The Costs of Counterparty Risk in Long-Term Contracts*

Natalia Fabra
Universidad Carlos III and CEPR

Gerard Llobet
CEMFI and CEPR

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Abstract

This paper identifies buyers' counterparty risk as a major market failure in long-term contracting, leading to inefficiently high prices, excessive risk, and underinvestment. This is especially relevant in sectors with capital-intensive, long-lived investments, and volatile spot prices, such as electricity markets, where it may undermine efforts to deploy renewable energy and delay carbon abatement. Eliminating counterparty risk using costly collateral may harm both buyers and sellers. Policy interventions aimed to boosting demand for long-term contracts, providing public guarantees, and allowing regulators to serve as counterparties, may be effective inasmuch as they tackle counterparty risk directly.

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*Emails: natalia.fabra@uc3m.es and llobet@cemfi.es. This paper has benefited from comments by 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, and CRESSE. The second author thanks the support of the Spanish Ministry of Science and Innovation through grant PID2021-128992NB-I00.

1 Introduction

Investments in capital-intensive, long-lived assets often rely on long-term contracts to reduce uncertainty about cost recovery, especially when market conditions over the asset's lifetime are highly volatile. Counterparty risk, i.e., the concern that the other party may fail to fulfill contractual obligations, or renegotiate them, either out of necessity or opportunistically (e.g. Blouin and Macchiavello (2019*a*)), can undermine the liquidity of these contracts and ultimately lead to underinvestment.

In this paper, we examine the impact of counterparty risk on equilibrium prices and investment in markets where price volatility makes long-term contracts essential to reduce financing costs. We also analyze the properties of several public policies proposed to address the distortions associated with counterparty risk in long-term contracting.

While enforcement issues have been documented in commodity markets — such as coffee (Macchiavello and Morjaria, 2020), coal (Joskow, 1990), and flowers (Macchiavello and Morjaria, 2015) — they are especially concerning 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, financing costs are critical in determining their profitability and viability. 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 unless secured by long-term fixed-price contracts.[1] However, markets for long-term power contracts often lack liquidity, mainly due to *"the credit risk that a consumer will not always be able to buy electricity over the whole period."* (European Commission, 2023), i.e., buyers' counterparty risk.

Investment in renewable energy is also vulnerable to this risk due to another unique characteristic: with nearly zero variable costs, these assets retain a positive continuation value once the investments are sunk, making plant owners more likely to accept lower renegotiated prices if buyers later access cheaper alternatives. In addition, buyers who use electricity as input or for resale may face a competitive pressure that limits their ability to honor the contracts if rival firms secure lower prices in the future. Unlike in other sectors, this feature also makes vertical integration a less effective hedge against

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

future price reductions.

Our model considers sellers and buyers who trade one unit of a homogeneous good in a spot market. Risk-averse sellers suffer a utility loss when exposed to volatile prices. Buyers and sellers may negotiate fixed-price contracts that hedge them against the volatility of spot markets. Buyers are always willing to engage in a fixed-price contract as they can default if the spot price turns out to be below the contract price.[2] Default exposes sellers to spot-price volatility and the associated utility loss.

Sellers' willingness to invest and sign a fixed-price contract depends, therefore, on the probability of contract default and on their outside options. Sellers with low investment costs find entry at spot prices profitable even after incurring the cost of price volatility. Hence, they invest regardless of whether they sign a contract or not, and they are willing to do so as long as they generate higher profits than the spot market. In contrast, high-cost sellers will only invest if the price stipulated in the contract allows them to break even.

Counterparty risk sets a limit on the costs that sellers can compensate through the contract. A higher price creates a trade-off for the seller, as the increase in the revenue comes at the cost of raising the probability of contract default. It follows that the supply of contracts is weakly increasing in the contract price up to the point where further price increases reduce sellers' profits due to the higher risk of default. Investment beyond this point is never profitable, even if there exists excess demand for contracts at that price. The equilibrium price for the contract is set through market clearing between the demand and supply for long-term contracts.

In this context, our model delivers two important results. First, it highlights the advantages that policymakers have attributed to long-term power contracts. Indeed, the market equilibrium with contracts is welfare superior to the no-contracts case. The reason is that contracts reduce the sellers' cost from spot-price volatility, and trigger investment that would not have been undertaken in their absence. However, this does not imply that promoting the demand for long-term contracts is always welfare-enhancing. Indeed, there is a trade-off, as strengthening contract demand also pushes contract prices up in order to make additional investments profitable, at the cost of raising the probability of default

[2]In our baseline model we normalize the costs of contract default to zero. However, in Section 3.2 we show that the model's main results remain unchanged if we add a collateral (as long as it is not too valuable) that the buyer forgoes in case of default.

for all contracts, including the inframarginal ones. As explained in Section 4, this result uncovers a potential drawback of policies pursued by many countries aimed at boosting demand through a compulsory minimum in the long-term contracts that buyers must take. Although this requirement can promote investment, it might also create excessive default.

Second, our model uncovers the cost of counterparty risk as a major market failure of markets for long-run contracts, leading to high prices, excessive contract default, poor contract liquidity, and a weak ability to leverage investments. In our model, all sellers receive the market-clearing contract price, which is above the one that inframarginal sellers would require to sign the contract. Hence, the equilibrium outcome entails excessive counterparty risk for all contracts. Therefore, there is scope to increase welfare through measures that allow for lowering contract prices and through that, a reduction in the probability of contract default. In turn, such an intervention enhances the social profitability of entry, leading to increased investment in renewable energy.

In our model, collateral mitigates the counterparty-risk problem. Buyers must pledge some funds that will be transferred to the seller in case of default. To the extent that collateral is costly, we show that it is often the case that a large collateral that eliminates the probability of default is inefficient. Its use should be optimally adjusted based to the default cost of the seller.

Although we have intentionally kept our analysis simple to highlight the main mechanism, its main implications are robust to alternative specifications as we illustrate in our extensions in Section 5. While we have interpreted counterparty risk as the result of contract default, we show that renegotiation and final-market competition combined with limited liability lead to similar outcomes for buyers and sellers even without introducing opportunistic behavior. Relatedly, vertical integration between a buyer and a seller, although it eliminates counterparty risk, does not mitigate the costs of exposure to volatile spot prices in the presence of downstream competition.

Enhancing buyers' incentives to enter long-term contracts — by introducing buyers' risk aversion or a positive premium — helps in aligning the incentives of both parties, thus reducing the costs associated to counterparty risk. Market power, whether on the seller's or buyer's side, exacerbates the effects of counterparty risk on underinvestment; however, buyers' power might lower contract prices, thereby lessening the underlying counterparty risk. Finally, incorporating dynamics, such as spot prices that are not perfectly correlated over time (as implicitly assumed in our static framework), would enrich the model's predictions by uncovering time-varying default probabilities while maintaining its main qualitative insights.

In Section 4, we use our framework to explore various welfare-enhancing market interventions, some of which have been proposed in the regulatory debate, including *"requiring Member States to ensure that instruments to reduce the financial risks associated with the buyer defaulting on its long-term payment obligations [...] These can be guarantee schemes at market prices, as well as public support for non-fossil fuels Power Purchase Agreements"* (European Commission, 2023). The suitability of public support and guarantees depends on the social cost of the funds associated to the scheme is not too high. However, they have different implications.

Public subsidies are effective to the extent that they are contingent on the seller signing a fixed-price contract. We show that these subsidies have two welfare-enhancing effects. First, they can boost participation in cases where counterparty risk limits the seller's incentives to invest. Second, by boosting supply, subsidies yield a lower equilibrium price in the market for long-term contract which mitigates the counterparty-risk problem for all contracts.

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

Lastly, we show that the most effective intervention is the promotion of regulator-backed long-term contracts. Depending on the volume of contracts allocated, this market can coexist with the private market for long-term contracts.[3] Because the regulator is the counterparty of these contracts, they constitute a risk-free option and contribute to more efficient investments through a demand expansion effect.

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

Related Literature This paper is related to the literature on contracting with imperfect enforcement. From a theoretical perspective, our research is inspired in the classical theory of the firm (Hart, 1995). In recent years, the consequences of this imperfect enforcement haves been document in multiple contexts. Strategic default in mortgage markets derived from negative equity is studied in Guiso et al. (2013). Blouin and Macchiavello (2019*b*) study bilateral negotiations where the seller can strategically default on the contract if market prices increase even if that jeopardizes the relational contract with the buyer. Antras and Foley (2015) study default in the trade between exporters and importers. We contribute to this literature by focusing on the market equilibrium derived from these strategic decisions and the implications for investment and trade.

In the context of electricity markets, the usage of long-term contracts has been extensively studied, particularly in developing countries. These contracts establish a price that the government guarantees for the sale of the electricity produced. Ryan (2024) empirically estimates the consequences of counterparty risk when the buyers of renewable energy are Indian states as opposed to the more trustworthy central government. Dobermann et al. (2024) study the nature of contracts for coal plants in Pakistan. Our work departs from this literature by studying long-term contracts between private parties. Section 4.2 relates to this literature as it studies the design of government backed contracts in contexts where they can intervene as a safer alternative.

The remainder of the paper is organized as follows. In Section 2, we describe the model. In Section 3 we characterize the contract market equilibrium and assess its welfare properties. In Section 4, we analyze several market interventions, including public subsidies and public guarantees. In Section 5 we analyze the robustness of the model and explore several extensions. Section 6 concludes and proofs are included in the Appendix.

2 Model Description

Consider a market for a homogeneous good. On the demand side, there is a unit mass of identical 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 $c \in [0, 1]$.

There is also a sufficient amount of existing capacity to always 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 $p \in [0, 1]$. We further assume that the hazard rate,

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

is strictly increasing in p. The expected marginal cost of existing capacity is denoted by $E(p)$. As a result, entry yields savings equal to the expected marginal cost of the existing capacity $E(p)$ minus the entrants' investment cost.[4]

The timing of the model 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 costs 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 marginal producer required to cover demand. Hence, the equilibrium price in the spot market becomes p. Since entrants have zero marginal cost, they produce at full capacity, earning expected spot market revenues $E(p)$.

