The Costs of Counterparty Risk in Long-Term Contracts*

Natalia Fabra
Universidad Carlos III and CEPR

Gerard Llobet
CEMFI and CEPR

February 6, 2025

Abstract

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

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

JEL Codes: L13, L94.

*Emails: natalia.fabra@uc3m.es and llobet@cemfi.es. This paper has benefited from comments by Guillermo Caruana, Caio Lorecchio, Massimo Motta, Patrick Rey, and Sugandha Srivastav, as well as seminar audiences at Universidad Complutense, Universidad Carlos III, Innsbruck University, Universidad de Málaga, Barcelona School of Economics, the 2024 ULB Energy Workshop, the 2024 CEPR Conference on Climate Change and the Environment, CRESSE 2024, JEI 2024, Hanken School of Economics, ULB, EUI, and DG Competition. The first author thanks the support of the European Research Council's Advanced grant ENERGY IN TRANSITION (Grant Agreement 101142583). The second author thanks the support of the Spanish Ministry of Science and Innovation through grant PID2021-128992NB-I00.

1 Introduction

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

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

Against this background, energy regulators envision long-term contracts between buyers and sellers as a way to reduce these risks and foster investments in renewable power sources, contributing to the energy transition and reducing the dependency on fossil fuels.[3] As the European Commission stated in its proposal to reform electricity markets, *"the ultimate objective is to provide secure, stable investment conditions for renewable and low-carbon energy developers by bringing down risk and capital costs while avoiding windfall profits in periods of high prices"* (European Commission, 2023).[4]

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

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

[3]These issues are even more pronounced in the case of nuclear power plants, where investment costs are significantly higher, and lifetimes can extend up to 60 years. As a result, nearly all nuclear power plants are developed with public support, often involving financing backed by public guarantees and long-term power contracts. For examples, see 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).

[4]In the same spirit, the World Bank has expressed that long-term power contracts are "*central to*

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."* However, beyond this concern, the implications of buyers' counterparty risk on the performance of long-term contract markets have not been explored in detail.

Our paper puts buyers' counterparty risk at the core of the analysis and uncovers the mechanisms by which it leads to high contract prices, excessive contract defaults, poor contract liquidity (including potential market unraveling) and a limited ability to leverage investments. This framework is then used to analyze the properties of public policies that have been proposed in the context of electricity markets to overcome the market failures of the long-term contract market.

Our model considers sellers and buyers who can trade one unit of a homogeneous good in a spot market with volatile prices. Sellers must incur heterogeneous investment costs to produce. Because they are risk averse, they are willing to enter into a fixed-price contract to mitigate their exposure to spot prices. However, fixed-price contracts offer only a partial hedge, as some buyers may opportunistically default if the spot price falls below the contract price.[5]

Sellers with low investment costs find entry profitable even when facing full exposure to spot prices. Thus, they invest regardless of contract availability. In contrast, high-cost sellers only invest if they can secure a favorable long-term contract. The higher the share of opportunistic buyers, the lower the sellers' expected profits and, hence, the higher the contract prices at which they are willing to invest.

A higher contract price creates a trade-off for sellers: increased revenue, but also a higher probability of default. Raising the contract price above the expected spot-market price is counterproductive, as only opportunistic buyers would accept it. While this finding echoes Stiglitz and Weiss (1981), our work emphasizes the impact of adverse

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

[5]In our baseline model, we normalize the cost of contract default to zero. In Section 4, we show that the model's main results hold if we add collateral that is forfeited upon default, provided it is not too valuable.

selection on equilibrium investment.

When there are few opportunistic buyers, the contract market clears, as there are enough sellers who can profitably invest to meet demand. However, the equilibrium contract price is higher than in a risk-free environment because the marginal investor must be compensated for the default risk. Since all sellers receive the market-clearing price, which exceeds the minimum price that inframarginal sellers would accept, the equilibrium involves excessive risk premia for all contracts.

If the share of opportunistic buyers is large, counterparty risk limits new investment by constraining the costs sellers can recover through the contract market. Specifically, investment occurs only by sellers who can break even at contract prices equal to the expected spot market price, considering the costs of contract default. If demand at that price exceeds available supply, inefficient contract rationing ensues, as expanding investment to meet demand would yield positive cost savings.

The equilibrium of the model shows that the price premium associated with counterparty risk is not simply a transfer from buyers to sellers to compensate for the default risk; it has broader efficiency implications as it raises the default probability for all contracts, including inframarginal ones, and depresses investment.

The analysis also reveals that opportunistic buyers may find themselves in a prisoner's dilemma. Individually, they gain from defaulting when spot prices drop below contract prices; however, collectively, their behavior results in higher equilibrium contract prices and reduced investment, leaving them worse off overall. Interestingly, when demand is inelastic and not excessively high, the full passthrough of the costs of default risk to prices means that sellers are not harmed by the presence of opportunistic buyers, provided there are not too many of them. In that case, buyers suffer the full welfare loss of poor contract enforcement.

Our results suggest potential welfare gains through public policies that address counterparty risk, some of which have been either implemented or proposed in regulatory debates in Europe and the US. For instance, in the context of electricity markets, the European Commission (2023) has recently emphasized that *"Member States should ensure that instruments to reduce the financial risks associated to the buyer defaulting on its long-term payment obligations in the framework of PPAs are accessible to companies* *that face entry barriers to the PPA market and are not in financial difficulty."*[6] The suitability of public support and guarantees depends on the social cost of the public funds involved, although implications vary between policy types.

Public subsidies, contingent on the seller signing a fixed-price contract, have two welfare-enhancing effects that ought to be balanced against the social costs of the public funds. First, they can boost investment when counterparty risk is a limiting factor. Second, by increasing the profitability of investment, subsidies lower the equilibrium price in the market for long-term contracts when demand is limited, mitigating counterparty risk across all contracts.

Public guarantees shift the cost of counterparty risk from sellers to regulators. Hence, as with subsidies, there is a trade-off between the benefits of protecting sellers against contract default and the public cost of these guarantees. However, a new effect arises: since sellers do not internalize the full cost of their investments, moral hazard problems through excessive risk-taking and inefficient entry may arise.

