) of Figure 7.

To construct the supply curve, in each simulation, we take a hundred draws from this average cost distribution, each one corresponding to a plant with a capacity of 50MW.<sup>31</sup>

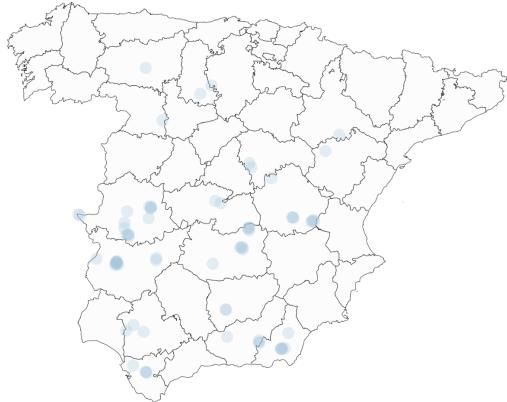
**Estimating spot and contract profits** In the spot market, a plant is paid the hourly market-clearing price at the time of production. To reflect uncertainty about future prices, we assume that spot prices vary between €0/MWh and €60/MWh, with an expected value of €40/MWh, consistent with the level at which electricity futures traded in 2021.

Because solar output tends to depress market prices, solar PV typically earns a *cap-*

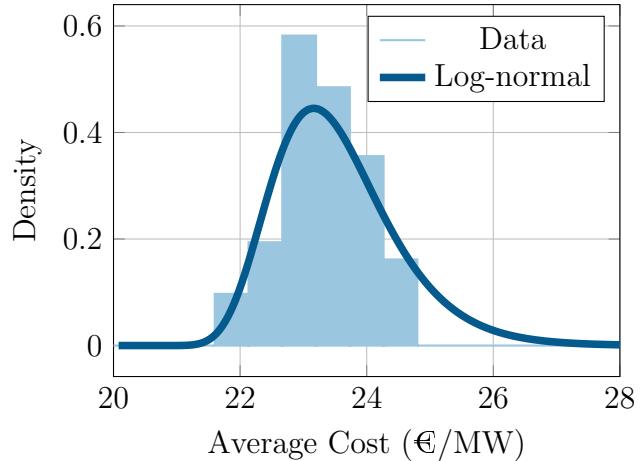
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<sup>30</sup>This price range is in line with the winning bids in the renewable energy auction held by the Spanish regulator in January 2021. The minimum and maximum winning bids for solar PV were €14.89/MWh and €28.90/MWh, with a weighted average price equal to €24.47/MWh. The contracts’ duration was 12 years, thus covering only about half of the plants’ lifetimes.

<sup>31</sup>This capacity is particularly relevant in the Spanish market as it corresponds to the threshold under which administrative authorization is carried out at the regional level. For higher capacities, a national authorization is also required. For this reason, in the data, we observe bunching at 50MW. See Cuberes et al. (2025) for further details.



(a) New solar PV plants in Spain (2022)



(b) Average Costs of solar PV plants

**Figure 7:** Solar PV Plants in Spain and their Average Cost Distribution

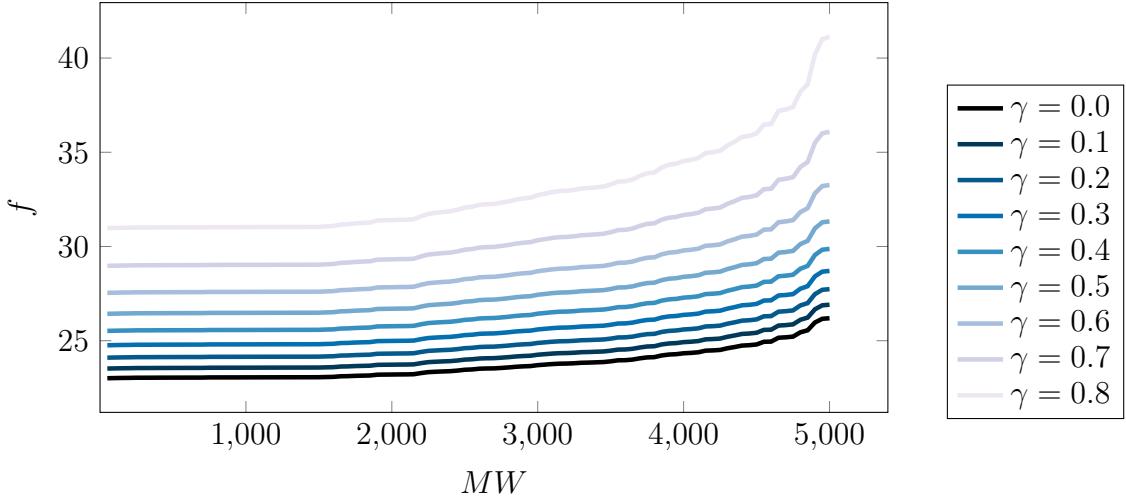
*Notes:* Panel (a) shows the locations of solar PV plants that began operating in Spain in 2022. Panel (b) plots the distribution of plants' average costs (in €/MW), constructed by mapping solar irradiation at each plant's geographic location into costs using IRENA (2023)'s cost parameters for Spain in 2021. The figure also overlays a log-normal approximation to the distribution of average costs, including both realized plants (truncated at the highest cost observed in the data) and projects that were not built.

tured price below the average spot price. We assume this captured rate at 60%, implying that a solar plant selling solely in the spot market earns a expected revenue of €24/MWh.

Given the assumed spot-price distribution, we compute expected revenues for sellers under fixed-price contracts with price  $f$  and for  $\gamma \in [0, 0.8]$ . To quantify sellers' risk premia, we assume investors have mean–variance preferences, as described in Appendix C. Under these preferences, the risk premium is typically convex in expected production. We calibrate the risk parameter  $r_0$  such that 30% of the plants in the sample earn strictly positive profits when operating exclusively in the spot market. Only these plants can invest profitably in the absence of long-term contracts.<sup>32</sup> By normalizing the capacity of all plants to 50 MW, we ensure that implied risk premia do not differ materially across plants.<sup>33</sup>

<sup>32</sup>This low share of profitable projects under spot-market trading is consistent with anecdotal evidence from industry practitioners. For instance, “*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, 2025).

<sup>33</sup>If plants had heterogeneous capacities, and therefore widely different production levels, the average cost ranking across plants could mechanically change with  $\gamma$ : a large plant that is more profitable than a smaller one at low  $\gamma$  could become less profitable at higher  $\gamma$  when risk premia matter more. Such rank reversals would be an artifact of scale in the risk-premium calculation, and are unlikely to hold in practice.



**Figure 8:** Contract Supply Curves

Notes: This figure shows the contract supply curves for different values of  $\gamma \in [0, 0.8]$ . Contract prices are expressed in €/MWh, and contract quantities are in MW. The case with  $\gamma = 0$  corresponds to perfect contract enforceability. As  $\gamma$  goes up, the supply curves shift inwards, leading to higher prices and potentially constrained investment in equilibrium.