Exposure to volatile spot market prices creates uncertainty over cost recovery, giving raise to a risk premium for the entrants denoted by $r \in (0, \phi^{-1}(0))$,[5] which could be interpreted as the extra costs entrants have to pay to the lenders financing their investments. Buyers do not incur in 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

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

Profitable entry requires spot market revenues to cover at least the investment cost c plus the risk premium r, i.e., only entrants with costs $c \leq c^0 \equiv E(p) - r$ decide to invest in equilibrium.

[4] New investments could generate positive or negative externalities not reflected in market prices. A parameter γ can be easily introduced to capture them. In this case, the savings from investment amount to $E(p) - c + \gamma$.

[5] For technical convenience, we impose an upper bound to r equal to $\phi^{-1}(0)$, which guarantees that the solution to the sellers' problem is interior. Other than this, this assumption is inconsequential as there are no constraints on the value of $\phi(0)$.

Notice that if sellers were not exposed to uncertain spot prices, they would invest until the marginal cost savings equaled the investment cost, i.e., for all $c \leq c^{FB} \equiv E(p)$. Hence, due to sellers' risk aversion ($r > 0$), the market solution is characterized by underinvestment relative to the First Best. Compared to welfare in the First Best, W^{FB}, the resulting loss can be computed as

$$W^{FB} - W^{0} = rG\left(E(p) - r\right) + \int_{E(p)-r}^{E(p)} \left(E(p) - c\right) g\left(c\right) dc > 0, \tag{1}$$

where the first term captures the social cost originated by entrants' risk aversion and the second term measures the marginal cost savings that would have realized under the efficient investment decision.

In the next section we explore fixed-price contracts as a way to hedge against the volatility in spot prices.

3 Fixed-price Contracts

Suppose that buyers and sellers are allowed to sign a fixed-price contract prior to entry, enabling them to hedge their spot market transactions. In particular, the contract requires the seller to compensate the buyer for the difference between the spot price p and the contract price f if $p > f$, and vice versa if $f > p$. We start by studying the case where both parties always honor the contract, allowing the seller to avoid the risk premium r.[6]

We assume that engaging in a fixed-price contract is costless for sellers but entails a heterogeneous transaction cost for buyers. In particular, a proportion $\theta \leq 1$ of buyers are *sophisticated* and incur in no cost. The remaining proportion of buyers $1 - \theta$ are *unsophisticated* and face a transaction cost sufficiently high so that they are never willing to participate.[7] To keep the discussion interesting, we focus on situations where demand for contracts exceeds the mass of sellers that would be willing to invest without contracts, i.e., $\theta > G(c^0) = G(E(p) - r)$.

At the contracting stage, the profits for (sophisticated) buyers and sellers from hedging

[6]For instance, in the context of power purchase agreements (PPA), the World Bank explicitly claims that "the structure and risk allocation regime under the PPA is central to the private sector participant's ability to raise finance for the project, recover its capital costs and earn a return on equity."

[7]In practice, this partition might reflect differences related to the size of buyers, leading to lower average participation costs for larger buyers. In section 3.2, we show that differences in the costs of pledging collateral might have similar consequences.

through a contract with a fixed price f can be written as

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

Buyers and sellers prefer to sign a fixed-price contract than transacting in the spot market as long as $\Pi_B(f) \geq \Pi_B^0$ and $\Pi_S(f; c) \geq \Pi_S^0$, respectively. It follows that the demand for contracts is θ for prices $f \leq E(p)$, and zero otherwise, while the supply of contracts is given by the mass of entrants that can break even at each contract price, $G(f)$, for $f \in [E(p) - r, 1]$, and zero otherwise. As $r > 0$, there is scope for contracting between buyers and sellers.

The equilibrium contract is determined by the interplay between demand and supply. Two cases must be considered. First, when the proportion of sophisticated buyers is low, i.e., $\theta \leq G(E(p))$, all demand is satisfied, $q^* = \theta$, at the market-clearing price $f^* = G^{-1}(\theta)$ (Figure 1a). Contracts make both buyers and sellers better off, allowing for 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,

$$W^{FB} - W^* = \int_{G^{-1}(\theta)}^{E(p)} (E(p) - c)\, g(c)\, dc > 0. \tag{2}$$

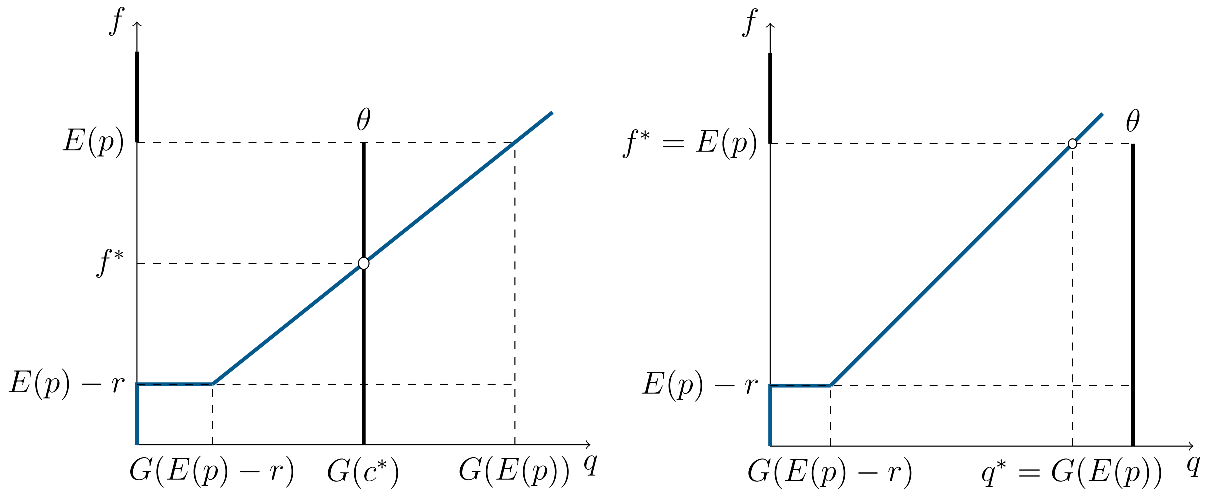
Hence, an increase in contract demand θ up to $G(E(p))$ would increase social welfare.

Second, when there is a high proportion of sophisticated buyers, $\theta > G(E(p))$, there is contract rationing, with only a fraction $q^* = G(E(p))$ of contract demand being served at the highest possible equilibrium contract price, $f^* = E(p)$ (Figure 1b). Importantly, contract rationing is efficient as further investment would involve investment with costs c exceeding the savings in marginal cost $E(p)$. Since the contract solution achieves the First Best, $W^* = W^{FB}$, the contribution of contracts to welfare is also given by (1).

These results are summarized in the following Proposition.

Proposition 1. *Assume no counterparty risk.*

(i) Without fixed-price contracts, there is equilibrium underinvestment due to sellers' risk exposure: the marginal entrant has costs $c^* = E(p) - r < E(p)$.



(a) The no contract rationing case

(b) The efficient contract rationing case

Figure 1: Market clearing with a fixed-price contract. In subfigure (a), the equilibrium price f^* 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, $E(p)$. Contract rationing in this case is efficient since the contribution to welfare of the marginal investor, $c^* = E(p)$, is zero.

(ii) With fixed-price contracts, sellers' risk premia are eliminated, leading to efficient investment if contract demand is sufficiently high: for $\theta \geq G(E(p))$, the marginal entrant has costs $c^* = E(p)$.

3.1 Buyer's Counterparty Risk

So far, we have assumed that buyers always honor the contract. However, if the spot market price p falls below the fixed price f, buyers may be tempted to default on the contract, introducing counterparty risk.[8] As a result, fixed-price contracts only protect sellers from price uncertainty when the spot market price p is above the fixed price f. Sellers therefore face a risk premium $r\Phi(f)$, which increases with the contract price, as a higher price makes default more likely.

Expected profits for buyers and sellers at the contracting stage can now be computed as

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

[8]We abstract from the possibility that the seller may act opportunistically. In practice, external financing is typically contingent on sellers securing a fixed-price for their production, which discourages them from breaching the contract later on.

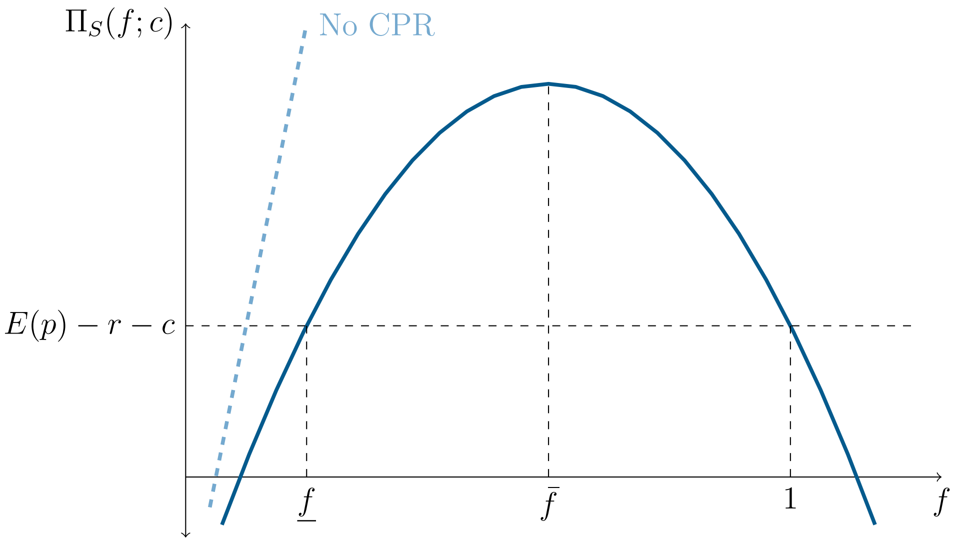


Figure 2: Seller's profits under a fixed-price contract as a function of f.

Buyers' expected profits are always decreasing in f. In contrast, under the hazard rate assumption sellers' expected profits are quasiconcave in f, as shown in Figure 2. The quasiconcavity arises from the trade-off between higher seller revenue when f increases and the contract is honored and a higher probability of default due to counterparty risk. A price $\bar{f} < 1$ maximizes sellers' profits by striking a balance between these two forces. It follows that sellers never find it optimal to sign contracts at prices above $\bar{f}$.

