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Entry, Imperfect Competition, and Futures Market for the Input

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Abstract. We analyze firms' production and hedging decisions under imperfect competition with potential entry. Specifically, we consider an oligopoly industry producing a homogeneous output in which risk-averse firms incur a sunk cost upon entering the industry, and, then, compete in Cournot with one another. Each firm faces uncertainty in the input cost when making production decision, and has access to the futures market to hedge its random cost. We provide two sets of results. First, we show that there exists a unique equilibrium in which, in contrast to previous results in the literature, production and output price depend on the distribution of the spot price and risk aversion, i.e., there is no separation when the firms have access to the futures market. Second, we study the effect of access to the futures market on entry, production, and prices. The effect of access to the futures market on the number of firms is ambiguous depending on the value of the futures price and the parameters of the model. We also show that hedging induces the risk-averse firm to produce more, while speculating reduces production.

Keywords. Cournot, entry, futures, hedging, imperfect competition.

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1 Introduction

Recent financial literature on firms' risk management of market risk has focused on the determinants of hedging and the economic value of financial coverage. The two main questions in this literature are: *Why do firms hedge?* and *Does hedging increase the economic value of the firms?* Firms' hedging is explained by managerial risk aversion (Stulz, 1990; Tufano, 1996) or market imperfections such as corporate income taxation (Smith and Stulz, 1985; Graham and Smith, 1999; Graham and Rogers, 2002), financial distress costs (Smith and Stulz, 1985), corporate governance (Dionne and Triki, 2011), investment opportunity costs (Froot et al., 1993; Froot and Stein, 1998), and information asymmetries (DeMarzo and Duffie, 1991). The empirical effect of hedging on firm value is rather mixed (Hoyt and Liebenberg, 2011; Campello et al., 2011).

Another strand of the literature analyzes the joint production and hedging decisions of the firm under output price uncertainty (Holthausen, 1979; Feder et al., 1980). The main result from this literature is that optimal output production is independent of the probability distribution of the output price and the manager's risk aversion. The distribution of the output price and risk aversion affect only firms' involvement in futures trading. The same separation result is obtained under perfect competition and input price uncertainty (Holthausen, 1979; Katz and Paroush, 1979; Paroush and Wolf, 1992). Paroush and Wolf (1992) show, however, that the separation result does not hold in the presence of basis risk, while Anderson and Danthine (1981) obtain a similar negative result with production uncertainty. Different extensions have been proposed by considering multiple risky inputs, background risk, and joint output price and input price uncertainty.[1]

Although there are many contributions regarding firms' hedging in both literatures, to our knowledge there are few analyses of firms' hedging behavior under imperfect competition, and none that consider entry in the output market.[2] We propose to fill the gap by analyzing firms' production and hedg-

[1]See Viaene and Zilcha (1998) for instance. See also Alghalith (2008) for a review of the literature with competitive markets.

[2]There are two notable exceptions for imperfect competition. First, Eldor and Zilcha

ing decisions under imperfect competition with potential entry. Specifically, we consider an oligopoly industry producing a homogeneous output in which risk-averse firms incur a sunk cost upon entering the industry, and, then, compete in Cournot with one another.[3] Each firm faces uncertainty in the input cost when choosing production, and has access to the futures market to hedge its random cost. There is only one source of risk in our analysis. One application of our model is the airline market, where it has been verified that Cournot competition is present in empirical investigations of U.S. airline industry (Brander and Zhang, 1990; Fisher and Kamerschen, 2003). In this market, airline companies face future fuel price uncertainty when they make their optimal routes decisions for the next few months, and purchase futures contracts for jet fuel (Morrell and Swan, 2006).[4] Here, entering or exiting the market is mainly interpreted as route decisions.