Parameters	Target Values
Plant size	50 MW
Number of solar PV plants in the sample	59
Number of draws per simulation	100
Distribution of average costs	Lognormal( $\mu = 1.22$ , $\sigma = 0.27$ ), shift $a = 20$
Solar PV price distribution	$p = 36 \times x$ , $x \sim \text{Beta}(2, 3)$ ; $E(p) = €24/\text{MWh}$
Capture price for solar PV	60% of the spot price
Proportion of profitable plants	30% at spot prices, with $r_0 = 2.99 \times 10^{-9}$
Cost of public funds ( $\lambda$ )	0.1

**Table 1:** Parameter and Target Values

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

Table 1 summarizes the targets and parameter choices used in the numerical exercise.

## 7.2 Simulation Results

For each of the contract demand levels considered (2,500 MW, 3,000 MW, 3,500 MW, and 4,000 MW), we compute the equilibrium outcomes, including prices, investment, and

the welfare gain relative to the no-contracts case, decomposed between seller and buyer surplus.

Figure 9 reports baseline outcomes in the absence of policy intervention. Panel (a) shows that the equilibrium contract price rises from about €23–24/MWh to roughly €32/MWh as the renegotiation parameter increases. As expected, prices are also higher when contract demand is higher, although price differences are small and they narrow down as  $\gamma$  increases. The reason is that, as illustrated in Panel (b), the market adjusts primarily along the quantity margin (i.e., through investment).

In all four scenarios, contract demand is fully met for low values of  $\gamma$ . However, once  $\gamma$  becomes sufficiently high, contract rationing emerges and, beyond that point, investment declines as  $\gamma$  increases. The first-best level of investment is attained (3,650 MW, shown by the dashed line) when contract demand is 4,000 MW, and there is no counterparty risk ( $\gamma = 0$ ). In that case, the maximum price consumers are willing to pay for solar production (€24/MWh) guarantees that investment is aligned with social welfare. In all other scenarios, investment falls short of the first best, reflecting the combined effect of counterparty risk and inefficiently low contract demand.

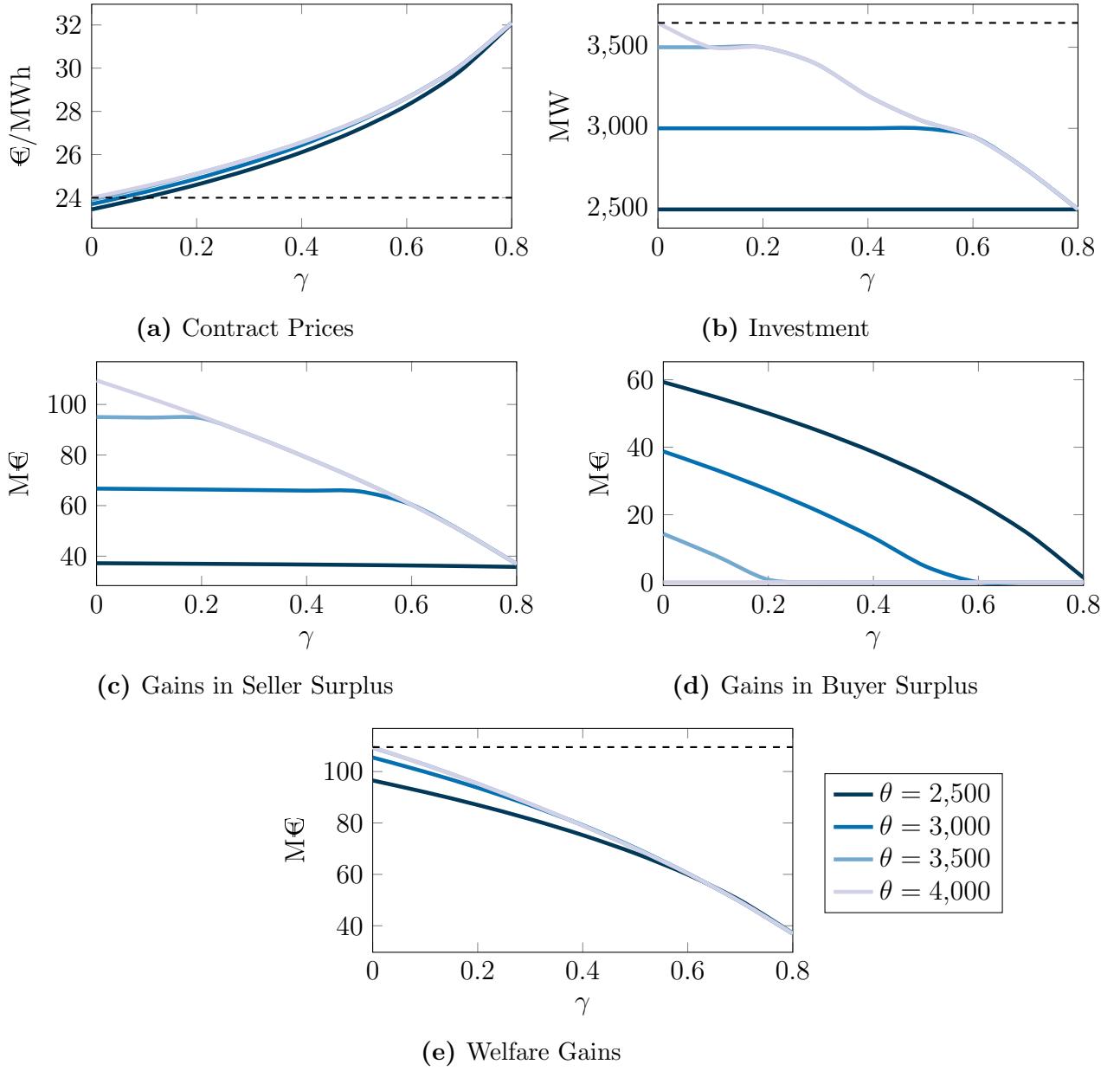
Panel (e) in Figure 9 illustrates how the increase in contract prices reduces the welfare gain relative to the no-contract case as  $\gamma$  rises. The effect is most pronounced under high contract demand, where the welfare loss is amplified not only by higher prices but also by reduced investment. When contract demand is 2,500 MW, welfare decreases by 62% as the probability of renegotiation rises from  $\gamma = 0$  to  $\gamma = 0.8$ . In contrast, with a 4,000 MW demand, welfare drops by 66% over the same range. This result is a consequence of the contraction in investment discussed before, together with the modest price increase.<sup>34</sup>

Fixed-price contracts generate substantial welfare gains relative to a benchmark in which all trade occurs in the spot market. In our baseline simulations, aggregate welfare increases by €37M–€109M. In per-unit terms, each MW of contracted capacity contributes €0.015M–€0.045M beyond the welfare level attained without contracts. These per-MW welfare gains decline with both contract demand and the renegotiation parameter  $\gamma$ .

As shown in Panels (c) and (d) of Figure 9, and consistent with Proposition 3, coun-

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<sup>34</sup>Recall that we are abstracting from positive externalities arising from renewable investment. To the extent that the increase in  $\gamma$  reduces investment, the welfare reduction would be stronger in the presence of these externalities.