We show that an effective intervention is to promote regulator-backed long-term contracts.[7] Because the regulator is the counterparty to these contracts, they constitute a risk-free option and contribute to more efficient investments through a demand expansion effect. Depending on the volume of contracts allocated, this market can optimally coexist with the private market for long-term contracts. The concern, however, is that the regulator may overstate contract needs, potentially leading to overinvestment.

Finally, our analysis reveals the trade-offs of collateral requirements, which reduce counterparty risk by requiring buyers to post funds that are transferred to sellers upon default. However, costly collateral lowers contract demand, limiting investment opportunities. Thus, a large collateral requirement that eliminates default is oftentimes inefficient. Collateral requirements should be optimally adjusted based on the default cost of the seller relative to the collateral cost of the buyer.

We have intentionally kept our analysis simple to highlight the main mechanisms, but its implications are robust to alternative specifications. Our model incorporates sellers' risk aversion by introducing a generic risk premium that is increasing in the probability

[6] Likewise, the World Bank has provided guarantees to support renewable power auctions in developing countries (Braud, 2018).

[7] These contracts are commonly used in Europe, where they are known as Contracts-for-Differences. In the United States, contracts signed by public utility companies can also fall into this category, provided the utility can pass the contract costs onto final consumers without encountering enforcement issues.

of contract default, consistent with (but not limited to) mean-variance preferences. This parametrization simplifies the analysis while remaining equivalent to a framework where sellers have a concave utility function.

Although we focus on contract default as the manifestation of buyer opportunism, the results are more general. As we explain in Section 6, our model can be easily reinterpreted to accommodate buyer renegotiation after investment has taken place. This concern is relevant in the case of renewable plants, as with nearly zero variable costs, the resulting assets retain a positive market value once investment is sunk, making owners more likely to accept lower renegotiated prices if later on buyers have access to cheaper alternatives.[8] In addition, energy intensive users (or electricity retailers) are particularly interested in signing long-term contracts to reduce their price exposure. But, at the same time, they are most vulnerable to the competitive pressure exerted by rivals who could secure lower prices in the future, limiting their ability to honor contracts. Unlike in other contexts (Klein et al., 1978; Baker et al., 2002), this feature implies that vertical integration does not address the exposure to volatile spot prices in the presence of downstream competition and becomes less effective as a hedge against future price reductions.

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

Related Literature This paper contributes to the literature on contracting with imperfect enforcement. Our research is grounded on the classical theory of the firm (e.g., Baker et al. (2002), Hart (1995, 2009) and Klein (1996)). In recent years, the effects of imperfect enforcement have been empirically documented in various contexts. Guiso et al. (2013) examine strategic default in mortgage markets when owners have negative

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

equity. Blouin and Macchiavello (2019) analyze bilateral negotiations 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. A key difference with the existing literature on imperfect contract enforcement is that we characterize the probability of contract default as an endogenous outcome determined in equilibrium, often making counterparty risk a self-defeating phenomenon for opportunistic buyers.

Long-term bilateral contracts have also been studied in the context of electricity markets, particularly in developing countries where governments often guarantee a wholesale price. In a study of solar auctions in India, Ryan (2024) identifies the impact of counterparty risk by comparing auctions where states 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.[9] Hara (2024) provides evidence on renewable investors' risk aversion in Brazilian wind-energy actions. More recently, Chen (2024) empirically studies the market for bilateral power contracts in the US, with a focus on how regulatory uncertainty delays investment through these contracts. Our work provides a theoretical framework consistent with these empirical findings. While our focus is on long-term contracts between private parties, we also relate to this body of work by examining the design of regulator-backed contracts in contexts where regulators can act as a safer alternative.

The remainder of the paper is organized as follows. In Section 2, we present the model. In Section 3, we characterize the contract-market equilibrium and assess its welfare properties. In Section 4, we introduce costly collateral, which serves to endogenize demand in the contract market, and assess its equilibrium consequences. In Section 5, we analyze several market interventions, including initiatives to promote contract demand, regulator-backed contracts, public subsidies, and public guarantees. In Section 6, we analyze the robustness of the model and explore several extensions. Section 7 concludes. Proofs are included in the Appendix.

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

2 Model Description

Consider a market for a homogeneous good. On the demand side, there is a unit mass of buyers with a maximum willingness to pay for one unit of the good equal to $v \geq 1$. On the supply side, there is a unit mass of (entrant) sellers, each capable of building one unit of capacity at a fixed cost c. Each 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 $c \in [0, 1]$.

Without entry, there is already enough existing capacity to meet total demand. Its marginal cost is denoted by p, and it is distributed according to $\Phi(p)$, with a positive and differentiable density $\phi(p)$ over the interval $[0, 1]$. The expected marginal cost of existing capacity is denoted by $E(p)$. 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.[10]

The timing of the game is as follows. First, at the investment stage, sellers decide whether to enter or not after observing their investment cost c but before knowing the realization of the marginal cost of the existing capacity, p. Second, at the production stage, once p is observed, buyers and sellers trade the good in a perfectly competitive spot market, where the market price is given by the marginal cost of the last producer required to cover demand, p.[11] Since entrants have zero marginal costs, they produce at full capacity, earning expected spot market revenues $E(p)$.

For sellers, exposure to volatile spot-market prices creates uncertainty over cost recovery, originating a risk premium $r > 0$.[12] Buyers do not incur any investment and are assumed to be risk-neutral.

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

---

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

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

[12]For instance, if sellers have mean-variance preferences, the risk premium would correspond to $r = r_0 Var(p)$, for some positive r_0.

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

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

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

3 Fixed-price Contracts

Suppose that buyers and sellers are allowed to sign a fixed-price contract prior to investment, enabling them to hedge their spot-market transactions. However, only a proportion $\theta \in (q^0, 1]$ of buyers participate in the contract market,[13] whereas the rest procure the good in the spot market. The contract requires the seller to compensate the buyer for the difference between the spot price p and the contract price, denoted by f, if $p > f$, and vice versa if $f > p$.