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

The fixed-price contract must also yield higher utility than the spot market for both buyers and sellers. For buyers, the result is straightforward as they always have the option to default on the contract to avoid paying a higher price. Thus, $\Pi_B(f) \geq \Pi_B^0$ for all $f \leq 1$.

For sellers, the fixed price must be above a threshold $\underline{f}$ at which the seller is indifferent between signing the contract or trading on the spot market. Therefore, $\Pi_S(\underline{f}, c) = \Pi_S^0 = E(p) - r - c$. In turn, since the buyers can always secure a payment below $E(p)$, sellers' profits are always below $E(p) - c$. This gap is important for the welfare analysis, as it implies that sellers can never fully capture all the social value engendered by their investment.

Lemma 2. *With counterparty risk and $r > 0$:*

(i) Equilibrium contract prices f^* are in the interval $[\underline{f}, \bar{f}]$, with

$$E(p) - r < \underline{f} < \bar{f} < 1.$$

(ii) Equilibrium profits $\Pi_B(f^*)$ are in the interval $[E(p) - r - c, E(p) - c)$.

The intersection between the demand and supply for contracts determines the equilibrium price in the contract market. Since buyers are always willing to sign contracts regardless of the price, demand is always equal to the proportion of sophisticated buyers, θ.

We can construct the supply for contracts 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 always 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 $f \geq \underline{f}$.

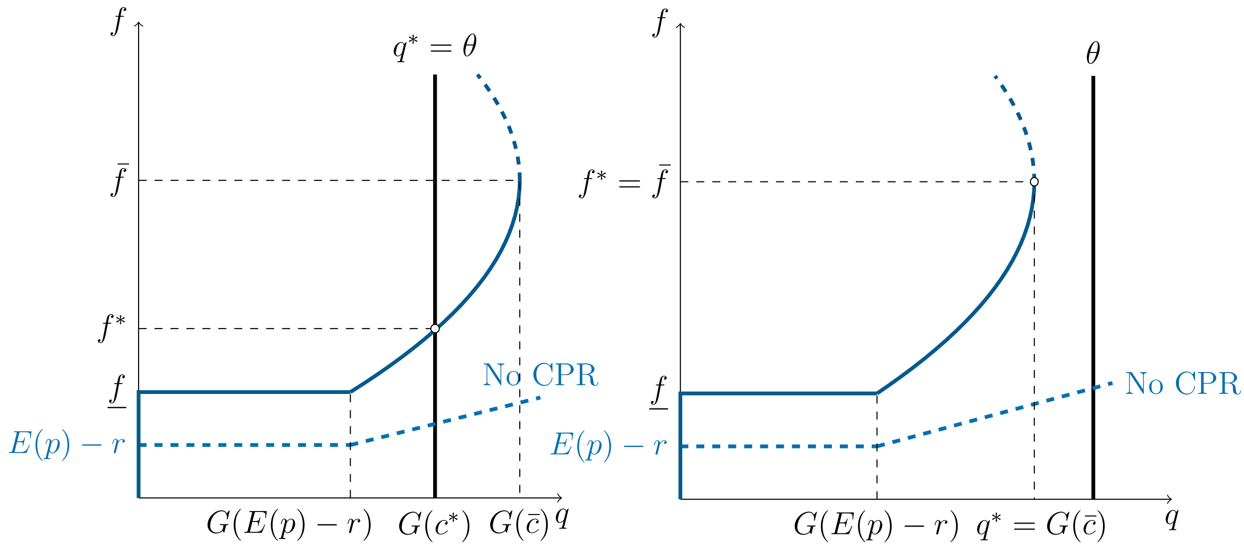
Otherwise, the seller invests only if the contract price allows for the recovery of the investment cost, which requires signing a contract at or above the investors' break-even price $\tilde{f}(c)$, implicitly defined by

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

Finally, for values of c for which the seller cannot break even at the profit-maximizing price, $\Pi_S(\bar{f}, c) < 0$, entry does not occur. We use $\bar{c}$ to denote the highest investment cost for which entry might be profitable, i.e., $\Pi_S(\bar{f}, \bar{c}) = 0$.

Figures 3a and 3b illustrate the supply function for contracts, which is weakly increasing in the contract price f. For prices above $\underline{f}$, the supply of contracts is constructed by mirroring the sellers' profit function in Figure 2. This curve bends backwards for $f > \bar{f}$ since, as stated in Lemma 1, sellers' profits decrease when the contract price increases beyond that point. Given that the contract price never exceeds the seller's profit-maximizing price $\bar{f}$, that region of the supply curve can be safely ignored.

These figures capture the two cases that can emerge depending on whether there is contract rationing in equilibrium or not. Figure 3a corresponds to a situation where the demand for contracts is low, $\theta \leq G(\bar{c})$, and it is fully satisfied in equilibrium, $q^* = G(c^*) = \theta$. The market clearing price is determined by the break-even condition of the marginal entrant, $\tilde{f}(c^*)$, as defined in (3). For higher demand levels, there is contract rationing in equilibrium, $q^* < \theta$, giving rise to the highest feasible contract price, $f^* = \bar{f}$.



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

Figure 3: Market clearing in the fixed-price contract market. In subfigure (a), the equilibrium price is given by the break-even price of the marginal investor, with investment cost c^*. In subfigure (b), demand θ is above the mass of sellers $G(\bar{c})$ that can break even at that price. Contract rationing implies inefficient investment given that $\bar{c} < E(p)$. The dashed line represents the supply curve when there is no counterparty risk.

Since the marginal entrant breaks even at that price, the equilibrium contract quantity is $q^* = G(\bar{c}) < \theta$. This case is illustrated in Figure 3b.

Lemma 3. *With counterparty risk and $r > 0$, equilibrium investment is $q^* = \min\{G(\bar{c}), \theta\}$. If $\theta \geq G(\bar{c})$, the equilibrium price is $f^* = \bar{f}$. Otherwise, f^* is implicitly given by $\Pi_S(f^*, G^{-1}(\theta)) = 0$.*

As expected, in the absence of contract rationing, the equilibrium contract price increases with the proportion of sophisticated buyers. The equilibrium price is also strictly monotonic in the risk premium, as an increase in r reduces sellers' profits, thereby lowering their supply.

This result allows us to characterize the inefficiencies that counterparty risk engenders compared to the First Best,

$$W^{FB} - W^* = r\Phi\left(f^*\right)G(c^*) + \int_{c^*}^{E(p)} \left(E(p) - c\right) g\left(c\right) dc.$$

The first term captures how contract default reduces the contribution of fixed-price contracts to welfare. This cost is increasing in the risk premium r both due to the direct effect but also due to the increase in f^*. Importantly, although f^* is determined by the marginal entrant with $c = c^*$, counterparty risk affects all inframarginal investors with

$c < c^*$. This means that, in the absence of contract rationing, an expansion in demand raises f^*, increasing the cost of contract default for all sellers. This issue does not arise in the absence of counterparty risk, as contract prices in that case would only affect the division of surplus between buyers and sellers, without a direct impact on efficiency.

The second term captures the distortion from underinvestment, $c^* < E(p)$. This cost can manifest itself in two ways. A low proportion of sophisticated consumers restricts contract liquidity to θ, just as in the case without counterparty risk. When θ is high, investment is inefficiently low because counterparty risk makes entry less profitable.

Nevertheless, fixed-price contracts increase social welfare relative to the no-contracts case. This improvement originates from the reduction in sellers' risk exposure and from new investments allowing for positive cost savings. Formally, the contribution of contracts to social welfare is

$$W^* - W^0 = (1 - \Phi(f^*))rG(E(p) - r) + \int_{E(p)-r}^{c^*} \left[E(p) - \Phi(f^*)r - c\right] g(c)\, dc. \tag{4}$$

The first term measures how all sellers that would otherwise serve the spot market are now better off due to the elimination of price exposure when $p \geq f^*$. The second term measures the social welfare contribution of the additional entry once we account for the losses due to counterparty risk, $r\Phi(f^*)$.

These results are summarized next.

Proposition 2. *With counterparty risk and $r > 0$,*

(i) Fixed-price contracts increase welfare relative to the no-contracts case, reducing sellers' risk exposure and underinvestment.

(ii) With fixed-price contracts, sellers' risk premia and underinvestment are not fully eliminated, implying lower welfare than under the First Best.

In sum, our results highlight buyers' counterparty risk as a significant 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.

3.2 Pledging Collateral

Our previous analysis assumed costless contract default for the buyer. While this is a useful simplification, contracts usually include provisions that penalize the buyer in case of default. The buyer often pledges a collateral $k > 0$, 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, let us now assume that collateral is onerous, with a per-unit cost, ρ, which is heterogeneously distributed among buyers according to $U[0, 1]$. 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.[9] To abstract from other dimensions of demand heterogeneity, in this section we assume that all buyers are sophisticated, $\theta = 1$, so that market participation is endogenously determined only 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, $k \geq f$, a buyer never finds it optimal to default. Hence, the utility of buyers and sellers simplifies 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

$$\Pi_B(f, k; \rho) = v - f\,(1 - \Phi(f - k)) - \int_0^{f-k} (p + k)\phi(p)\,dp - \rho k, \tag{5}$$

$$\Pi_S(f, k; c) = \int_0^{f-k} (p + k)\phi(p)\,dp + f\,(1 - \Phi(f - k)) - r\Phi(f - k) - c. \tag{6}$$

The level of the collateral affects the range of prices at which buyers and sellers are willing to trade. Consider sellers first. Since their profits increase with k, participation in the contract becomes more profitable the more collateral has been pledged. As a result, the new minimum price a seller is willing to accept, now denoted with a subindex S, $\underline{f}_S(k)$, decreases with k. Additionally, since default is less likely, sellers can profitably demand a higher price. Hence, a seller's profit-maximizing price, $\bar{f}_S(k)$, increases with k. Therefore, more collateral enlarges the range of prices at which sellers are willing to sign a fixed-price contract. As in the baseline case, the supply function corresponds to the

[9]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.

mass of sellers that break even at each price. Since sellers' profits increase with 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

$$\Pi_B(f, k; \rho) - \Pi_B^0 = E(p) - f - \rho k \geq 0, \tag{7}$$

whereas when $k < f$, they participate if

$$\Pi_B(f, k; \rho) - \Pi_B^0 = \int_{f-k}^{1} (p - f)\phi(p)\, dp - k\Phi(f - k) - \rho k \geq 0. \tag{8}$$

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

These results are summarized next.