**Figure 9:** The Contract Market Equilibrium in the Baseline Scenario

*Notes:* These figures report equilibrium outcomes in the no-intervention scenario for four levels of contract demand (2,500 MW, 3,000 MW, 3,500 MW, and 4,000 MW), across values of  $\gamma \in [0, 0.8]$ . The case  $\gamma = 0$  corresponds to perfect contract enforceability. As  $\gamma$  increases, contract prices in panel (a) rise. Investment in panel (b) is constant in  $\gamma$  up to  $\hat{\gamma}$ , the threshold above which contract rationing arises for a given demand level; for  $\gamma > \hat{\gamma}$ , investment declines. Seller surplus, buyer surplus, and Welfare are net from their corresponding values in the no-contracts case. Seller surplus in panel (c) is constant up to  $\hat{\gamma}$  and falls thereafter, while the opposite holds for buyer surplus in panel (d). Welfare in panel (e), defined as the sum of buyer and seller surplus, declines monotonically in  $\gamma$  and is strictly below the first-best except when  $\theta = 4,000$  and  $\gamma = 0$ . Welfare is higher for higher demand levels when  $\gamma$  is low, but this ranking reverses for  $\gamma \in [0.6, 0.8]$ , although the differences become very small.

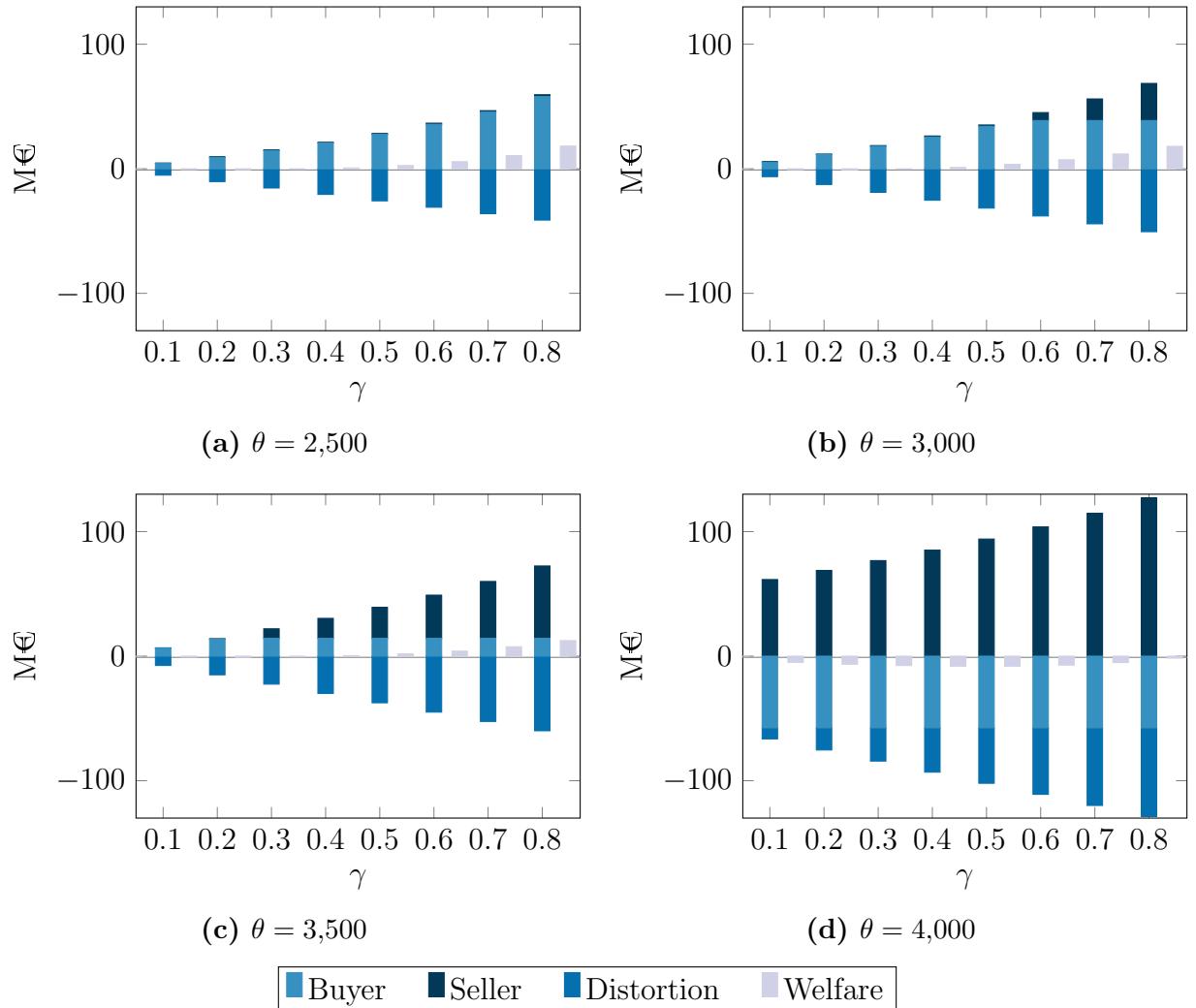
terparty risk (weakly) reduces both seller and buyer surplus. When  $\gamma$  is low and the contract market clears, counterparty risk does not affect seller surplus: the additional risk is fully passed onto buyers through higher contract prices. This case is more likely to arise at lower levels of contract demand. When  $\gamma$  becomes sufficiently large for contract rationing to emerge, investment falls, and seller surplus declines because sellers can no longer offset counterparty risk through price adjustments alone.

The effect on buyers is a mirror image of that for sellers. When increases in counterparty risk are fully reflected in higher prices, buyers are worse off. Once demand binds, leading to rationing, all buyers' surplus is extracted by sellers and further increases in  $\gamma$  do not have an effect. Overall, these results highlight that counterparty risk harms buyers collectively: aggregate welfare falls and buyers capture a progressively smaller share of it.

**Public Policies** We can use our simulations to evaluate the welfare consequences of the two policy instruments analyzed before: public guarantees and investment subsidies. As discussed in Section 5, both policies lower equilibrium contract prices and increase investment relative to the no-intervention benchmark. Their welfare and distributional implications, however, differ.

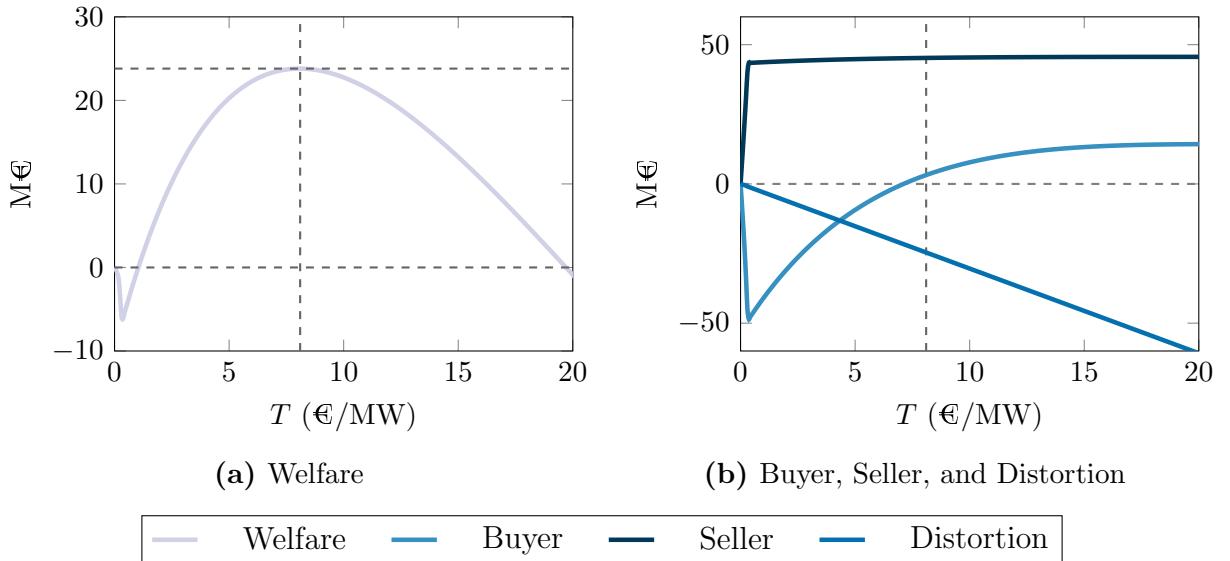
Figure 10 examines the effects of public guarantees relative to the baseline with fixed-price contracts and no policy intervention. We decompose the resulting welfare effects into three components: changes in buyer surplus, changes in seller surplus, and efficiency distortions. The buyer component aggregates (i) the equilibrium effects of guarantees (lower prices or higher quantities) and (ii) the direct cost of the public guarantees. This accounting mirrors how such programs are typically financed in practice, often through a surcharge on final electricity bills. The seller component reflects not only price and quantity changes, but also the reduction in the risk premia. Finally, the distortion component captures the shadow cost of public funds.