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

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

are always decreasing in the contract price f.

Sellers do not observe the buyers' trustworthiness when signing contracts but hold correct expectations regarding the probability of a buyer being opportunistic, denoted as z. Seller profits from signing the contract are

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

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

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

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

These properties are consistent (but not limited to)[14] mean-variance preferences, as shown next:

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

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

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

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

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

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

It follows that the mean-variance framework satisfies Assumption 1 if r is sufficiently low.[15]

The assumption that $R(f,z)$ increases in f captures the fact that higher fixed prices increase the probability of contract default, and thus the degree of spot-market exposure. The other assumptions imply that seller profits increase with f, as r is low enough so

[14] As we show in Section 6, these properties of the risk premium are also satisfied by standard concave utility functions.

[15] See the appendix for further details.

that the direct effect of increasing f outweighs the costs of the corresponding increase in the risk premium.

As it is natural, we also assume that seller profits are decreasing in the proportion of opportunistic buyers.[16]

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

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

First, note that the probability that a seller faces an opportunistic buyer, z, depends on the contract price. Since a fixed-price contract must provide higher profits than the spot market, trustworthy buyers only sign contracts if $f \leq E(p)$. In contrast, non-trustworthy buyers are willing to sign contracts at any price $f \leq 1$ since they default if the spot price falls below the contract price.[17] Hence, for contract prices $f > E(p)$, in equilibrium $z^* = 1$. Likewise, assuming that buyers are proportionally rationed, for contract prices $f \leq E(p)$, in equilibrium $z^* = \gamma$.

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

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

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

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

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

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

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

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

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

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

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

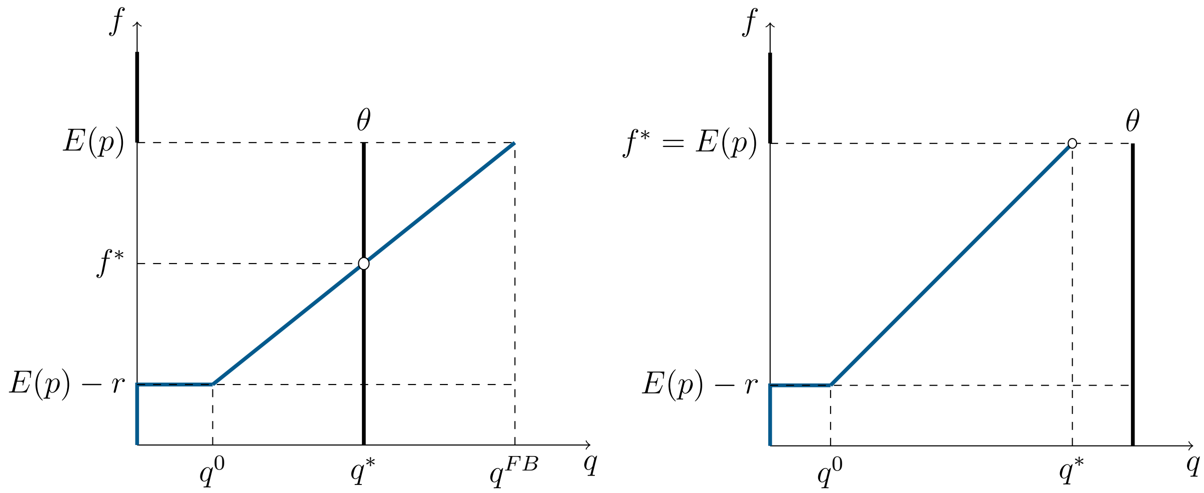
The supply of contracts can be constructed by considering three cases as a function of the investment cost. First, if $c \leq E(p) - r$, then $\Pi_S^0 \geq 0$, i.e., the seller invests regardless of whether a contract is signed or not. In this case, the contract is accepted by the seller as long as it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

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

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

Finally, entry does not occur for values of c for which the seller cannot break even at the profit-maximizing price, $\Pi_S(E(p); c; \gamma) < 0$. We use $\bar{c}(\gamma)$ to denote the highest investment cost for which entry might be profitable, i.e., $\Pi_S(E(p); \bar{c}(\gamma), \gamma) = 0$. This threshold is decreasing in γ as seller profits decrease with the proportion of opportunistic buyers.

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



(a) The no-contract-rationing case

(b) The efficient contract rationing case

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

In subfigure (a), the market clears at f^*, which is given by the cost of the marginal investor c^*. In subfigure (b), the equilibrium price is given by the highest price buyers are willing to pay, $E(p)$. There is contract rationing, but it is efficient since the contribution to welfare of the marginal investor, $c^* = E(p)$, is zero.

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

Two cases must be considered. First, when contract demand is low, i.e., $\theta \leq G(E(p))$, there is market clearing at a quantity $q^* = \theta$ and price $f^* = G^{-1}(\theta)$ (Figure 1a).[18] 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 taking place. Letting W^{FB} and $W^*(\gamma)$ measure welfare under the First Best and welfare with fixed-price contracts and perfect enforcement (equivalent to the case with no opportunistic buyers, $\gamma = 0$), respectively, we have

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

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

Second, when demand is high, $\theta > G(E(p))$, there is contract rationing as only part of the contract demand, $q^* = G(E(p))$, is satisfied at the highest possible equilibrium price, $f^* = E(p)$ (Figure 1b). Importantly, contract rationing is efficient in this case as further

[18] All figures assume that $G(c)$ is $U[0, 1]$ implying that, absent counterparty risk, the supply curve is piecewise linear.

investment would involve a cost c exceeding the marginal cost savings, $E(p)$. Since the contract solution achieves the First Best, $W^*(0) = W^{FB}$.