Lemma 4. *Assume there is counterparty risk, $r > 0$, and collateral k.*

(i) The lowest contract price sellers are willing to accept, $\underline{f}_S(k)$, decreases with k, while the sellers' profit-maximizing price, $\bar{f}_S(k)$, increases with k.

(ii) The highest contract price a buyer with collateral cost ρ is willing to accept, $\bar{f}_B(k; \rho)$, 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. A buyer with zero collateral cost is willing to accept any contract with a fixed-price below $E(p)$ even when pledging a high collateral, $\bar{f}_B(k; 0) \geq E(p)$. This is above the minimum price that a seller would be willing to accept, $\underline{f}_S(k) \leq E(p) - r$. However, buyers with a high collateral cost might be excluded from the market when k is high as the maximum price they are willing to pay could fall below the minimum acceptable price for a seller, i.e. $\bar{f}_B(k; \rho) < \underline{f}_S(k)$.

The demand curve for contracts with collateral k and a fixed-price f is given by the mass of buyers with $\rho \leq \hat{\rho}(f, k)$, a threshold that is 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. Interestingly, 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, allows for endogenous market participation. Buyers with low collateral costs resemble the sophisticated buyers discussed in the previous section. Conversely, high collateral costs function similarly to the transaction costs assumed earlier, deterring unsophisticated sellers from participating in the contract market.

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

$$\hat{\rho}(f^*, k) = G(c^*), \tag{9}$$

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

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^* and low k such that $f^* > k$, an increase in k reduces f^* until $f^* = \hat{k}$, at which point the probability of default becomes zero. Further increases in k lead to $f^* < k$, maintaining a zero probability of default.

Lemma 5. *There exists a unique $\hat{k}$ such that $f^*(k) \leq k$, implying $\Phi(f^* - k) = 0$, 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. However, this is not feasible for low r. 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 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. In such a case, and as shown in the proposition below, even if setting $k = \hat{k}$ were feasible, sellers may be better off with lower collateral requirements that avoid the price-reduction effect.

From a social-welfare perspective, setting $k = \hat{k}$ needs not be optimal either. The net welfare effect of increasing collateral depends on the costs associated with counterparty risk and the collateral itself. When r is low, the social cost of counterparty risk

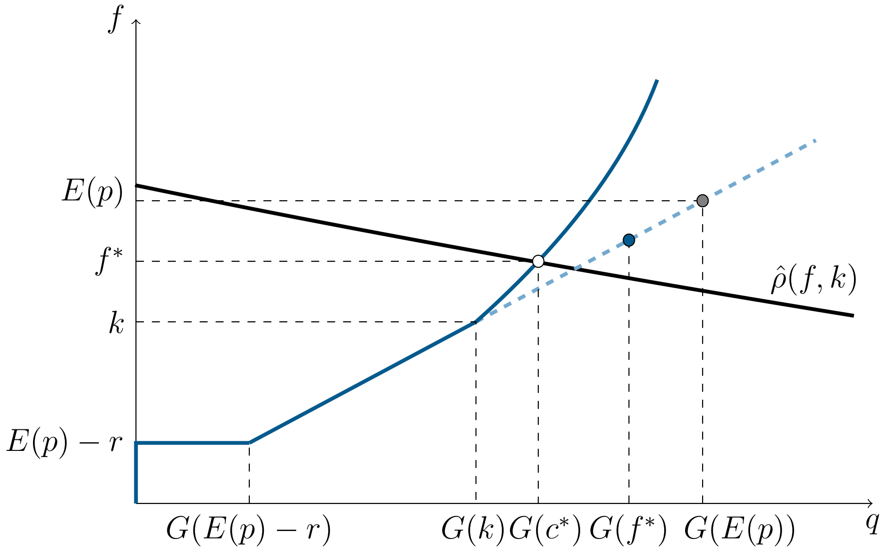


Figure 4: Market clearing when buyers pledge collateral. Contract demand is downward sloping because of the cost of collateral. Demand and supply intersect at $f^* > k$, so there is a positive probability of default. Without counterparty risk, the equilibrium would be at $(f^*, G(f^*))$ (blue dot). With costless collateral, the equilibrium would be at $(E(p), G(E(p))$ (gray dot).

is relatively small compared to the social cost of collateral. Therefore, if the risk premium is sufficiently low, it is socially worthwhile to raise the collateral to a point where counterparty risk is entirely eliminated.

Proposition 3. *Assume there is counterparty risk, with $r > 0$ and collateral $k > 0$:*

(i) There exists a unique r_S such that sellers' profits are higher at some $k < \hat{k}$ than at $k = \hat{k}$ if and only if $r < r_S$.

(ii) There exists $r_W < r_S$ such that social welfare is higher at some $k < \hat{k}$ than at $k = \hat{k}$ if and only if $r < r_W$.

Interestingly, for values of $r \in (r_W, r_S)$, eliminating counterparty risk is optimal for society, but not 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

$$W^{FB} - W^* = G(c^*)\,\Phi(f^* - k)r + \int_{c^*}^{E(p)} (E(p) - c)\,\phi(p)\,dp + \frac{\hat{\rho}(f^*)^2}{2}k. \tag{10}$$

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.[10] The last term captures the costs of the collateral for the buyers.

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. Specifically, relative to the First Best, the welfare loss of setting $k = \hat{k}$ is $\hat{k}^3/2$. This loss can be significant if $\hat{k}$ is large, such as when $E(p)$ is high.[11]

Corollary 1. *At the value of the collateral k that maximizes social welfare, total welfare is higher than without collateral but lower than under the First-Best.*

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 risk premium 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.

4 Market Interventions

In this section, we consider several market interventions aimed at addressing the market failures identified in the previous section. For simplicity, we base our analysis on the benchmark model, where the proportion of sophisticated buyers is $\theta < 1$ and there is no collateral, $k = 0$. Our previous analysis suggests that the results would remain qualitatively unchanged under the optimal collateral, provided r is sufficiently low so that some meaningful counterparty risk persists.

4.1 Promoting Contract Demand

Our previous analysis revealed that weak demand for fixed-price contracts is one of the sources of underinvestment. Specifically, cases with $\theta < G(E(p))$ result in inefficient investment, even in the absence of counterparty risk. Contract demand could grow

[10]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 4, where the solid dots give the allocation without counterparty risk and with costless collateral.

[11]Note that $\hat{k}$ only depends on $E(p)$. In particular, it is the same for all mean-preserving price distributions, and it does not depend on the risk premium r.

if participation costs went down (e.g., through contract standardization)[12] or whether contracting became compulsory for a larger fraction of buyers. Even if we ignore the potential changes in transaction costs, would increasing θ necessarily alleviate market inefficiencies?

First, note that an increase in contract demand above $G(\bar{c})$ is ineffective, as there is contract rationing. For lower values of θ, increasing contract demand boosts investment but also raises the equilibrium contract price, thereby increasing the default probability of all inframarginal contracts. As the following result shows, when θ is sufficiently high, welfare decreases as demand for contracts rises. This contrasts with the case without counterparty risk, where increasing participation in the contract market always improves welfare (Proposition 1).

Proposition 4. *There exists $\hat{\theta} < G(\bar{c})$ such that increasing contract demand reduces welfare for all $\theta \in [\hat{\theta}, G(\bar{c})]$.*

To interpret this result, it is useful to consider the case where θ is slightly below $G(\bar{c})$. In that situation, since the supply of contracts is perfectly inelastic, a small increase in demand significantly increases the equilibrium contract price. The resulting increase in the default probability for all inframarginal contracts outweighs the benefits of minimally increasing investment. This result illustrates a trade-off when considering demand mandates, as they can foster investment at the cost of an increasing counterparty risk.

4.2 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. Since the regulator has the authority to enforce payment even if spot prices fall below the contract price, counterparty risk is eliminated.[13]

Let the mass of regulator-backed contracts be denoted $\theta_R \leq G(E(p))$. On the demand side, we assume that contracts are allocated among buyers proportionally to their

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

[13] 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). Since public utility companies can pass on their costs to end-consumers, these contracts can be considered free of counterparty risk. In Europe, regulators act play this role by running auctions of regulator-backed contracts, often referred to as Contracts-for-Differences (CfDs).

demands. Hence, the regulator allocates a proportion θ of these contracts to sophisticated buyers, while the remaining contracts are allocated to unsophisticated buyers, for whom the intervention removes transaction costs. Therefore, the residual demand for private contracts by sophisticated buyers is reduced to $\theta(1-\theta_R)$.

On the supply side, we assume that regulator-backed contracts are allocated through an auction among sellers, which is common practice. This auction takes place before private contracts are signed and before any investment occurs. Sellers compete by offering the fixed price at which they are willing to produce under the contract, and the auctioneer selects them in ascending order. Sophisticated buyers and sellers who do not secure a regulator-backed contract can then trade in the private contracts market.

The final outcome critically depends on the available amount of regulator-backed contracts. First, suppose that this amount exceeds the mass of sellers who can profitably trade in the private contracts market, $\theta_R \geq G(\bar{c})$. In this case, regulator-backed contracts fully crowd out private contracts as sellers do not find it profitable to serve the residual demand of the sophisticated buyers. This case is illustrated in Figure 5b.