The welfare effects of public guarantees vary with both the renegotiation parameter  $\gamma$  and the level of contract demand  $\theta$ . When demand is low, buyers benefit the most from the reduction in counterparty risk: guarantees lower prices and (weakly) expand contract quantities, outweighing the associated financing cost. Sellers benefit relatively little, since the risk reduction is almost always passed through to buyers via lower prices. As demand



**Figure 10:** Welfare Effects of Public Guarantees

*Notes:* For each level of contract demand, the figures report the effect of public guarantees on welfare (gray bars) and decompose it into three components: buyer surplus net of transfers to sellers when guarantees are exercised (light blue bars), seller surplus (dark blue bars), and the welfare loss from the distortionary cost of public funds (blue bars), computed assuming  $\lambda = 0.1$ .



**Figure 11:** Welfare Gains of Public Subsidies

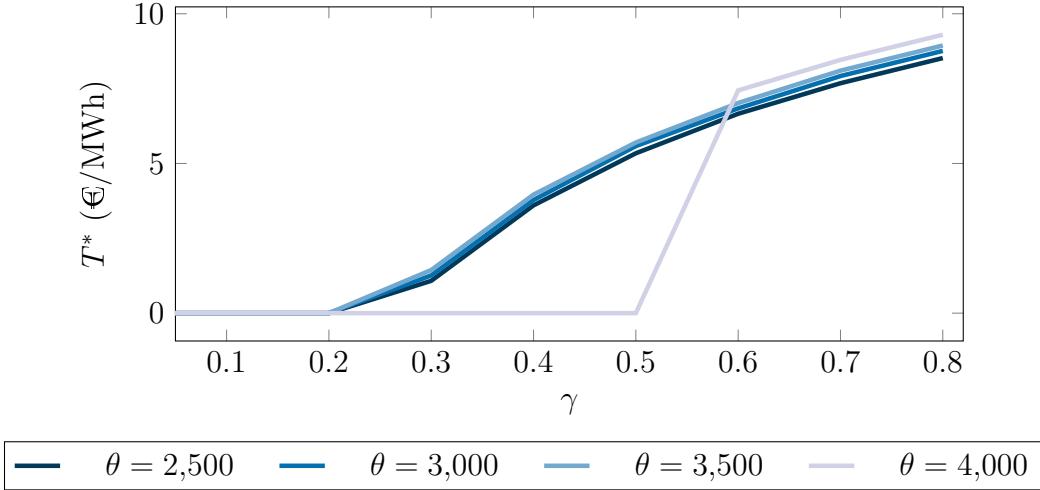
*Notes:* Panel (a) shows welfare gains relative to the no-intervention benchmark as a function of the public subsidy  $T$ . The vertical dashed line indicates the welfare-maximizing subsidy  $T^* \approx 8.1$ , and the horizontal dashed line reports the corresponding maximum welfare level. Panel (b) decomposes welfare into buyer surplus, seller surplus, and distortion. All results are for  $\theta = 3,500$  and  $\gamma = 0.7$ .

increases, however, buyers capture a smaller share of the welfare gains. Investment rises significantly, while the price decline becomes less pronounced, shifting a larger fraction of the surplus toward sellers, while buyers must finance a larger mass of guarantees.

Indeed, at high demand levels, guarantees can even make buyers worse off. Panel (d) illustrates how guarantees may induce excessive investment when contract demand,  $\theta = 4,000$ , exceeds the first-best level. The resulting efficiency costs are ultimately borne by buyers, who end up paying prices above the ones they would pay in the spot market, reducing their net surplus.

Combining these effects, public guarantees raise welfare primarily when counterparty risk is worrisome (high  $\gamma$ ) and demand participation is limited (low  $\theta$ ). Otherwise, guarantees can reduce welfare: when  $\gamma$  is low, the welfare gains from lowering risk premia are small relative to the shadow cost of the scheme; and when demand is high, the costs of overinvestment due to moral hazard generate deadweight losses, even for high values of  $\gamma$ .

Matters are different when assessing the welfare effects of investment subsidies. Because subsidized output is paid with certainty while counterparty risk still exists, the fiscal



**Figure 12:** The Optimal Subsidies

*Notes:* This figure shows the welfare-maximizing subsidy levels as a function of  $\gamma$ , for the various demand levels, under the assumption of  $\lambda = 0.02$ .

cost of the subsidy (under our benchmark assumption of  $\lambda = 0.1$ ) dominates the relatively modest welfare gains from slightly lower prices and higher investment. Consequently, the net welfare effect of public subsidies is broadly negative.<sup>35</sup>

To further characterize these effects, we consider a lower value of the shadow cost of public funds ( $\lambda = 0.02$ ) and quantify how welfare changes as the subsidy rate  $T$  increases. The effects of public subsidies are illustrated in Figure 11 for a particular case with  $\theta = 3,500$  MW and  $\gamma = 0.7$ . Panel (a) shows how the welfare gain (relative to the no-intervention baseline) varies with the subsidy level  $T$ . For small subsidies, welfare initially falls as  $T$  increases: prices remain essentially unchanged, so there is no reduction in the risk premium, while the subsidy still generates a fiscal cost through the shadow cost of public funds. As  $T$  rises and contract rationing disappears, welfare starts to increase because prices decline and the risk premium falls; these benefits outweigh the fiscal cost up to the welfare-maximizing subsidy  $T^*$  of about €8.1/MWh. Beyond this point, additional subsidies reduce welfare again.

Unsurprisingly, sellers benefit the most from subsidies. Buyers are initially worse off, but they eventually benefit due to the reduction in prices that the subsidy entails. Overall, the largest welfare distortion comes from the shadow cost of financing the subsidy.