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

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

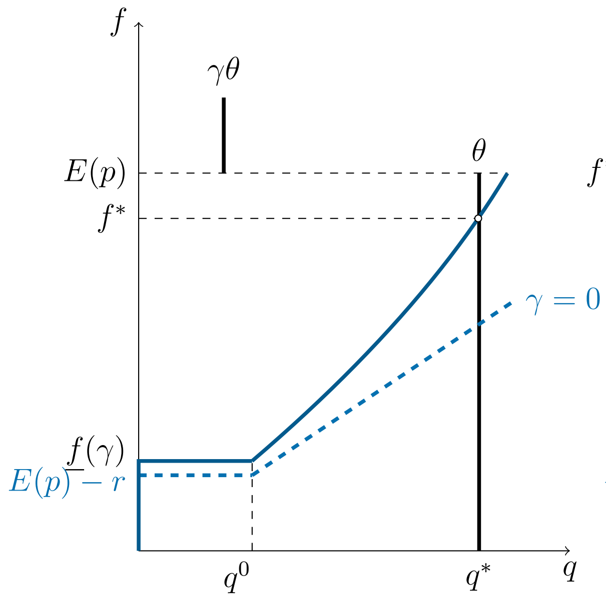
We now analyze the consequences of imperfect contract enforceability. Throughout the rest of the paper, we will focus on the case where contract rationing does not arise under perfect contract enforceability. This ensures that, whenever contract rationing occurs, it is only due to counterparty risk.

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

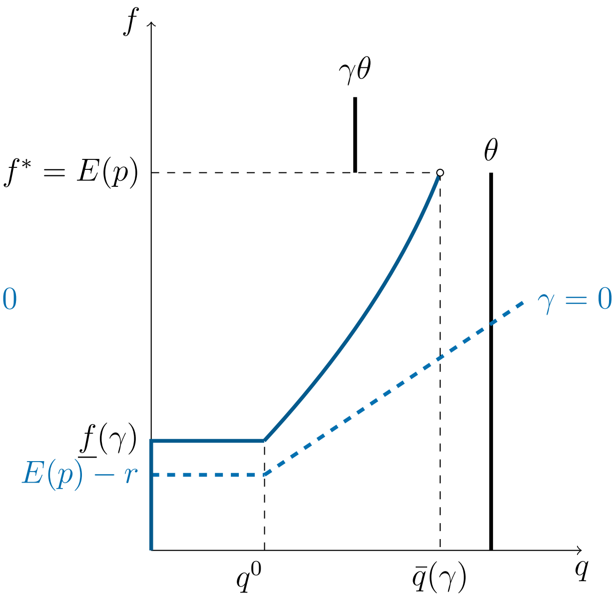
Figure 2 depicts contract supply under imperfect enforceability. Consistent with the properties of the seller's profit function, contract supply is weakly increasing in the contract price f and shifts inward as γ increases. In Figure 2a, γ is low enough so that $\theta \leq \bar{q}(\gamma) \equiv G(\bar{c}(\gamma))$,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

Our second proposition summarizes the equilibrium characterization under imperfect contract enforceability, when the share of opportunistic buyers is small enough for the market not to unravel (Corollary 1).

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



(a) The no contract-rationing case



(b) The inefficient contract-rationing case

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

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

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

3.1 Welfare Analysis under Imperfect Contract Enforceability

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

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

where W^0 measures welfare when only the spot market exists. The first term shows that all sellers that would invest even without contracts (those with $c \leq E(p) - r$) are better off with contracts thanks to the reduced price exposure. The second term measures the social welfare contribution of additional entry, $E(p) - c$, net of the losses due to counterparty risk. Since these two terms are positive, fixed-price contracts contribute positively to welfare.

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

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

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

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

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

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

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

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

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

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

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

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

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

This result highlights the importance of understanding the equilibrium effects of counterparty risk. When the proportion of opportunistic buyers is large, counterparty risk exposes them to a prisoner's dilemma. While individually, they prefer to default on the contract when spot market prices are low, in equilibrium they are harmed by the resulting price increase and, possibly, the reduction in investment. While one might expect sellers to be harmed by buyers' counterparty risk, their ability to fully pass on the associated cost makes them indifferent between the cases where buyers are opportunistic or not, at least when there are not too many of them.

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

4 Pledging Collateral

Our previous analysis assumed that opportunistic buyers default at no cost. While this is a useful simplification, contracts usually include provisions that penalize the party that does not honor them. In this case, these provisions take the form of a collateral

$k > 0$ pledged by the buyer and which is forfeited and transferred to the seller in case of default.

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

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

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

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

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

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

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

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

The level of collateral affects the range of prices at which buyers and sellers are willing to trade. Consider sellers first. Since their profits increase with k, participation in the

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

contract becomes more profitable the more collateral has been pledged. As a result, the new minimum price a seller is willing to accept is $\underline{f}(k)$, which, with some abuse of notation, is now denoted as a decreasing function of k. Additionally, by Assumption 1, seller profits are increasing in f and k. More collateral shifts the supply curve outward.

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

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

whereas when $k < f$, they participate if

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

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

These results are summarized next.

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

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

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

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

The demand curve for contracts with collateral k and a fixed-price f is composed of the mass of buyers with $\rho \leq \hat{\rho}(f, k)$, a threshold implicitly defined by $\Pi_B(f, k; \hat{\rho}) = \Pi_B^0$. 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.

While in this section we assume full access to the contract market for all buyers, i.e., $\theta = 1$, the variation in collateral costs, ρ, results in endogenous market participation.

When the required k is low, the cost of collateral does not reduce demand or expand supply significantly, resulting in contract rationing with $q^* = \bar{q}(\gamma) = G(\bar{c}(\gamma))$ and a price $\bar{f}_S(k)$. In contrast, a sufficiently large k gives rise to market clearing at the intersection between demand and supply,

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

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

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

Lemma 3. *There exists a unique $\hat{k}$ for which $f^*(\hat{k}) = \hat{k}$, so that $\Phi(f^* - k) = 0$ 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, for r low enough, the candidate for the equilibrium contract price would fall below the minimum price that makes sellers indifferent between hedging through contracts or selling their output in the spot market, $\underline{f}(k)$. In such a case, and as shown in the proposition below, even if setting $k = \hat{k}$ were feasible, sellers would be better off with lower collateral requirements and a higher price.