To understand why, consider the auction for regulator-backed contracts, where sellers offer their production at a price that makes them indifferent relative to their outside option. Specifically, the alternative for investors with costs $c \leq E(p) - r$ is trading in the spot market, while for higher-cost investors, the outside option is not to invest. Since $\theta^R \geq G(\bar{c})$, the auction price is set by these higher-cost investors at $f_R^* = G^{-1}(\theta^R)$. The winning sellers earn higher profits than they could achieve in the private contracts market, $\Pi_S(\bar{f}, c)$. Conversely, the investment costs of the remaining sellers make it unprofitable for them to meet the residual demand of the sophisticated buyers, even if contract prices rise to $\bar{f}$. Hence, regulator-backed contracts fully crowd out private contracts, and counterparty risk is eliminated. This equilibrium outcome is the same as under Proposition 1, where θ is replaced by θ_R.

Matters change when $\theta_R < G(\bar{c})$ as, in this case, the residual demand from sophisticated buyers, $\theta(1-\theta_R)$, can be profitably met in the private market. According to the previous analysis, if the total demand for fixed-price contracts, $\theta_R + \theta(1-\theta_R)$, exceeds $G(\bar{c})$, contract rationing limits investment to $q^* = G(\bar{c})$, resulting in an equilibrium price in the private market $f^* = \bar{f}$. Otherwise, f^* is implicitly defined by the zero-profit condition of the marginal investor, $\Pi_S(f^*, c^*) = 0$, leading to market clearing with total investment $q^* = G(c^*) = \theta_R + \theta(1-\theta_R)$, as illustrated in Figure 5a. In either case, regulator-backed contracts (weakly) increase total investment but decrease the number of private contracts signed. Because of the increase in total contract demand, private contracts are now sold at (weakly) higher prices.

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. This means that the highest bid that a seller with cost c is willing to make in the auction, f_R, is determined by

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

All sellers for whom selling in the private-contracts market is profitable make the same bid, regardless of c.[14]

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

$$f_R^* = \int_0^{f^*} p\phi(p)dp + f^*(1-\Phi(f^*)) - r\Phi(f^*) < f^*. \tag{11}$$

This price is below the equilibrium price on the private contract market, f^*, as sellers are willing to receive a lower but risk-free price. An increase in f^* rises the sellers' opportunity cost, which translates into an increase in f_R^*.

The following proposition summarizes the previous results.

Proposition 5. *When regulator-backed contracts are auctioned off among sellers, private contracts are*

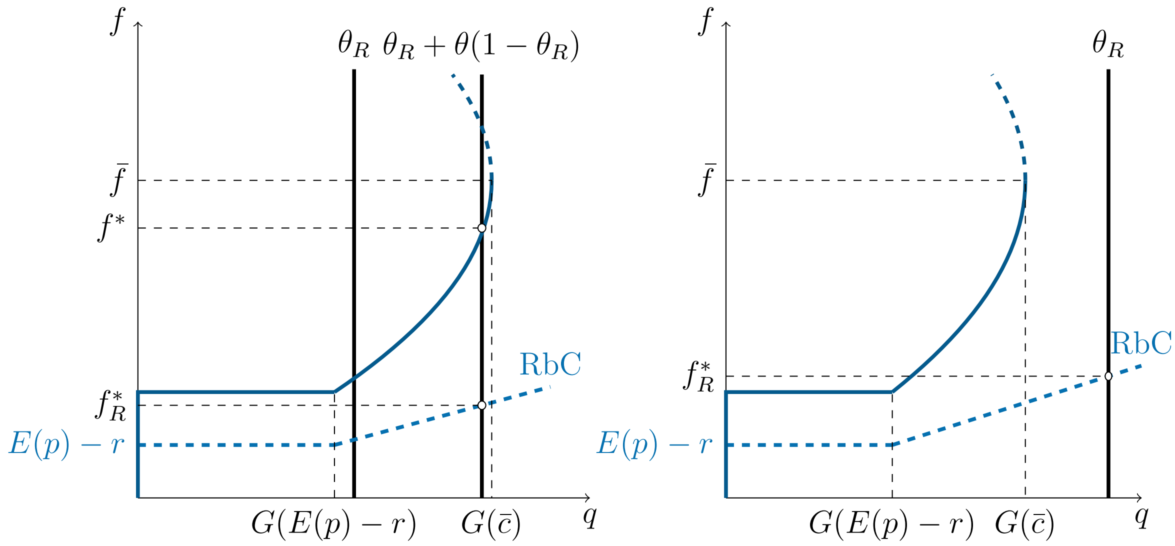
(i) completely crowded out when $\theta^R \geq G(\bar{c})$. The equilibrium price for regulator-backed contracts is $f_R^* = G^{-1}(\theta_R)$, resulting in total investment $q^* = \theta_R$.

(ii) partially crowded out when $\theta^R < G(\bar{c})$. The equilibrium price for regulator-backed contracts f_R^*, defined in (11), is lower than the equilibrium price for private contracts, f^*. Total investment is $q^* = \min\{G(\bar{c}), \theta_R + \theta(1-\theta_R)\}$.

The welfare loss compared to the First Best can be expressed as

$$W^{FB} - W^R = (G(c^*) - \theta_R)\Phi(f^*)r + \int_{c^*}^{E(p)} (E(p) - c)g(c)dc.$$

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



(a) Partial crowd-out. **(b)** Full crowd-out.

Figure 5: Market clearing under Regulator-backed Contracts.

This means that the welfare impact of regulator-backed contracts can be decomposed in three effects. First, as shown in the first term, they positively impact welfare by eliminating counterparty risk for an investment amount θ_R. Second, they also increase total contract demand, which (weakly) increases c^*, thus reducing underinvestment, as captured by the second term. Finally, regulator-backed contracts also have a negative impact on welfare by (weakly) driving up the equilibrium price of private contracts, exposing sellers in that market to greater counterparty risk, as captured by $\Phi(f^*)$ in the first term of the expression. This negative effect is akin to the exogenous increase in contract demand discussed in the previous section, the difference being that the increase in counterparty risk now affects a subset of investors, $\theta(1-\theta_R)$.

Nevertheless, the potential trade-off vanishes when θ_R is large enough to trigger contract rationing in the private market. In this case, the private-contract price, $\bar{f}$, and total investment, $G(\bar{c})$, are unaffected by further increases in θ_R. Since only the first effect remains, increasing θ_R improves welfare for sufficiently large values of θ_R, as long as θ_R does not exceed $G(E(p))$. From a welfare perspective, intermediate values of θ_R may be dominated by much lower or much higher values of θ_R, allowing for the benefits of investment expansion without significantly increasing counterparty risk.

Proposition 6. *If there is contract rationing in the private contracts market, social welfare increases monotonically with θ_R. Conversely, if there is market clearing, there* *exists* $\hat{\theta}_R < \frac{G(\bar{c})-\theta}{1-\theta}$ *such that welfare is monotonically decreasing for* $\theta_R \in \left(\hat{\theta}_R, \frac{G(\bar{c})-\theta}{1-\theta}\right)$*, and monotonically increasing for* $\theta_R \geq \frac{G(\bar{c})-\theta}{1-\theta}$*.*

This equilibrium outcome is the same as under Proposition 1, where θ is replaced by θ_R. Accordingly, as long as $\theta^R \leq G(E(p))$, the welfare conclusions obtained from equation (2) also apply. In particular, welfare increases in θ_R up to $G(E(p))$, attaining the First Best. Increasing θ_R beyond this level would lead to inefficient overinvestment. Since the regulator mediates between buyers and sellers, buyers cannot effectively communicate that the highest fixed price they are willing to pay is $E(p)$, which would be sufficient to prevent overinvestment.[15]

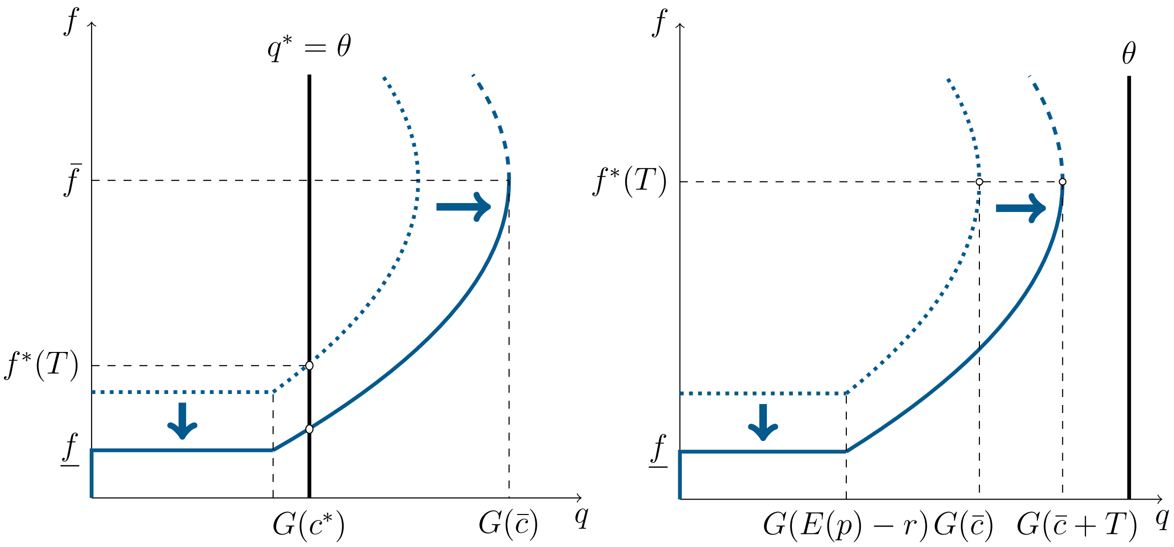
Note that regulator-backed contracts influence market outcomes solely through the increase in demand they engender. When these contracts are auctioned among sellers, the supply curve remains unchanged because the benefits of reducing counterparty risk accrue to buyers. Specifically, regulator-backed contracts make buyers better off, $v - f_R^* > \Pi_B(f^*)$, as the efficiency gains from reduced counterparty risk, $\Phi(f)r$, fully translate into lower contract prices. An alternative approach would be to share the efficiency gains between buyers and sellers, which could also promote supply expansion. This could be achieved by offering the good to buyers at a higher price, while still benefiting them, and using the difference to provide investment support to sellers.