We provide two sets of results. First, we show that there exists a unique equilibrium in which a finite number of firms enter the market as long as the sunk cost is not too high (the standard case) or not too low. Indeed, if the cost of entry is too low, an infinite number of firms may enter and engage in speculation, which yields the competitive outcome in the real sector. That is, the price of the output is equal to the marginal cost and the firms only make profits from speculating on the input market. We also show that, in

(1990) study the hedging behavior of an oligopoly under uncertainty in the output sector. However, while the spot price is endogenous (and the firms exercise market power under uncertainty), the futures (or forward) price is exogenous and fixed. In other words, the firms exercise market power in the spot output market, but behave perfectly competitively for the futures market of the same good. In addition, Eldor and Zilcha (1990) do not consider entry, which is our main focus in this paper. Second, in a very different setting, Allaz and Villa (1993) isolate the strategic reasons for using futures contracts. By selling futures contracts, Cournot firms attach a lower value to a high spot price and commit to aggressive behavior on the spot price, which implies more production at a lower price in equilibrium, and thus benefits consumers but not producers.

[3]In this study, we assume that the firms have a concave payoff due to managerial risk aversion. Concavity can be explained by different market imperfections. See Froot et al. (1993) for a discussion.

[4]Fuel cost represents about 15% of the airlines' costs. Other costs are usually less volatile so hedging fuel costs guarantees stable profits. Usually, airlines do not hedge business cycle risk. The airline companies can also purchase other derivatives products such as options and even collars. These options would introduce more flexibility for the firm but would not affect the main results of the paper.

contrast to previous results in the literature, production and output price depend on the distribution of the spot price and risk aversion, i.e., there is no separation when the firms have access to the futures market. The key element is that the entry decision limits the ability of the firms to adjust their production decisions, which implies that they are no longer independent from uncertainty and risk aversion. One implication is that access to the futures market alters the comparative analysis. Indeed, while an increase in risk increases production under access to the futures market, an increase in risk induces firms to produce less without financial access.[5] In other words, financial access reverses the effect of risk on per-firm production.

The second set of results concern the effect of access to the futures market on entry, production, and prices. The effect of access to the futures market on the number of firms is ambiguous depending on the value of the futures price and the parameters of the model. Further, the equilibrium number of firms is convex in the futures price when the firms partially hedge. In particular, an increase in the futures price of the input can yield an increase in the number of firms in the output sector. This is due to the fact that an increase in the futures price induces firms to produce less, which reduces the market externality in a Cournot game and induces more firms to enter while hedging their cost. Finally, we show that hedging induces the risk-averse firm to produce more, while speculating reduces production.

The paper is organized as follows. Section 2 presents the model. Section 3 states the equilibrium and presents results related to the issue of separation between production (and output price) and uncertainty. Section 4 discusses the effect of access to futures market on entry, production, and output price. Section 5 concludes the paper. Proofs and extensions are found in the Appendix.

[5] The result without financial access is consistent with classical results obtained in a static environment (i.e., without entry decision) for perfect competition (Sandmo, 1971; Batra and Ullah, 1974) and quantity-setting monopoly (Leland, 1972).

2 The Model

2.1 Preliminaries

We embed access to the futures input market in a two-stage entry game. At the first stage, all potential firms decide whether to enter an industry in the output sector. Each entering firm pays an exogenous entry cost $K > 0$.[6] At the second stage, all firms that have entered make production and financial decisions while competing in Cournot in the output sector. The firms face uncertainty in the input price, and have access to perfectly competitive spot and futures input markets.

We now describe the second stage of the game in detail . In an industry with J firms, firm j produces $q_j \geq 0$ units of output and faces the inverse demand $p = D\left(\sum_{k=1}^{J} q_k\right)$ where p is the output price and q_k is the output sold by firm k. The technology to transform the input into the output is assumed to be linear and deterministic. A unit of input can be purchased in the spot market at price $\tilde{S}$, which is unknown at the time of setting output.[7] In addition to the spot market, there is a futures market for the input. A futures contract can be purchased at known price F in order to be delivered one unit of input.