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

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

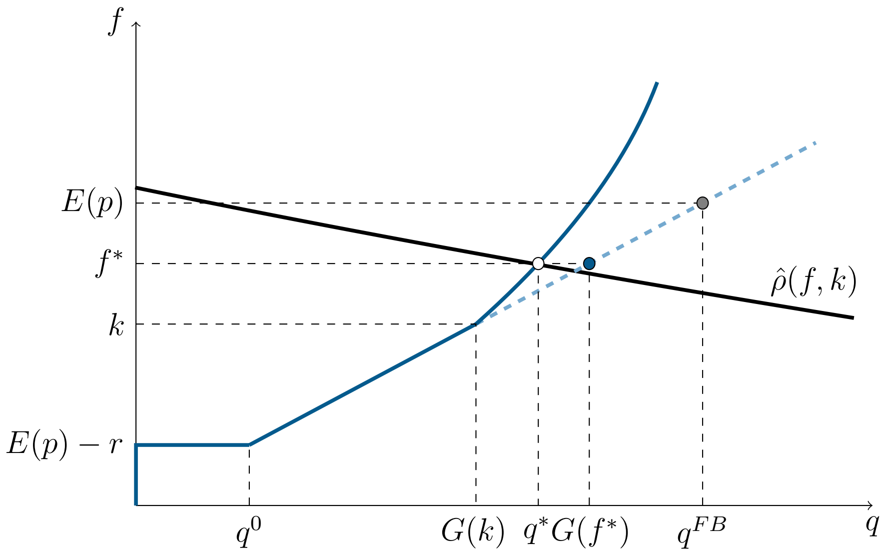


Figure 3: Market clearing when buyers pledge collateral.

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

(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 $r_W^0 < r_S^0$ *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 fixed-price contracts.

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

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

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

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

The last term captures the total cost of the collateral.

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

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

5 Market Interventions

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

5.1 Promoting Contract Demand

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

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

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

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

would always increase efficiency under perfect contract enforcement, we now analyze to which extent this result extends to cases with counterparty risk.

First, consider high values of γ such that $\bar{q}(\gamma) \leq \theta$. In this case, contract rationing occurs, making increases in contract demand ineffective. For lower values of γ, when demand is not rationed, raising contract demand boosts investment but also increases the equilibrium contract price, thereby raising the default probability for all inframarginal contracts.

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

5.2 Regulator-Backed Contracts

An alternative way to address the market failures caused by buyers' counterparty risk is for the regulator to demand fixed-price contracts, which are then passed on to final buyers.[24] Since the regulator has the authority to enforce payment even if spot prices fall below the contract price, counterparty risk is eliminated.[25]

We denote the amount of regulator-backed contracts as θ_R and, in line with Assumption 3, we set $\theta_R \leq G(E(p))$. On the demand side, contracts are uniformly allocated among the unit mass of buyers, i.e., the regulator allocates a proportion θ of these contracts to buyers who would have participated in the private-contract market anyway, while the remaining contracts are distributed to buyers who would otherwise trade in the spot market. Therefore, the residual demand for private contracts is reduced to $\theta(1-\theta_R)$, of which a fraction γ corresponds to opportunistic buyers.[26]

On the supply side, and consistent with common practice, regulator-backed contracts

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

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

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

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

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

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

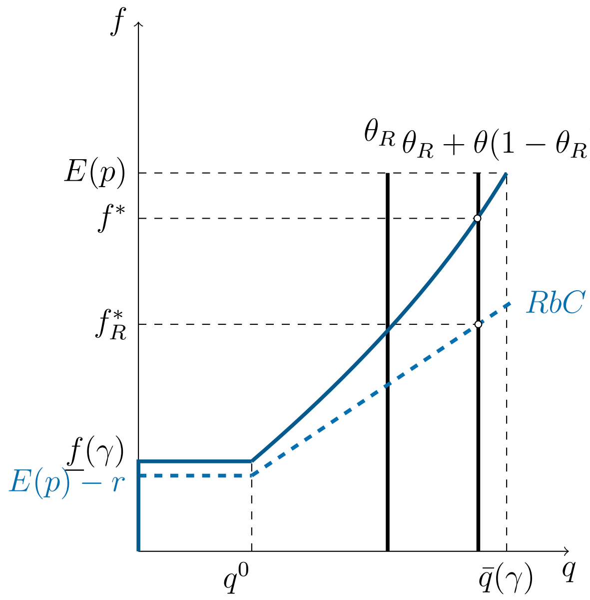
Since private contracts are not fully crowded out, investors now have the alternative to trade in the private-contracts market, which affects their opportunity cost of signing a regulator-backed contract. This means that, when competing for these contracts, the highest bid of a seller with cost c, f_R, is determined by

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

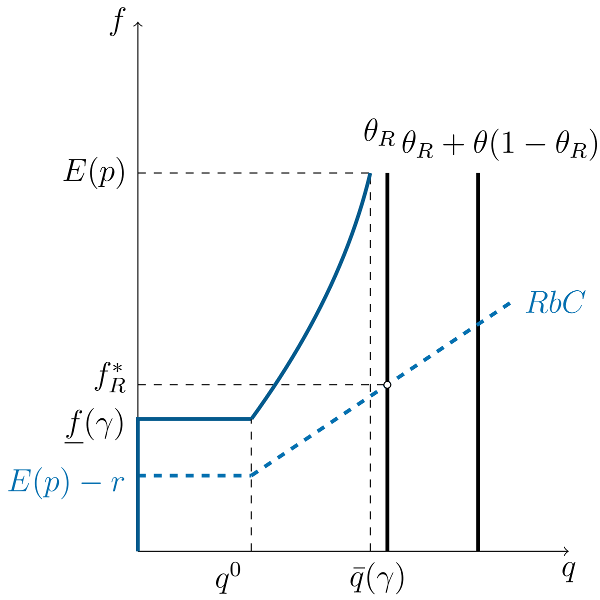
All sellers for whom participation in the private-contracts market is profitable make the same bid, regardless of c.[27]

In equilibrium, all sellers must be indifferent between contracting with the regulator

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



(a) Partial crowd-out (low γ)



(b) Full crowd-out (high γ)

Figure 4: Market clearing under Regulator-backed Contracts.