Figure 12 characterizes the optimal subsidy for different values of  $\gamma$  and  $\theta$ . It is

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<sup>35</sup>The only case where public subsidies are welfare-increasing is for  $\theta = 2,500$  and  $\gamma = 0.8$ .

increasing in  $\gamma$ , as a higher risk of renegotiation makes counterparty risk more relevant, making higher values of  $T$  optimal. Likewise, the optimal subsidy is increasing in  $\theta$ , with a remarkable exception: when  $\theta = 4,000$  and  $\gamma \leq 0.5$ , the subsidy levels that are optimal at lower demand values induce overinvestment (recall that the first-best capacity is 3,650 MW), making it optimal to eliminate the subsidy.

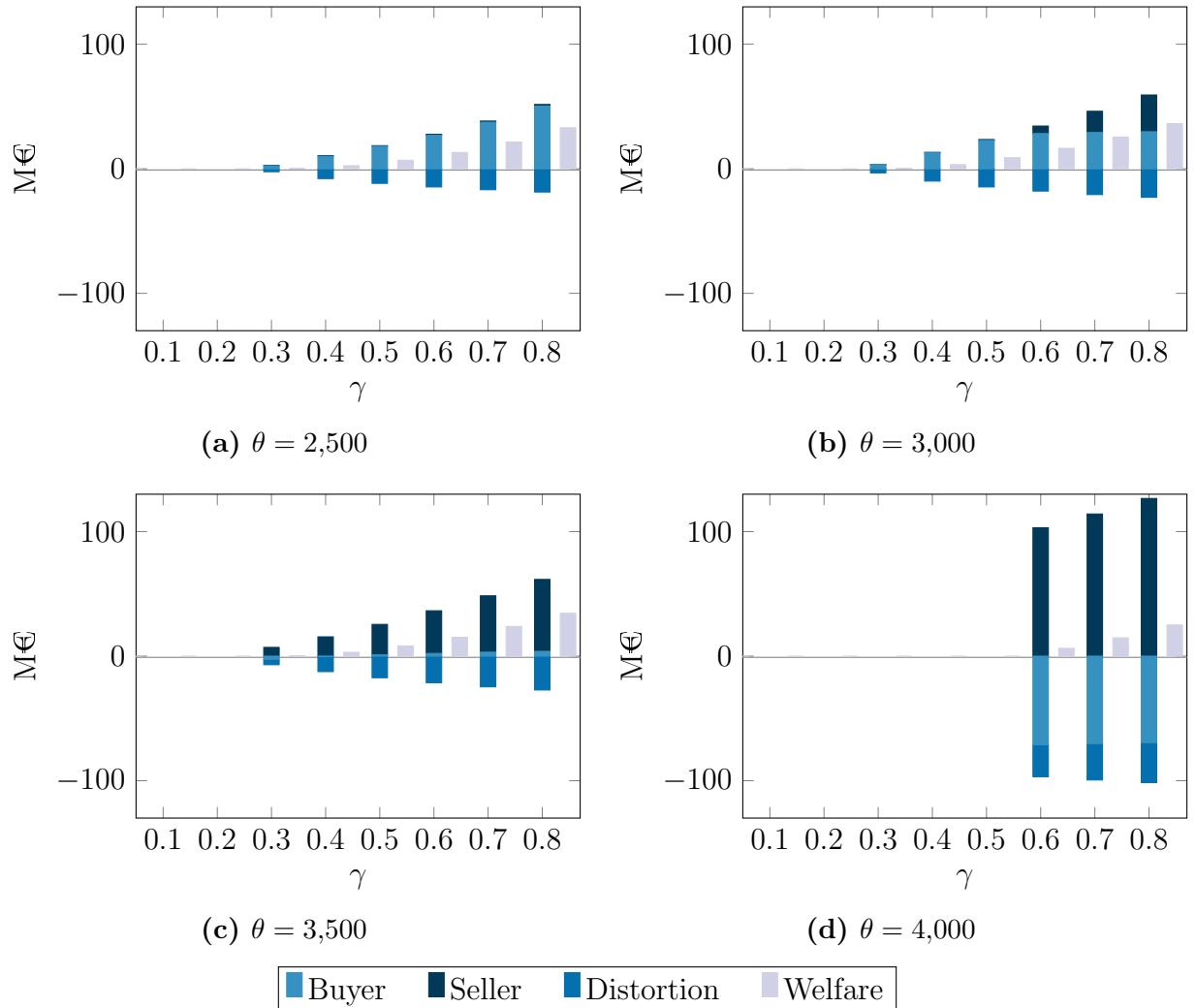
Finally, Figure 13 illustrates the welfare effects induced by the optimal subsidies. Consistent with Figure 12, when  $\gamma$  is low, subsidies are rarely optimal, and the welfare effects on buyers and sellers remain largely unchanged. As with public guarantees, the gains from subsidies accrue primarily to sellers, and increasingly so as contract demand rises. Buyers benefit at low subsidy levels, but as demand increases, they eventually become worse off, reflecting the higher fiscal burden associated with larger subsidies.

## 8 Concluding Remarks

In this paper, we have uncovered 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 buyer counterparty risk may appear in various settings, we argue it is especially 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 fills this gap, offering a flexible framework to analyze their impacts. Overall, our findings suggest that policies need to address the root cause of counterparty risk; without mitigating this risk, countervailing measures, such as public guarantees or public subsidies, may incur high costs, whether from public funds or from inefficient overinvestment.



**Figure 13:** Welfare Effects of the Optimal Subsidies

*Notes:* For each level of contract demand, the figures report the effect of the optimal public subsidy on welfare (gray bars) and decompose it into three components: buyer surplus net of transfers to sellers (light blue bars), seller surplus (dark blue bars), and the welfare loss from the distortionary cost of public funds (blue bars), computed assuming  $\lambda = 0.02$ .