The decisions of the firm can be summarized by two variables: one related to production and another one related to financial activity. Specifically, firm j sets output $q_j \geq 0$ and chooses the hedge coverage $\omega_j \in \mathbb{R}$ for the random cost so that firm j purchases $(1 - \omega_j)q_j$ units of input in the spot market at the random spot input price $\tilde{S}$, and buys futures contracts at the futures input price F for the remaining $\omega_j q_j$ units of input.[8] Given production and financial decisions, the random profit of firm j when there are J firms in the

[6]The case of no entry cost is excluded. In the data, industries with access to and participation in the futures *input* market generally comprise a small number of large firms. See Campello et al. (2011).

[7]A tilde sign distinguishes a random variable from its realization.

[8]In other words, firm j purchases $x_j \equiv (1-\omega_j)q_j$ units of input in the spot market, and the remaining $y_j \equiv \omega_j q_j$ units are purchased in the futures market. Hence, $q_j = x_j + y_j$ units of output are produced.

industry is

$$\pi\left(J, q_j, \omega_j, \sum\nolimits_{k\neq j} q_k, \tilde{S}, F\right) = D\left(q_j + \sum\nolimits_{k\neq j} q_k\right) q_j - \tilde{S}(1-\omega_j)q_j - F\omega_j q_j, \tag{1}$$

where the firms compete in Cournot in the output market, but are price-takers in the input (spot and futures) markets.[9]

Firms may engage in various types of financial activities. Specifically, firm j may decide not to access the futures market, i.e., $\omega_j = 0$. It may also partially hedge ($\omega_j \in (0,1)$) or fully hedge ($\omega_j = 1$).[10] It may finally engage in two forms of speculation. First, when $\omega_j < 0$, firm j sells futures contracts at price F which are deliverable by purchasing the input in the spot market.[11] Second, when $\omega_j > 1$, firm j fully hedges, and buys additional units of input in the futures market for resale in the spot market.[12] While firms whose main activity is production rarely speculate (e.g., the board often prevents the firm's managing team from speculating), it may occur and has occurred. For our analysis, it turns out that allowing firms to engage in speculation simplifies the characterization of the equilibrium (i.e., no corner solution), and, more importantly, has no effect on most of our results.[13]

2.2 Assumptions

Each firm is managed by an officer (e.g., the CEO) whose objective is to maximize the expected utility of profit over output and hedge coverage. Managers' preferences on profit are assumed to exhibit constant absolute risk aversion. Output demand is linear and the firms' beliefs about the spot input price

[9] This situation is representative of industries that participate in the futures input markets. For instance, while airline companies have market power in providing their services, they cannot have an effect on the financial prices of the futures contracts because many other industries interact in the futures market for fuel.

[10] Full hedging means that the input is purchased only in the futures market, whereas, under partial hedging, the input is purchased in both the spot and the futures markets.

[11] Consistent with Footnote 8, $\omega_j < 0$ implies that $x_j > 0, y_j < 0$, so that production is $q_j = x_j + y_j < x_j$ because some of the input purchased in the spot market is used for delivery via the futures market, while the remaining input is used for production.

[12] Consistent with Footnote 8, $\omega_j > 1$ implies that $x_j < 0, y_j > 0$.

[13] See Appendix F for a full characterization of the equilibrium when the firms have partial access to the futures market, i.e., the firms may hedge but cannot speculate.

are assumed to be normally distributed. There always exists an output price high enough to cover the input cost using both input markets so that trivial cases for which the output market does not exist or is only served by one market are ignored. The next four assumptions hold for the remainder of the paper.

Assumption 2.1. *The coefficient of absolute risk aversion is $\alpha > 0$. In other words, the utility function for profit x is exponential: $u(x) = -e^{-\alpha x}$.*

Assumption 2.2. *Inverse demand is linear, i.e.,*

$$D\left(\sum\nolimits_{k=1}^{J} q_k\right) = \theta - \gamma \sum\nolimits_{k=1}^{J} q_k, \tag{2}$$

where $\theta, \gamma > 0$ are demand parameters.