4.3 Public Subsidies

Counterparty risk creates risk premia and prevents sellers from capturing part of the social value they generate, leading to underinvestment. Investment subsidies are a common policy tool used to mitigate this inefficiency. However, 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 fixed-price contracts or reduce distortions caused by counterparty risk.[16] For this reason, we focus on uniform 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

[15] Consequently, if the regulator has asymmetric information about the cost distribution of investors, there is a risk that θ_R is set inefficiently high. In contrast, if there are positive externalities not captured by spot prices, regulator-backed contracts can serve to eliminate the market's tendency toward underinvestment even with full market participation, $\theta = 1$, and no counterparty risk.

[16] 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 Rent-Counterparty-Risk Trade-off. **(b)** The Rent-Investment Trade-off.

Figure 6: The Effect of Public Subsidies.

of funds, $\lambda \geq 0$. Additionally, we assume $\theta \leq G(E(p))$ to prevent overinvestment driven by excess demand.

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

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

As a result, the minimum contract price, $\underline{f}$, is decreasing in T. Second, since supply expands as more sellers can break even at every contract price, the market-clearing price (weakly) decreases. When the subsidy fosters additional investment, this price, f^*, is now implicitly defined by the solution to the new break-even constraint for the marginal seller,

$$\Pi_S(\tilde{f}(c^*, T); c^*) + T = 0, \tag{12}$$

if $c^* < \bar{c}$, or by the profit-maximizing price, $f^* = \bar{f}$, otherwise. While $\bar{f}$ remains unchanged with or without subsidies, the potential mass of sellers who can profitably enter the market at that price expands. As a result, total investment weakly increases with the subsidy T.

In sum, subsidies either (weakly) increase investment or (weakly) reduce contract prices, mitigating counterparty risk for all inframarginal contracts. These positive welfare effects must be balanced against the social costs of the subsidy.

Formally, the regulator selects the subsidy T to maximize the contribution of contracts to social welfare, accounting for how subsidies influence the equilibrium price, f^*, both for new investment and for sellers who would otherwise trade in the spot market, minus the social costs of the subsidies. The welfare loss, compared to the first best, now becomes,

$$W^{FB} - W^T = G(c^*)r\Phi(f^*) + \int_{c^*}^{E(p)} [E(p) - c]g(c)dc + \lambda G(c^*)T. \tag{13}$$

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,*

(i) When $\theta \leq G(\bar{c})$, 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 (12), $\underline{\lambda} = \frac{r\phi(0)}{1-r\phi(0)} > 0$ and $\overline{\lambda} = \frac{r\phi(f^*(0))}{1-\phi(f^*(0))-r\phi(f^*(0))} > \underline{\lambda}$.

(ii) Suppose $\theta > G(\bar{c})$. There exists $\hat{\lambda}$ such that for $\lambda > \hat{\lambda}$, $q^* = \bar{c}+T^*(\lambda)$ and $f^*(\lambda) = \bar{f}$. 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, either because demand is low or because the cost of public funds is low enough to encourage sufficient investment, 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 $\lambda = 0$.

If demand is high and the cost of social funds is sufficiently high so that 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 that case, the equilibrium price remains unchanged at $\bar{f}$.

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 such 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.

4.4 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 utility remains unchanged. The immediate implication of this result is that sellers will request the highest possible price contingent on not being undercut by a competitor. This price will be $f^G = G^{-1}(\theta)$ and the total quantity sold will be $q^G = \theta$.

Suppose first that demand is low so that, without guarantees, there is no contract rationing, $\theta \leq G(\bar{c})$. 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 expressed as

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

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, with higher contract demand such that $\theta > G(\bar{c})$, 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,

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

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 $G(\bar{c})$. 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.

The last term is noteworthy as it captures the social value of new investment in the absence of counterparty risk. However, if contract demand is sufficiently large, i.e., $\theta > G(E(p))$, then $E(p) < c$ for high-cost sellers. This scenario suggests that inefficient entry might occur, as marginal cost savings from new capacity fall below the investment cost. This outcome reflects a form of moral hazard, where sellers fail to fully internalize the social costs of increasing f. Specifically, the high equilibrium contract price encourages excessive contract defaults, leading to socially inefficient investments.

A solution to this inefficiency is to introduce a cap on the guarantee, as the next proposition highlights.

Proposition 8. *The social value of public guarantees increases under a limit $\bar{f}^G(\lambda)$, decreasing in λ. For $\lambda = 0$, $\bar{f}^G(0) = G^{-1}(E(p))$ attains the First Best when $E(p) \leq \bar{f}$.*

Under $\lambda = 0$, the outcome replicates the First Best as in Figure 1b in Section 3. As it is intuitive, the higher the cost this guarantee, the lower will be the cap. By doing so, the cost of the mechanism is reduced at the cost of restricting investment.

5 Robustness and Extensions

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

5.1 Renegotiation and Limited Liability

In the baseline model, we assumed that when the spot market price drops below the contract price, the buyer defaults, creating counterparty risk. However, there are alternative sources 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, the buyer may propose a renegotiation with probability $\eta \leq 1$, 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. Alternatively, if we assume that the buyer always proposes renegotiation, η can capture the buyer's bargaining power. Consequently, the seller's profits are given by

$$\Pi_S(f,c) = \int_0^f (\eta p + (1-\eta) f)\phi(p)\, dp + f(1-\Phi(f)) - r\eta\Phi(f) - c. \tag{14}$$

Our baseline model is a special case of this framework, where $\eta = 1$, implying that the buyer always renegotiates and has the whole bargaining power when the spot price is below f. Allowing for lower η (lower likelihood of renegotiation and/or reduced buyer bargaining power) mitigates counterparty risk and increases welfare through lower equilibrium contract prices or higher investment. Nonetheless, our main results hold qualitatively under this more general formulation.

Results also remain unchanged if contract default arises not from the buyer's opportunistic behavior but from limited liability. Suppose that the buyer is an intermediary that purchases the input to resell it to final consumers in a downstream market. With probability η, 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 from the downstream market and, due to limited liability, it does not fulfill the obligations in the contract. As a result, the seller is forced to offer its output in the spot market at p rather than the contract price f. Seller's profits in this scenario match those in expression (14).

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.

5.2 Vertical Integration

In our baseline model, counterparty risk arises because the seller's and buyer's incentives are misaligned. Thus, one might expect vertical integration to eliminate counterparty risk (Hart, 1995), allowing the integrated firm to capture the full value of the investment without incurring costly risk, as in Proposition 1.

However, this prediction does not hold when the buyer acts as an intermediary between the seller and final consumers. In this context, and as if in the previous case suppose there is a downstream competitor (with probability η), the vertically integrated firm remains exposed to spot market price volatility. The profits of the integrated structure are given by

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

Consequently, when $\eta = 0$, the integrated structure captures the full value of the investment. However, 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 (2).

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.

5.3 A Premium for the Buyer

In the baseline model, we assumed that the buyer does not incur a risk premium when exposed to spot prices. Therefore, the buyer views the contract as beneficial only insofar as it provides access to lower prices.

Consider now a scenario where, analogously to the seller, the buyer incurs in a premium $r_B > 0$ when exposed to spot-price volatility. This parameter can also be viewed as a positive benefit for the buyer from securing clean energy sources through a long-term contract, either due to regulatory requirements or Corporate Social Responsibility considerations. For clarity, in this section we now denote the seller's risk premium as $r_S > 0$.

The primary implication of this assumption is that the buyer will default on the contract if $f > p + r_B$. Consequently, seller's profits can now be expressed as

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

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.[17]

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

$$\Pi_S(f;c) - \Pi_S^0 = \int_{\underline{f}-r_B}^{1} (\underline{f} + r_S - p)\phi\,(p)\,dp = 0.$$

Since this expression is increasing in r_B, it follows that $\underline{f}$ is decreasing in r_B.

Combining the previous results, a higher risk premium for the buyer shifts the contract supply curve downwards, resulting in either lower prices or higher investment. Welfare increases as a consequence, since the buyer's risk premium aligns the incentives of buyers and sellers, thereby reducing the cost of contract enforcement.

5.4 Dynamic Interactions and Time-Varying Prices

Thus far, we have relied on a static model despite the long-term nature of contracts. The implicit assumption has been that price realizations along the duration of the contract are perfectly correlated over time, capturing the notion that the primary source of uncertainty is the future average price level. This setup implies that the buyer's optimal decision to honor the contract depends entirely on the initial price realization, allowing us to model the dynamic interaction within a simple static framework.

However, it is also interesting to consider the possibility of imperfectly correlated future prices, introducing time-varying incentives to default on the contract. In particular, the buyer's incentives would then depend on each period's price realization and the remaining duration of the contract.

To fix ideas, consider a simple dynamic game in which price realizations are *iid* over time, according to the same distribution $\Phi(p)$. Contracts last for two periods, and all payoffs are discounted at a rate $\delta \leq 1$. After observing the price realization for each period, the buyer can decide whether to default on the contract or not. If default occurs,

[17] Specifically, no default occurs when $r_B \geq \bar{r}_B = \bar{f}(\bar{r}_B)$, where $\bar{f}$ is now a function of the buyer's risk premium. For instance, when $\Phi(p)$ is uniform, $\bar{r}_B = \bar{f} = 1 - r_S$.