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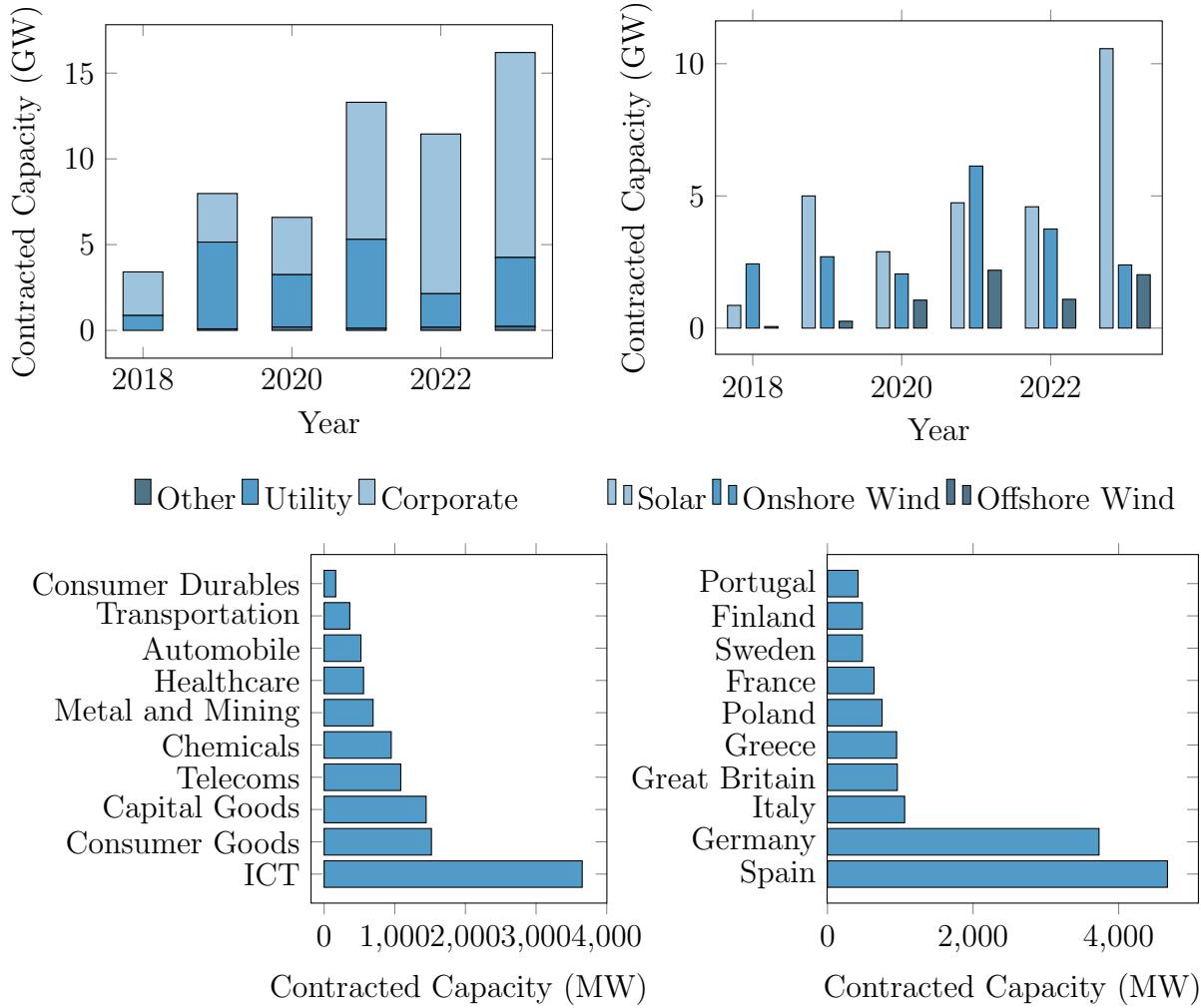
## A Background Evidence: Renewable Energy Contracts and Renegotiation

This section first documents recent patterns in European Power Purchase Agreements (PPAs) for renewable energy investments, describing the main buyer types, the sectors and countries in which corporate demand concentrates, and the technologies being contracted. It then concludes with real-world examples of buyer-driven contract renegotiations.

Figure 14 reports annual PPA volumes in Europe by buyer type. It shows a pronounced shift toward corporate offtakers over 2018–2023, while utility procurement remains substantial. The figure also indicates that corporate PPA demand is concentrated in a handful of sectors—most notably ICT—alongside a long tail of smaller contracting industries. Figure 14 also shows that the technology mix evolves: solar accounts for most recent contracted volumes, while onshore and offshore wind contribute materially in several years. Finally, geographic concentration of PPA activity, with Spain and Germany standing out as the largest markets in 2023.

Tables 2 and 3 list several cases of renewable energy contracts that were renegotiated by buyers. References of newspaper articles citing those cases are listed below:

- 1 *The Impact of the Hourly Spot Market Price (PLD) Recently Adopted in Brazil* (International Bar Association). <https://www.ibanet.org/impact-market-price-brazil>
- 2 *Bulgaria to Seek Conversion of Existing Feed-in Tariff Contracts to Feed-in Premium* (SeeNews). <https://seenews.com/news/bulgaria-to-seek-conversion-of-existing-feed-in-tariff-contracts-to-feed-in-premium-1124313>
- 3 *ICSID Tribunal Concludes Bulgaria Breached the ECT Through Frustration of Legitimate Expectations* (IISD). <https://www.iisd.org/itn/2024/07/02/icsid-tribunal-concludes-bulgaria-breached-the-ect-through-frustration-of-legitimate-expectations-and-awards-damages-will-this-award-push-bulgaria-toward-withdrawing-from-the-ect/>
- 4 *Andhra Pradesh's Decision to Renegotiate Solar and Wind PPAs Sets Bad Precedent* (Mercom India). <https://www.mercomindia.com/andhra-pradesh-solar-win>



**Figure 14:** The market for PPAs in Europe. Contracted capacity by type of buyer (upper left) and the industry to which corporate buyers belong (lower left). Capacity by technology (upper right) and new capacity contracted by country in 2023 (lower right). Source: Pexapark (2024).

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5 *Andhra Pradesh's Forceful Contract Renegotiations Could Derail US\$40bn in Renewable Investment* (IEEFA). <https://ieefa.org/resources/ieefa-india-andhra-pradeshs-forceful-contract-renegotiations-could-derail-us40bn>

6 *PPAs and Renewable Energy: Lessons from the 2019 Andhra Pradesh Dispute* (Economic and Political Weekly). <https://www.epw.in/journal/insight/ppas-and-renewable-energy.html>

7 *Tariff Renegotiations of Solar PPAs: Can We Really Bring Foreign Investments with This Level of Regulatory Uncertainty?* (Firstgreen Consulting). <https://fi>

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- 8 *MNRE to Penalize for Modification or Renegotiation of Solar PPAs* (CleanFuture).  
<https://www.cleanfuture.co.in/2017/09/12/mnre-to-penalize-for-modification-or-renegotiation-of-solar-ppas/>
- 9 *Amidst India's Lagging Renewable Targets, Investments in the Indian Solar Sector May Perish Due to Policy Insecurities* (The Indian Wire). <https://www.theindianwire.com/environment/amidst-indias-lagging-renewable-targets-investments-in-the-indian-solar-sector-may-perish-due-to-policy-insecurities-315275/>
- 10 *Pain in Spain: New Retroactive Changes Hinder Renewable Energy* (Renewable Energy World). <https://www.renewableenergyworld.com/solar/pain-in-spain-new-retroactive-changes-hinders-renewable-energy/>
- 11 *Spain Approves Retroactive Policy to Replace Feed-in Tariff* (Institute of Energy for South-East Europe). <https://www.iene.eu/spain-approves-retroactive-policy-to-replace-feed-in-tariff-p692.html>
- 12 *Spain Loses Another International Arbitration Over Retroactive Cuts to Renewables* (Strategic Energy). <https://strategicenergy.eu/spain-loses-another-international-arbitration-over-retroactive-cuts-to-renewables/>
- 13 *Greeneville Energy Authority Renegotiate Power Purchase Agreement With Silicon Ranch for Period of 35 Years* (WGRV). <https://wgrv.com/2024/04/02/greeneville-energy-authority-renegotiate-power-purchase-agreement-with-silicon-ranch-for-period-of-35-years/>

**Table 2:** Evidence on contract renegotiations by buyers (I)

Country	Period	Buyer types	Description	Refs.
Brazil	2014–2017	Distribution companies; regulated buyers	After spot and auction prices fell following rapid renewables deployment, several distribution companies sought to revise PPAs signed at higher tariffs, pressuring generators to accept lower effective prices or restructuring to reflect new market conditions.	[1]
Bulgaria	2018–	Government/Parliament; obligated buyers	Parliament announced plans to renegotiate long-term PPAs and FiT contracts by converting them into FiP schemes, forcing generators to sell at wholesale prices plus a premium, lowering guaranteed revenues when spot prices are below the original FiT.	[2], [3]
India (Andhra Pradesh) India (other states)	2019 2017–2020	State distribution companies (DISCOMs) State DISCOMs	New state government ordered a review and downward revision of tariffs in roughly 139 solar and wind PPAs, citing that previously agreed prices exceeded current market/auction prices; developers challenged the move before the regulator and courts. Several states considered or pursued downward renegotiation of solar and wind PPAs signed at higher historical tariffs after later auctions revealed much lower prices; generators reported pressure to accept reduced tariffs on concluded long-term contracts.	[4], [5], [6] [7], [8], [9]