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

or a private buyer. It follows that the equilibrium price for regulator-backed contracts is

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

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

The following proposition summarizes the previous results.

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

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

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

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

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

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

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

In the remaining cases, where γ is low enough so that $\bar{q}(\gamma) > \max(\theta, \theta^R)$, introducing regulator-backed contracts introduces a trade-off similar to that encountered when promoting contract demand. On the one hand, regulator-backed contracts are risk-free but, through the demand expansion effect, also increase the price and hence the risk premia of private contracts. On the other, the welfare contribution of regulator-backed contracts to reducing underinvestment remains present. As a result, in this case, the overall welfare effect of regulator-backed contracts cannot be determined in general, as it depends on the relative magnitude of these effects.

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

5.3 Public Subsidies

Investment subsidies are a common policy tool to mitigate inefficiencies arising from underinvestment. In this section, we show that they also reduce counterparty risk, even in the absence of fostering investment.

Unconditional subsidies, i.e., those provided to all investors regardless of whether they sign a fixed-price contract, encourage investment but do not effectively promote contract liquidity or mitigate the distortions caused by counterparty risk.[28] For this reason, we focus on uniform and conditional subsidies, $T \geq 0$, paid specifically to sellers who sign a fixed-price contract. In the spirit of the market-regulation literature, we assume that such subsidies carry a per-unit social cost of funds, $\lambda \geq 0$.

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

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

As a result, the minimum contract price, $\underline{f}$, is decreasing in T. Second, supply expands as more sellers can break even at every contract price. When γ is low so that $c^* = G^{-1}(\theta) < \bar{c}(\gamma)$, the equilibrium price, f^*, is equal to $\tilde{f}(c; \gamma)$, now implicitly defined by the solution to the new break-even constraint for the marginal seller,

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

When γ is high enough so that $c^* = \bar{c}(\gamma) < G^{-1}(\theta)$, the equilibrium price maximizes seller profits, $f^* = E(p)$.

Notice that for low γ, a marginal increase in the subsidy reduces prices but leave investment unchanged. In contrast, for high γ, subsidies increase investment without reducing prices. Figure 5 illustrates these effects.

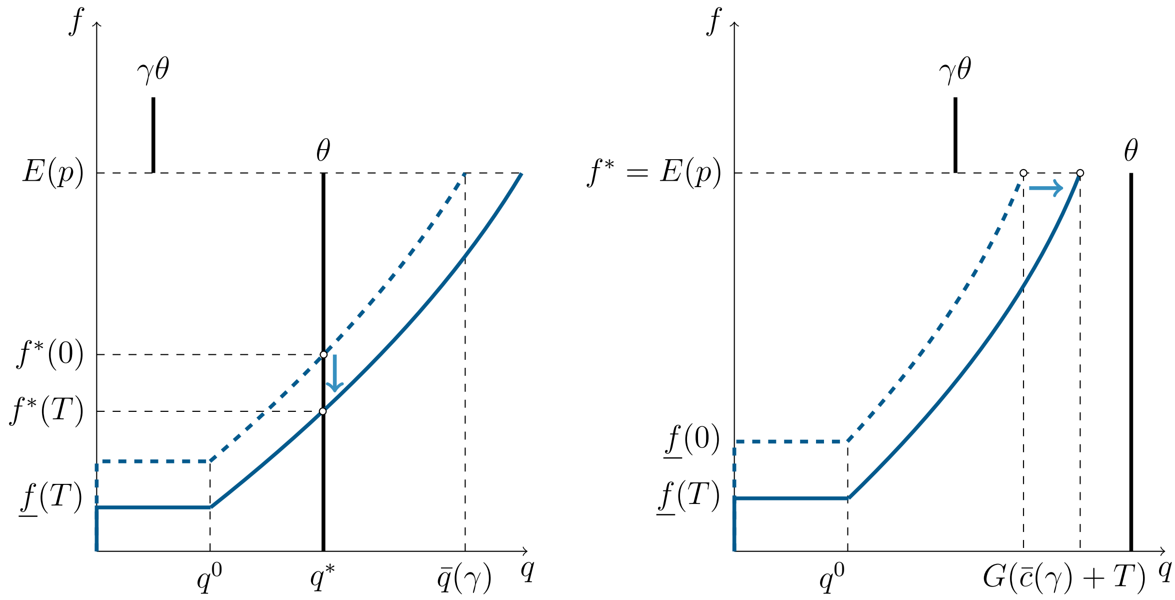
The optimal subsidy weights the price or investment effects against the social costs of the subsidy. Formally, the regulator selects the level of the subsidy T to maximize the contribution of contracts to social welfare, accounting for the effect on the equilibrium price, f^*, and on investment, minus the social costs of the subsidy. The welfare loss, compared to the first best, now becomes,

$$W^{FB} - W^T = G(c^*)R(f^*, \gamma) + \int_{c^*}^{E(p)} [E(p) - c]g(c)dc + \lambda G(c^*)T. \tag{15}$$

The next result characterizes the subsidy that minimizes the welfare distortions.

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

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



(a) The low γ case. **(b)** The high γ case.

Figure 5: The Effect of Public Subsidies.