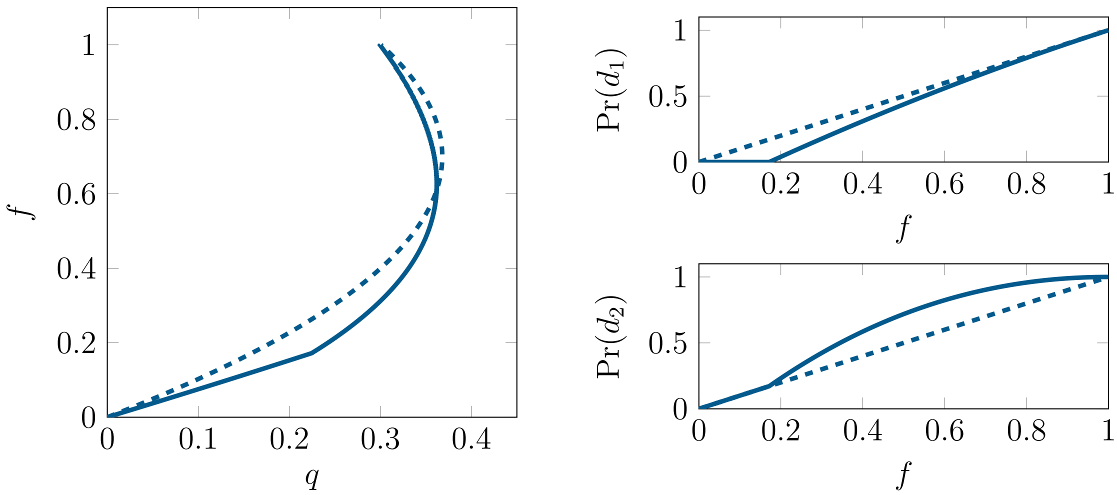


Figure 7: Supply and default probabilities when spot price realizations are perfectly correlated over time (dashed line) versus *iid* (solid line). The left panel displays the supply of contracts. The right panels show the probability of default in the first and second periods. Parameters: $r = 0.4$, $\delta = 0.5$, and $\Phi(p) = p$.

future transactions are conducted in the spot market. The game is solved by backward induction. At $t = 2$, if the buyer honored the contract at $t = 1$, the problem is reduced to our baseline model. Alternatively, if the buyer defaulted on the contract, both the seller and the buyer trade in the spot market at $t = 2$. Hence, in period $t = 1$, the buyer's profits from honoring the contract are $v - f + \delta\Pi_B(f)$, whereas the profits in case of default are $v - p + \delta(v - E(p))$. As a result, the buyer will optimally decide to default at $t = 1$ if and only if p falls below $\hat{p}$, defined as[18]

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

The second term in the above expression corresponds to the option value of honoring the contract in the first period, which enables the buyer to hedge against high prices in the second period. The higher δ and the lower f, the greater the option value of honoring the contract.

Since in the second period the buyer defaults whenever p falls below $f > \hat{p}$, the probability of default increases over time, as illustrated in the right panels of Figure 7. Furthermore, this probability increases with f in both periods, while the default probability in the first period (weakly) decreases with δ.

[18]Note that for sufficiently low f and/or sufficiently high δ, this trigger price becomes negative, implying the the first period default probability is zero.

Consequently, the net present value of profits for the seller can now be written as

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

Compared to our baseline model, for a given f, the probability of being exposed to spot prices in the first period is now lower, $\Phi(\hat{p}) < \Phi(f)$. However, in the second period, this probability is higher than in the baseline model. This is because default in either the first or second period now exposes the seller to spot price volatility, an event that occurs with probability $\Phi(\hat{p}) + (1-\Phi(\hat{p}))\Phi(f) > \Phi(f)$. The right panels of Figure 7 compare the default probability with perfectly correlated versus *iid* spot price realizations.

Relative to the baseline model, for low contract prices f, the reduced default probability in the first period outweighs the increased default probability in the second period. Conversely, for high values of f, the higher second-period default probability dominates. This suggests that the contract supply curves in the two cases may intersect, as illustrated in the left panel of Figure 7. Therefore, for low contract demand θ, equilibrium contract prices are lower when spot price realizations are *iid*. In contrast, for high contract demand, equilibrium investment may be lower than in the baseline model.

Beyond differences in equilibrium outcomes, the qualitative implications of our baseline model hold in more complex dynamic versions. Specifically, under both formulations, counterparty risk persists, leading to inefficiently high prices and underinvestment.

5.5 Introducing Market Power

In our baseline model, we assumed that both sellers and buyers behave competitively. Introducing market power on the seller side would exacerbate the underinvestment problem, as sellers would withhold contract supply to inflate equilibrium contract prices. This raises a natural question: could market power on the demand side act as a countervailing force, mitigating the effects of counterparty risk?

Consider a variation of the model where the continuum of buyers is replaced by a finite number of symmetric buyers $N \geq 1$. We assume that buyers compete *à la* Cournot in the contract market, with each buyer i offering to purchase a quantity q_i of contracts. These buyers face a supply function $f = S(Q)$, where $Q = \sum_{i=1}^{N} q_i = G(c^*)$, arising from the marginal seller's participation condition, $\Pi_S(f; c^*) = 0$. For $f < \bar{f}$, this function is strictly increasing in Q.

Buyers understand that higher contract demand drives up the price for all contracts. Therefore, they may choose to cover part of their needs on the spot market at a price $E(p)$, even when $E(p) > f$. Specifically, buyers aim to maximize the difference $E(p) - f = E(p) - S(Q)$, which represents the advantage for buyer i of entering a long-term contract compared to purchasing on the spot market.

First, suppose there is no counterparty risk. As a result, $S(Q) = G^{-1}(Q)$, and the buyer's problem can be characterized as

$$\max_{q_i} \, (E(p) - S(Q))q_i,$$

with first-order condition

$$E(p) - S(Q) - S'(Q)q_i = 0.$$

As a result, monopsony power reduces contract demand, giving rise to a wedge between spot prices $E(p)$ and equilibrium contract prices, which ultimately reduces investment and welfare.

We can now turn to the case with counterparty risk, where the contract is honored only if $p \geq S(Q)$. Hence, the buyer's problem can be characterized as

$$\max_{q_i} \int_{S(Q)}^{1} (p - S(Q))q_i\phi(p)dp.$$

The first-order condition of the problem becomes

$$\int_{S(Q)}^{1} (p - S(Q))\phi(p)dp - (1 - \Phi(S(Q)))q_i S'(Q) = 0.$$

The decision to withhold demand now considers the impact on contract prices in the absence of default, as otherwise the buyer pays the spot market price. In this sense, counterparty risk mitigates the buyer's incentives to exercise monopsony power.

Importantly, buyers will always restrict contract demand to avoid the contract-rationing region. The reason is that a slight reduction in demand below $G(\bar{c})$ results in a large decrease in the equilibrium price without significantly affecting the quantity purchased, as $S'(Q)$ approaches infinity when $Q \to G(\bar{c})$.[19]

In summary, introducing market power on the supply side would strengthen our baseline results. The effect of introducing market power on the demand side is more nuanced. Although investment is curtailed due to demand withholding, equilibrium contract prices also decrease, thereby mitigating some of the costs associated with counterparty risk.

[19] This result relies on the assumption that, whenever demand exceeds supply, all buyers are allocated the same quantity.

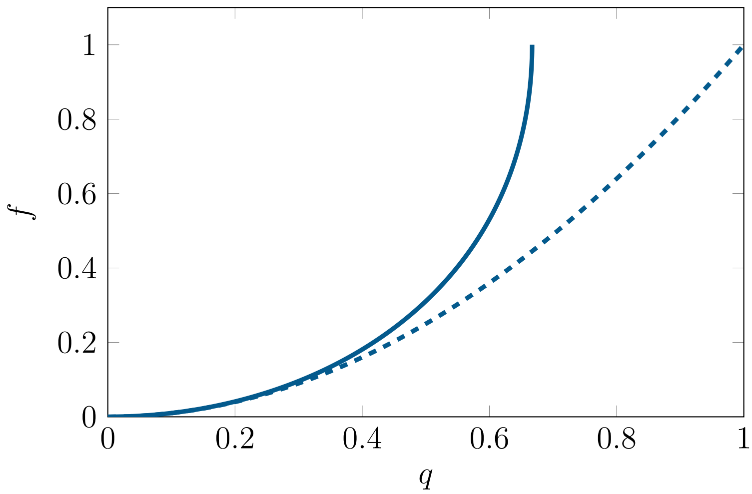


Figure 8: Supply function with risk-averse sellers with counterparty risk (solid line) and without (dashed line). The utility function is $u(p) = \frac{1}{2}\frac{p^{1-\sigma}}{1-\sigma}$ for $\sigma \in [0, 1]$.

5.6 Risk Aversion

In the baseline model, we captured the costs of price volatility through a fixed risk premium r. Alternatively, one could explicitly model sellers' risk aversion through a utility function $u(p)$, with $u' > 0$ and $u'' < 0$. The expected utility of a seller with investment cost c would now be

$$U_S(f, c) = \int_0^f u(p)\phi(p)dp + (1 - \Phi(f))u(f) - c.$$

This expression results in a supply function that is convex in f and it has a maximum at $f^* = 1$. The supply function shifts in the higher the degree of risk aversion.

As it can be observed in Figure 8, risk aversion has qualitatively the same effects as the risk premium that we have assumed throughout the paper. Compared to the situation where the fixed-price contract can be perfectly enforced, counterparty risk implies, for low values of the demand, a higher price and a higher probability of default. When demand is high, counterparty risk reduces investment.

6 Concluding Remarks

In this paper, we uncover buyers' counterparty risk as a significant market failure in long-term contracting, leading to inefficiently high prices, excessive risks, and under-investment—even in the absence of other commonly studied failures like market power or environmental externalities. We show that adding costly collateral does not always resolve the market failures associated with counterparty risk 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 promote demand for long-term contracts, provide public guarantees or support, and encourage regulatory bodies to serve as counterparties. Overall, our findings suggest that policies will only succeed if they address the root cause of counterparty risk; without mitigating this risk, countervailing measures may incur high costs—whether from public funds or from excessive investment driven by moral hazard.

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A Proofs

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

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

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

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

The previous derivative is 0 when

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

The solution to this equation, which we denote as $\bar{f}$, is unique due to the hazard rate assumption. Moreover, it corresponds to an interior maximum since

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

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

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

Notice that $\frac{\partial \Pi_S}{\partial f}(1) = -\phi(1) r < 0$, so that the profit function cannot be monotonically increasing. Furthermore, $\frac{\partial \Pi_S}{\partial f}(0) = 1 - \phi(0) r > 0$ so the solution is interior if $r < \frac{1}{\phi(0)}$.