**Table 3:** Evidence on contract renegotiations by buyers (II)

Country	Period	Buyer types	Description	Refs.
Spain	2010–2014; 2018–2021	Government; utilities; Corporate offtakers	Successive reforms to renewable support schemes (e.g., RD 14/2010, RD 413/2014) reduced remuneration of existing plants relative to originally contracted FiTs (often described as <i>de facto</i> downward renegotiations). Later, some early corporate/utility PPAs signed around 2018–2019 at higher fixed prices were reportedly repriced or restructured after wholesale/forward prices fell during the pandemic.	[10], [11], [12]
United States	2010s	Utilities; corporate offtakers	Following the shale gas boom and sharp declines in solar PV costs, some utilities and large corporate buyers sought to renegotiate early renewable PPAs signed at relatively high fixed prices, requesting downward revisions or restructuring (e.g., longer tenors) to align with lower costs and wholesale prices.	[13]

## B Proofs

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

**Proof of Proposition 1:** In the text. □

**Proof of Lemma 1:** Define  $\tilde{P}(f, \gamma) = \gamma \int_0^f p\phi(p)dp + f[1 - \gamma\Phi(f)]$ , increasing in  $f$  and decreasing in  $\gamma$ . As a result,  $\Pi_B(\bar{f}, \gamma) = v - \tilde{P}(\bar{f}, \gamma) = E(p) - r$  and

$$\Pi_S(\underline{f}, \gamma, c) = \tilde{P}(\underline{f}, \gamma) - R(\underline{f}, \gamma) - c = \max\{E(p) - r - c, 0\}.$$

When  $\gamma = 0$  and no counterparty risk exists,  $\Pi_B(f, 0) = v - f$  and  $\Pi_S(f, 0) = f - c$ , meaning that the buyer and seller only accept a fixed price if  $f \leq E(p) = \bar{f}(0)$  and  $f \geq \max\{c, E(p) - r\} \equiv \underline{f}(0, c)$ .

When  $\gamma = 1$ ,  $\Pi_B(f, 1) > v - E(p)$  for all  $f < 1$  and  $\Pi_B(f, 1) = v - E(p)$  otherwise. Hence,  $\bar{f}(1) = 1$ . By Assumption 1,  $\Pi_S(f, 1) \leq \Pi_S(1, 1) = E(p) - r - c$ . This means that when  $c \leq E(p) - r$ ,  $\underline{f}(1, c) = 1$  and  $\underline{f}(1, c) > 1$  otherwise.

Finally, using the Implicit Function Theorem,

$$\frac{\partial \bar{f}}{\partial \gamma} = -\frac{\frac{\partial \tilde{P}}{\partial \gamma}}{\frac{\partial \tilde{P}}{\partial f}} \geq -\frac{\frac{\partial \tilde{P}}{\partial \gamma} - \frac{\partial R}{\partial \gamma}}{\frac{\partial \tilde{P}}{\partial f} - \frac{\partial R}{\partial f}} = \frac{\partial \underline{f}}{\partial \gamma} > 0,$$

where, due to Assumption 1,  $\frac{\partial R}{\partial \gamma} > 0$  and  $\frac{\partial \tilde{P}}{\partial f} - \frac{\partial R}{\partial f} > 0$ . Furthermore,  $\frac{\partial \tilde{P}}{\partial \gamma} - \frac{\partial R}{\partial \gamma} < 0$  since  $\frac{\partial \tilde{P}}{\partial \gamma} < 0$ . □

**Proof of Lemma 2:** Immediate from Lemma 1 and Corollary 1. □

**Proof of Proposition 2:** In the text. □

**Proof of Proposition 3.** Let  $V_S(\gamma)$  and  $V_B(\gamma)$  denote, respectively, the equilibrium aggregate surplus of sellers and buyers as a function of  $\gamma$ .

(i) *Sellers.* Since the marginal investor with cost  $c^*$  breaks even, aggregate seller surplus equals

$$V_S(\gamma) = \int_0^{c^*} (c^* - c) g(c) dc.$$

This expression is increasing in  $c^*$ .

If  $\gamma \leq \hat{\gamma}$ , the market clears. Therefore, the marginal investor has a cost  $c^* = G^{-1}(\theta)$ , which coincides with the benchmark under perfect enforceability and, equivalently, with the case  $\gamma = 0$ . It follows that  $V_S(\gamma) = V_S(0)$  for all  $\gamma \leq \hat{\gamma}$  and seller surplus is, therefore, independent of  $\gamma$ .

If instead  $\gamma > \hat{\gamma}$ , the market does not clear and the marginal investor has a cost  $c^* = \bar{c}(\gamma) < G^{-1}(\theta)$ , where  $\bar{c}(\gamma)$  is implicitly defined by the zero-profit condition at the equilibrium contract price,  $\Pi_S(\bar{f}, \gamma, \bar{c}(\gamma)) = 0$ . This threshold is decreasing in  $\gamma$ . Since  $V_S(\gamma)$  is increasing in  $c^*$  we have that  $V_s(\gamma)$  is decreasing in  $\gamma$  for all  $\gamma > \hat{\gamma}$  and  $V_S(\hat{\gamma}) = V_S(0)$ .

(ii) *Buyers.* If  $\gamma \leq \hat{\gamma}$ , since sellers do not lose from counterparty risk, buyers suffer the full welfare loss,

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

which is decreasing in  $\gamma$ .

Otherwise, if  $\gamma > \hat{\gamma}$ , the equilibrium price  $f^* = \bar{f}(\gamma)$  implies  $V_B(\gamma) = 0$ , which is independent of  $\gamma$ .  $\square$

**Proof of Lemma 3:** Regarding a seller with investment cost  $c$ , the lowest acceptable price,  $\underline{f}(k, c)$ , satisfies (8) with equality. Since

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

using Assumption 1, it follows that  $\underline{f}(k, c)$  must be decreasing in  $k$ .

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

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

Since buyer profits are decreasing in  $k$ ,  $f$ , and  $\rho$ , and the right-hand side is a constant, it follows that  $\bar{f}(k, \rho)$  must be decreasing in  $k$  and  $\rho$ . For  $k = 0$ , we revert to the baseline model, with buyers accepting the contract regardless of the price,  $\bar{f}(0, \rho) = 1$  for all  $\rho$  (recall that here we are assuming  $\gamma = 1$ ). 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 4:** 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 a contract with such collateral to eliminate counterparty risk, it must lead to  $f^*(\hat{k}) = \hat{k} \geq E(p) - r$ , as this is the lowest price sellers are willing to accept under

perfect contract enforceability. When this is not the case, eliminating counterparty risk is incompatible with sellers participating in the market for fixed-price contracts.  $\square$

**Proof of Proposition 4:** From Lemma 4, 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

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

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

$$\frac{d\Pi_S(f^*, k, c)}{dk}\Big|_{k=\hat{k}} = \frac{\partial R}{\partial f}(0, 1) + \left(1 - \frac{\partial R}{\partial f}(0, 1)\right) \frac{df^*}{dk}\Big|_{k=\hat{k}}. \quad (15)$$

The first term captures how much an increase in the 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. Since  $f^*$  is decreasing in  $k$ , a necessary condition for this derivative to be negative is that  $\frac{\partial R}{\partial f}(0, 1) < 1$ .