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

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

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

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

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

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

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

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

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

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

5.4 Public Guarantees

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

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

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

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

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

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

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

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

6 Robustness and Extensions

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

6.1 Risk Aversion

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

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

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

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

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

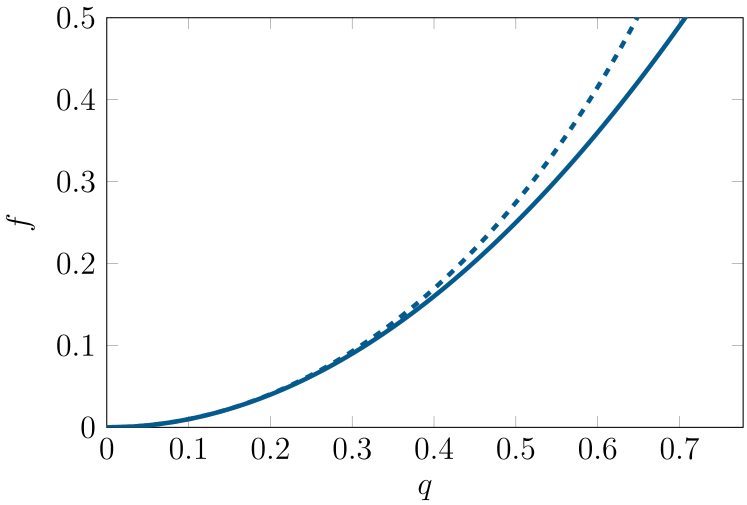


Figure 6: Contract supply when sellers have a concave utility function.

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

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

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

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

Likewise, the expected utility for sellers from 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 properties of the risk premium assumed in our reduced-form baseline model.

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

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

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

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

6.2 Renegotiation and Limited Liability

In the baseline model, we assumed that when the spot market price drops below the contract price, opportunistic buyers default, creating counterparty risk. However, there are alternative manifestations of counterparty risk that would result in similar profits for both buyers and sellers.

Consider, for example, the possibility of contract renegotiation. Specifically, when the realized spot price p falls below f, buyers may propose a renegotiation with probability $\gamma \leq 1$, making a take-it-or-leave-it offer to reset the contract price to p. The buyer defaults only if the seller rejects this offer.

Results also remain unchanged if contract default arises not from the buyer's opportunistic behavior but from limited liability and market competition. Suppose that the buyer is an intermediary that purchases the input to resell it to final consumers in a downstream market. With probability γ, a Bertrand competitor offering a homogeneous good enters the downstream market, purchasing the input in the spot market at price p. Consequently, whenever $p < f$, the buyer is priced out of the downstream market and, due to limited liability, it cannot fulfill the contract obligations. As a result, the seller is forced to offer its output in the spot market at p rather than at the contract price f. Under both interpretations, seller profits in this scenario match those in the baseline model.

Thus, our baseline model can also be interpreted in the context of limited liability and Bertrand competition in the downstream market. Interestingly, this formulation implies that greater downstream market power reduces counterparty risk, leading to lower contract prices and increased investment, notwithstanding the potential adverse effects on final consumers.

6.3 Vertical Integration

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

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

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

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

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

6.4 A Buyer's Premium

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

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

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

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

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

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

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

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

Combining the previous results, a small buyer premium shifts the contract supply curve downwards. Depending on the share of opportunistic buyers, this results in either lower prices or higher investment. Welfare increases as a consequence, as a buyer's premium aligns the incentives of buyers and sellers, thereby reducing the cost of imperfect contract enforcement.

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

6.5 Dynamic Interactions and Time-Varying Prices

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

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

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

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

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

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

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

The second term in the above expression represents the option value of honoring the contract in the first period, as it allows the buyer to hedge against high prices in the second period. This option value decreases with higher f and lower δ_B, increasing the default probability.[29] In the second period, the buyer defaults whenever p falls below f. Since $\hat{p} < f$, the probability of default increases over time. Notably, when $\delta_B = 0$, the continuation value falls to zero and the trigger price for defaults remains f, as in the static model.

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

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

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

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

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

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

Under these assumptions, the derivative of seller profits becomes

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

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

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

period while ensuring a positive risk-free return,

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

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

Now, consider forward-looking or patient sellers ($\delta_S > 0$). The present value of seller profits can be expressed as:

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

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

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

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

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

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

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

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

Finally, forward-looking sellers can prevent the collapse of the contract market even when buyers are myopic. Specifically, suppose $\delta_B = 0$, so the buyer's trigger price is $\hat{p} = f$. For a given contract price f, seller profits are lower in the dynamic framework compared to the static one. This is because the probability of facing the spot-market premium in the second period is higher, $\Phi(f) + (1 - \Phi(f))\Phi(f) > \Phi(f)$, as a first-period default automatically leaves the seller unhedged in the second period. Lowering the contract price reduces the probability of default, which in turn decreases the risk premium by $r - R(f, 1)$. This result is evident from the previous example, where the profit derivative remains negative even when $\delta_B = 0$.

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

7 Concluding Remarks

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

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

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

References

ACER, "Expert Group on Power Purchase Agreements (PPAs)," Technical report, 2024.

Aldy, J. E., T.D. Gerarden and R.L. Sweeney, "Investment versus Output Subsidies: Implications of Alternative Incentives for Wind Energy," *Journal of the Association of Environmental and Resource Economists*, 2023.

Antràs, Pol and C. Fritz Foley, "Poultry in Motion: A Study of International Trade Finance Practices," *Journal of Political Economy*, 2015, *123*(4), pp. 853 – 901.

Baker, George, Robert Gibbons and Kevin J. Murphy, "Relational Contracts and the Theory of the Firm," *The Quarterly Journal of Economics*, 2002, *117*(1), pp. 39–84.

Bessembinder, Hendrik and Michael L. Lemmon, "Equilibrium Pricing and Optimal Hedging in Electricity Forward Markets," *Journal of Finance*, 2002, *57*(3), pp. 1347–1382.

Blouin, Arthur and Rocco Macchiavello, "Strategic Default in the International Coffee Market," *The Quarterly Journal of Economics*, 2019, *134*(2), pp. 895–951.

Braud, Arnaus, "Guarantees light the way for clean energy through renewable auctions," Technical report, World Bank, 2018.

Chen, Luming, "The Dynamic Efficiency of Policy Uncertainty: Evidence from the Wind Industry," 2024, mimeo.

de Maere d'Aertrycke, Gauthier, Andreas Ehrenmann and Yves Smeers, "Investment with incomplete markets for risk: The need for long-term contracts," *Energy Policy*, 2017, *105*, pp. 571–583.

Dobermann, Tim, Faraz Hayat and Sugandha Srivastav, "The Economic Costs of Lopsided Contracts: Evidence from Pakistan's Power Sector," 2024, mimeo.