Finally, since $\frac{\partial \Pi_S}{\partial f \partial r} < 0$, using the Implicit Function Theorem we can establish that $\bar{f}$ and $\Pi_S(\bar{f})$ are decreasing in r. $\square$

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

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

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

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

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

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

Finally, notice that

$$E(p) - r - c = \Pi_S^0 = \Pi_S(\underline{f}, c) < \underline{f} - c.$$

Likewise, notice that $\Pi_B(f) + \Pi_S(f; c) = v - r\Phi(f) - c$. Since the buyer can always guarantee to pay at most $E(p)$, then $\Pi_B(f) \geq v - E(p) - c$. Hence, it follows that $\Pi_S(f; c) < E(p) - c$. □

Proof of Lemma 3: In the text. □

Proof of Proposition 2: Regarding part (i), the contribution of contracts to welfare relative to the no-contracts case is given in equation (4) as

$$W^* - W^0 = (1 - \Phi(f^*))rG(E(p) - r) + \int_{E(p)-r}^{c^*} [E(p) - \Phi(f^*)r - c]\, g(c)\, dc > 0.$$

The first term is positive. Regarding the second term, note that for the marginal seller obtains profits,

$$\begin{aligned} \Pi_S(f^*; c^*) &= \int_0^{f^*} p\phi(p)\, dp + (1 - \Phi(f^*)) f^* - r\Phi(f^*) - c^* \\ &= E(p) - \int_{f^*}^1 (p - f^*)\, \phi(p)\, dp - r\Phi(f^*) - c^* = 0. \end{aligned}$$

Hence,

$$c^* = E(p) - \int_{f^*}^1 (p - f^*)\, \phi(p)\, dp - r\Phi(f^*) < E(p) - r\Phi(f^*).$$

As the term in the integral is decreasing in c, the second term is also positive.

With respect to (ii), the market inefficiency relative to the First Best solution is:

$$W^{FB} - W^* = r\Phi(f^*)\, G(c^*) + \int_{c^*}^{E(p)} (E(p) - c)\, g(c)\, dc > 0.$$

In equilibrium, there is underinvestment since $c^* \leq \bar{c} < E(p)$ and counterparty risk is not fully mitigated since $f^* \leq \bar{f} < 1$. □

Proof of Lemma 4: We will denote the highest and lowest prices sellers are willing to accept for a fixed-price contract with collateral k as $\bar{f}_S(k)$ and $\underline{f}_S(k)$, respectively. In turn, the highest price a buyer with cost of collateral ρ is willing to pay for a contract with collateral k is denoted $\bar{f}_B(k,\rho)$.

Regarding the seller, the lowest acceptable price, $\underline{f}_S(k)$, satisfies (7) with equality. Since

$$\frac{\partial \Pi_S\left(f,k;c\right)}{\partial k} = r\phi\left(f-k\right) + \Phi\left(f-k\right) > 0,$$

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

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

$$\frac{\partial \Pi_S\left(f,k;c\right)}{\partial f} = \left(1-\Phi\left(f-k\right)\right) - \phi\left(f-k\right)r,$$

the first-order condition implies that

$$\frac{\phi\left(\bar{f}_S(k)-k\right)}{1-\Phi\left(\bar{f}_S(k)-k\right)} = \frac{1}{r_S}.$$

The cross-derivative with respect to f and s is

$$\frac{\partial \Pi_S\left(f,k;c\right)}{\partial k \partial f} = r_S\phi'\left(f-k\right) + \phi\left(f-k\right),$$

which, evaluated at $\bar{f}_S$ and using the FOC can be re-written as

$$\frac{\partial \Pi_S\left(f,k;c\right)}{\partial k \partial f} = \frac{1-\Phi\left(\bar{f}_S(k)-k\right)}{\phi\left(\bar{f}_S(k)-k\right)}\phi'\left(\bar{f}_S(k)-k\right) + \phi\left(\bar{f}_S(k)-k\right) > 0.$$

The sign makes use of the hazard rate condition, which implies that

$$\left(1-\Phi\left(\bar{f}_S(k)-k\right)\right)\phi'\left(\bar{f}_S(k)-k\right) + \phi^2\left(\bar{f}_S(k)-k\right) > 0.$$

Hence, it follows that $\bar{f}_S(k)$ is increasing in k.

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

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

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

Proof of Lemma 5: In an interior solution, defined as an outcome with positive counterparty risk, f^* is obtained from equation (9). 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 $f^*(0) > 0 > f^*(1) - 1$, 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 $f^*(\hat{k}) = \hat{k} \geq \underline{f}_S = E(p) - r$. When this is not the case, eliminating counterparty risk is incompatible with sellers participating in the fixed-price contract. □

Proof of Proposition 3: From Lemma 5, we only need to consider thresholds that exceed $E(p) - \hat{k}$. When the following thresholds 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 (6) with respect to k is

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

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

$$\left.\frac{d\Pi_S\left(f^*, k; c\right)}{dk}\right|_{k=\widehat{k}} = r\phi\left(0\right) + \left(1 - r\phi\left(0\right)\right)\frac{df^*}{dk}\cdot \tag{15}$$

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.

To compute $\frac{df^*}{dk}$ we use the Implicit Function Theorem on the market clearing condition which can be written as

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

where $c^* = \int_0^{f-k}(p + k)\phi(p)dp + f(1 - \Phi(f - k)) - r\Phi(f - k)$. We can compute

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

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

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

Replacing in (15), we obtain that eliminating counterparty risk decreases seller profits if and only if

$$r < r_S \equiv \frac{1}{\phi\,(0)} \frac{G(\hat{k})}{1 + G(\hat{k})}.$$

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

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

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

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

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

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

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

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

$$r < r_W = \frac{1}{\phi(0)} \frac{G(\hat{k})(1+g(\hat{k})\hat{k})}{2 + 2g(\hat{k})\hat{k} + 2G(\hat{k}) + G(\hat{k})g(\hat{k})\hat{k}}.$$

Furthermore,

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

□

Proof of Proposition 4: Consider contract demand $\theta \in (G(E(p) - r), G(\bar{c})]$. The welfare loss compared to the First Best can be expressed as

$$W^{FB} - W^* = \theta\Phi(f^*)r + \int_{c^*}^{E(p)} (E(p) - c)g(c)dc.$$

where $c^* = G^{-1}(\theta)$. The derivative with respect to contract demand can be obtained as

$$\frac{\partial(W^{FB} - W^*)}{\partial\theta} = \Phi(f^*)r + \theta\phi(f^*)\frac{\partial f^*}{\partial\theta}r - [E(p) - c^*]\,.$$

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

Proof of Proposition 5: In the text. $\square$

Proof of Proposition 6: Consider total contract demand $\theta_R+\theta(1-\theta_R) \in (G(E(p)-r), G(\bar{c})]$. The welfare loss compared to the First Best can be expressed as

$$W^{FB} - W^R = \theta(1-\theta_R)\Phi(f^*)r + \int_{c^*}^{E(p)} (E(p)-c)g(c)dc,$$

where $c^* = G^{-1}(\theta_R + \theta(1-\theta_R))$. The derivative with respect to the amount of regulator-backed contracts can be obtained as

$$\frac{\partial(W^{FB}-W^R)}{\partial\theta_R} = -\theta\Phi(f^*)r + \theta(1-\theta_R)\phi(f^*)\frac{\partial f^*}{\partial\theta_R}r - (1-\theta)\left[E(p)-c^*\right].$$

When evaluated at $\theta_R = \frac{G(\bar{c})-\theta}{1-\theta}$, $\frac{\partial f^*}{\partial \theta_R} \to \infty$ since $f^* = \bar{f}$, at which the first-order condition of the seller's profit-maximizing problem is satisfied. As a result, $\left.\frac{\partial(W^{FB}-W^*)}{\partial\theta_R}\right|_{\theta_R=\frac{G(\bar{c})-\theta}{1-\theta}} > 0$. By continuity, there exists $\hat{\theta}_R < \frac{G(\bar{c})-\theta}{1-\theta}$ for which the welfare loss is also increasing in $\theta_R \in \left[\hat{\theta}_R, \frac{G(\bar{c})-\theta}{1-\theta}\right]$. Otherwise, the welfare loss is also decreasing in θ_R.

Now consider cases with $\theta_R + \theta(1-\theta_R) > G(\bar{c})$ and $\theta_R < G(\bar{c})$. The welfare loss compared to the First Best can be expressed as

$$W^{FB} - W^R = (G(\bar{c})-\theta_R)\Phi(\bar{f})r + \int_{\bar{c}}^{E(p)} (E(p)-c)g(c)dc.$$

The derivative with respect to the amount of regulator-backed contracts can be obtained as

$$\frac{\partial(W^{FB}-W^R)}{\partial\theta_R} = -\Phi(\bar{f})r < 0.$$

Hence, the welfare loss is always decreasing in θ_R. $\square$

Proof of Proposition 7: When $\theta \leq G(\bar{c})$, the first-order condition of the objective function of (13), contingent on $T > 0$, can be obtained as

$$\left(r\frac{\partial f^*}{\partial T}\phi(f^*) + \lambda\right)\theta = \left(\frac{r}{-\frac{1-\Phi(f^*)}{\phi(f^*)} - r} + \lambda\right)\theta = 0, \tag{16}$$

where $f^* = \tilde{f}(G^{-1}(\theta), T) \in (0, \bar{f})$ arises from (12) so that $\frac{\partial f^*}{\partial T} = -\frac{1}{1-\Phi(f^*)-r\phi(f^*)} < 0$. 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, and since $\frac{1-\Phi(f)}{\phi(f)}$ is decreasing in f, we have that $f^* = 0$. This contract price characterizes a corner solution as long as $\lambda \leq \underline{\lambda} = \frac{r\phi(0)}{1-r\phi(0)} > 0$. 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 $\lambda \geq \overline{\lambda} = \frac{r}{\frac{1-\Phi(\tilde{f}(G^{-1}(\theta),0))}{\phi(\tilde{f}(G^{-1}(\theta),0))} - r} > \underline{\lambda}$, where the last condition comes from the hazard-rate condition on $\phi(f)$.

When $\theta > G(\bar{c})$, there are two possible optimal configurations. Contingent on $T \in (0, G^{-1}(\theta) - \bar{c}]$, $c^* = \bar{c} + T$ resulting in $f^* = \bar{f}$. As a result, the first-order condition corresponding to (13) can be written as

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

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 $T > G^{-1}(\theta) - \bar{c}$ the solution is characterized by (16). 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,

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

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). $\square$

Proof of Proposition 8: TBW.