We can rewrite the market clearing condition (11) using (7) equated to the outside option  $\Pi_B^0$  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

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

Evaluated at  $k = \hat{k} = f^*(\hat{k})$  we have, using Assumption 1, that  $c^* = f^*(\hat{k}) - R(0, 1) = \hat{k}$  and we can compute

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

Replacing in (15), 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

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

where we can write  $c^* = \Pi_S(f^*, k, 0)$ . The derivative of this function with respect to  $k$  evaluated at  $f^*(\hat{k}) = \hat{k}$  becomes

$$W'(k) = G(c^*) \frac{d\Pi_S(f^*, k, 0)}{dk} + \hat{\rho} \left[ -(1 - \Phi(f - k)) \frac{df}{dk} - \Phi(f - k) - \frac{\hat{\rho}}{2} \right],$$

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

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

$$W'(\hat{k}) = G(\hat{k}) \left[ \frac{\partial R}{\partial f}(0, 1) \left( 1 - \frac{df}{dk} \Big|_{k=\hat{k}} \right) - \frac{G(\hat{k})}{2} \right].$$

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 counter-party risk, it is also good for society—but not the other way around.  $\square$

## C Risk Aversion

We start by proposing an example that satisfies Assumption 1. We later show that these assumptions are also satisfied by standard concave utility functions.

**Lemma 5.** *Suppose that the manager of the seller firm has mean-variance preferences:*

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

where  $x$  is a random variable representing seller payoffs. Assumption 1 is satisfied for  $r_0 > 0$  sufficiently small.

*Proof.* 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  $1 - \gamma$ ,  $x$  is degenerate at

$f$ , whereas with probability  $\gamma$  the seller receives a random return  $\tilde{p}$ , distributed as the minimum of  $p$  and  $f$ . Letting  $r \equiv r_0 \text{Var}(p)$ , the risk premium is

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

Notice that  $R(0, \gamma) = R(f, 0) = 0$  and  $R(1, 1) = r$ .

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

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

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,

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

which is always non-negative.

Finally, we now show that the manager's utility is decreasing in  $\gamma$ . Notice that,

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

where

$$\frac{\partial R}{\partial \gamma} = r \frac{\text{Var}(\tilde{p}) + (1 - 2\gamma)(f - E(\tilde{p}))^2}{\text{Var}(p)} > -r_0(2\gamma - 1)(f - E(\tilde{p}))^2 > -\frac{(2\gamma - 1)(f - E(\tilde{p}))}{2\gamma},$$

when  $r_0 \leq \frac{1}{2\gamma(f - E(\tilde{p}))}$ . As  $f - E(\tilde{p}) = \int_0^f (f - p)\phi(p)dp$ , this implies that

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

□

As we have just seen, the costs of price volatility can be captured using a premium  $R(f, \gamma)$  satisfying Assumption 1, and which is consistent with mean-variance preferences. We now 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.

The expected utility of a seller in the second period can be written as

$$U_S(f, \gamma) = \gamma \left[ \int_0^f u(p)\phi(p)dp + (1 - \Phi(f))u(f) \right] + (1 - \gamma)u(f). \quad (16)$$

This expression is increasing in  $f$  and decreasing in  $\gamma$ , consistently with our baseline model under Assumption 1.

Letting  $R^u(f, \gamma)$  denote the risk premium under a contract price  $f$ , this expression can be re-written as

$$U_S(f, z^*) = u \left( \gamma \int_0^f p\phi(p)dp + f(1 - \Phi(f)\gamma) - R^u(f, \gamma) \right)$$

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 6.** *The risk premium is  $R^u(f, \gamma)$  increasing in  $f$  and satisfies  $R^u(0, \gamma) = R^u(f, 0) = 0$  and  $R^u(1, 1) = r$ .*

*Proof.* We can write the seller's expected utility as

$$U_S(f, \gamma) = \gamma \int_0^f u(p)\phi(f)dp + u(f)(1 - \Phi(f)\gamma) \quad (17)$$

$$= u \left( \gamma \int_0^f p\phi(f)dp + f(1 - \Phi(f)\gamma) - R^u(f, \gamma) \right) \quad (18)$$

Solving for the premium:

$$R^u(f, \gamma) = \gamma \int_0^f p\phi(f)dp + f(1 - \Phi(f)\gamma) \quad (19)$$

$$- u^{-1} \left( \gamma \int_0^f u(p)\phi(f)dp + u(f)(1 - \Phi(f)\gamma) \right) \quad (20)$$

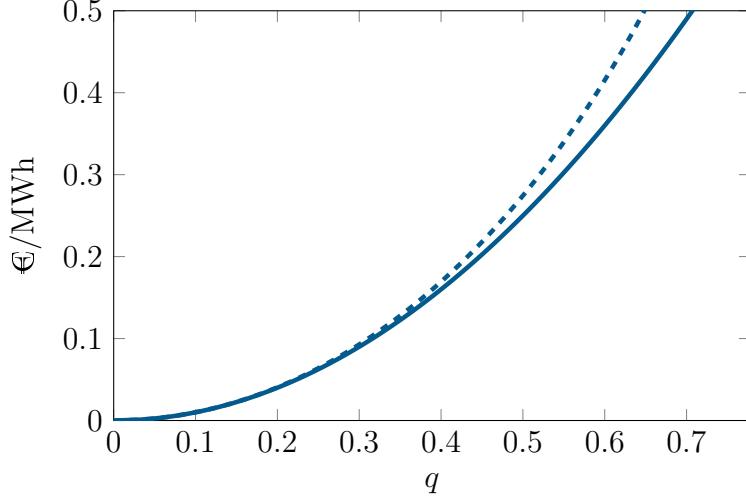
The premium  $R^u(f, \gamma)$  is a continuous function, and it is continuously differentiable given the properties of the utility function.

Taking derivatives on both sides of (18) with respect to  $f$  we obtain

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

Solving it,

$$\frac{\partial R^u(f, \gamma)}{\partial f} = (1 - \Phi(f)\gamma) \left( 1 - \frac{u'(f)}{u' \left( \gamma \int_0^f p\phi(f)dp + f(1 - \Phi(f)\gamma) - R^u(f, \gamma) \right)} \right) > 0, \quad (21)$$



**Figure 15:** 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  $\gamma = 0$  (solid line) and when  $\gamma = \frac{1}{2}$  (dashed line).

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 (21) 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 (20) 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 (20) 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

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

□

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:

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

where  $\Pi_S(f, \gamma, c)$  is defined in (2). Since the risk premium  $R^u(f, \gamma)$  has similar properties as  $R(f, \gamma)$ , we can approximate  $U_S(f, \gamma, c)$  with the profit function  $\Pi_S(f, \gamma, c)$ . Figure 15 provides an example.