Draghi, Mario, "The Future of European competitiveness – A competitiveness strategy for Europe," Technical report, European Commission, 2024.

Dukan, Mak and Lena Kitzing, "A bigger bang for the buck: The impact of risk reduction on renewable energy support payments in Europe," *Energy Policy*, 2023, *173*, p. 113395.

Duma, Daniel and Miquel Muñoz-Cabré, "Risk mitigation and transfer for renewable energy investments: A conceptual review ," Technical report, Stockholm Environment Institute, 2023.

European Comission, "Commission Decision of 08.10.2014 on the aid measure SA.34947 (2013/C) (ex 2013/N) which the United Kingdom is planning to implement for Support to the Hinkley Point C Nuclear Power Station," Technical report, 2014.

—, "Commission Decision of 6.3.2017 on the measure / aid scheme / state aid SA.38454 - 2015/C (ex 2015/N) which Hungary is planning to implement for supporting the development of two new nuclear reactors at Paks II nuclear power station," Technical report, 2017.

—, "State Aid SA.58207 (2021/N) – Czechia - Support for the construction and operation of a new nuclear power plant at the Dukovany site," Technical report, 2024.

European Commission, "Proposal for a Regulation of the European Parliament and of the Council amending Regulations (EU) 2019/943 and (EU) 2019/942 as well as Directives (EU) 2018/2001 and (EU) 2019/944 to improve the Union's electricity market design," Technical Report COM(2023) 148 final, European Commission, 2023.

Fabra, Natalia and Juan Pablo Montero, "Technology-Neutral vs. Technology-Specific Procurement," Technical Report 15554, CEPR Discussion Papers, December 2020.

Fan, Lin, Benjamin F. Hobbs and Catherine S. Norman, "Risk aversion and CO2 regulatory uncertainty in power generation investment: Policy and modeling implications," *Journal of Environmental Economics and Management*, 2010, *60*(3), pp. 193–208.

Gamache, Caileen, "Renegotiating PPAS," Technical report, Norton Rose Fullbright, 2022.

Gohdes, Nicholas, Paul Simshauser and Clevo Wilson, "Renewable entry costs, project finance and the role of revenue quality in Australia's National Electricity Market," *Energy Economics*, 2022, *114*, p. 106312.

Guiso, Luigi, Paola Sapienza and Luigi Zingales, "The Determinants of Attitudes Toward Strategic Default in Mortgages," *Journal of Finance*, 2013, *68*, pp. 1473–1515.

Hara, Konan, "Encouraging Renewable Investment: Risk Sharing Using Auctions ," mimeo, University of Chicago, 2024.

Hart, Oliver, *Firms, Contracts, and Financial Structure*, Clarendon Press, 1995.

—, "Hold-up, Asset Ownership, and Reference Points," *The Quarterly Journal of Economics*, 2009, *124* (1), pp. 267–300.

Joskow, Paul, "The Performance of Long-Term Contracts: Further Evidence from Coal Markets," *RAND Journal of Economics*, 1990, *21* (2), pp. 251–274.

Kim, Harim and Mario Samano, "Renewable Portfolio Standards, Vertical Structure, and Investment," Technical report, HEC Montreal, 2024.

Klein, Benjamin, "Why Hold-Ups Occur: The Self-Enforcing Range of Contractual Relationships," *Economic Inquiry*, July 1996, *34* (3), pp. 444–463.

Klein, Benjamin, Robert G Crawford and Armen A Alchian, "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process," *Journal of Law and Economics*, October 1978, *21* (2), pp. 297–326.

Macchiavello, Rocco and Ameet Morjaria, "The Value of Relationships: Evidence from a Supply Shock to Kenyan Rose Exports," *American Economic Review*, September 2015, *105* (9), pp. 2911–2945.

—, "Competition and Relational Contracts in the Rwanda Coffee Chain," *The Quarterly Journal of Economics*, 12 2020, *136* (2), pp. 1089–1143.

Mays, Jacob, Michael T. Craig, Lynne Kiesling, Joshua C. Macey, Blake Shaffer and Han Shu, "Private risk and social resilience in liberalized electricity markets," *Joule*, 2022, *6* (2), pp. 369–380.

Polo, Michele, Mar Reguant, Karsten Neuhoff, David Newbery, Matti Liski, Gerard Llobet, Reyer Gerlagh, Albert Banal-Estanol, Francesco Decarolis, Natalia Fabra, Anna Creti, Claude Crampes, Estelle Cantillon, Sebastian Schwenen, Camile Landais, Iivo Vehviläinen and Stefan Ambec, "Electricity market design: Views from European Economists," December 2023, (120).

Ryan, Nicholas, "Holding Up Green Energy: Counterparty Risk in the Indian Solar Power Market," *Econometrica*, 2024, *conditionally accepted*.

Stiglitz, Joseph E and Andrew Weiss, "Credit Rationing in Markets with Imperfect Information," *American Economic Review*, June 1981, *71* (3), pp. 393–410.

Stroebel, Johannes and Arthur van Benthem, "Resource Extraction Contracts under Threat of Expropriation: Theory and Evidence," *The Review of Economics and Statistics*, 2013, *95* (5), pp. 1622–1639.

Willems, Bert and Joris Morbee, "Market completeness: How options affect hedging and investments in the electricity sector," *Energy Economics*, 2010, *32* (4), pp. 786–795, policymaking Benefits and Limitations from Using Financial Methods and Modelling in Electricity Markets.

World Bank, "Power Purchase Agreements (PPAs) and Energy Purchase Agreements (EPAs)," Technical report, World Bank, 2024.

A Proofs

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

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

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

This implies that

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

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

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

The derivative of this expression with respect to f is

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

As a result,

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

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

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

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

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

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

where

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

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

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

Proof of Lemma 1: In the text. □

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

Proof of Proposition 1 and 2: In the text. □

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

by Assumption 1.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Furthermore,

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Solving for the risk premium:

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

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

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

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

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

Solving it,

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

which is positive because of concavity of u and

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

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

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

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

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

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

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

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

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

□