Assumption 2.3. *The input spot price is normally distributed, i.e., $\tilde{S} \sim N(\mu_S, \sigma_S^2)$, $\mu_S \in (0, \theta)$.*

Assumption 2.4. *$F \in (0, \theta)$.*

We make three comments regarding our assumptions. First, Assumptions 2.1 and 2.3 yield a strictly monotonic relation between expected utility and the certainty equivalent

$$\begin{aligned} CE\left(J, q_j, \omega_j, \sum\nolimits_{k \neq j} q_k\right) = D\left(q_j + \sum\nolimits_{k \neq j} q_k\right) q_j - \mu_S(1 - \omega_j) q_j \\ - F\omega_j q_j - \alpha\sigma_S^2 (1 - \omega_j)^2 q_j^2 / 2, \end{aligned} \tag{3}$$

as shown in Appendix A. The certainty equivalent is used throughout the paper.[14] Second, Assumptions 2.1, 2.2, and 2.3 ensure the existence of a unique Cournot equilibrium in the second stage of the game. Third, Assumption 2.4 implies that no restriction is imposed on the futures price. Specifically, in addition to having an actuarially fair futures price (i.e., $F = \mu_S$), the futures market may be either in *normal backwardation* (i.e., $F < \mu_S$) or in *contango* (i.e., $F > \mu_S$).[15]

[14] We abstract from bankruptcy or solvency problems that could arise after the spot input price is realized. Because we use futures contracts, there is no credit risk in the financial market.

[15] The futures markets for fuel (oil and natural gas) were in contango during the fall

2.3 Definition of Equilibrium

Definition 2.5 provides the free-entry equilibrium with full access to the futures market, i.e., $\omega_j \in \mathbb{R}$. The term *free entry* means that there is no institutional constraint on firms entering the market, i.e., firms may enter the market in response to profit opportunities. The equilibrium consists of the number of firms entering the industry J^*, the Cournot strategies $\{q^*(J^*), \omega^*(J^*)\}$, and the output price $p^*(J^*)$.

Definition 2.5. *The tuple* $\{J^*, q^*(J^*), \omega^*(J^*), p^*(J^*)\}$ *is an equilibrium if*

1. *For all* j*, given* J^* *and the strategies* $\{q^*(J^*), \omega^*(J^*)\}$ *of firm* $k \neq j$*,* $q^*(J^*)$ *and* $\omega^*(J^*)$ *solve*

$$\max_{q_j \geq 0, \omega_j \in \mathbb{R}} CE\left(J^*, q_j, \omega_j, (J^* - 1)q^*(J^*)\right). \tag{4}$$

2. *Given* J^* *and* $q^*(J^*)$*,* $p^*(J^*) = D\left(J^* q^*(J^*)\right)$*.*

3. *Given the strategies* $\{q^*(J^*), \omega^*(J^*)\}$*,* $J^* \geq 1$ *is an integer that satisfies*

$$CE(J^*, q^*(J^*), \omega^*(J^*), (J^* - 1)q^*(J^*)) \geq K \tag{5}$$

and

$$CE(J^* + 1, q^*(J^* + 1), \omega^*(J^* + 1), J^* q^*(J^* + 1)) < K. \tag{6}$$

From Definition 2.5, Conditions 1 and 2 define the Cournot equilibrium at stage 2 of the game. Condition 3 is related to the entry decision at stage 1. Specifically, the equilibrium number of firms in the industry is such that, from (5), each entering firm receives a certainty equivalent weakly greater than the entry cost, and, from (6), further entry yields a certainty equivalent strictly smaller than the entry cost.

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of 2011. This situation is generally explained by the recent political situation in Arab countries. Other futures markets for agricultural commodities (e.g., cotton) were in normal backwardation during the same period. See `http://www2.hmc.edu/~evans/e136l7.pdf`.

3 The Equilibrium

Having presented the model and defined the equilibrium, we now characterize and analyze the free-entry equilibrium with full access to the futures market. In Section 4, we study the effect of access to the futures market by comparing our model with the benchmark model of no access to the futures market. While the full characterization of the equilibrium is relegated to Appendix B, all equilibrium variables and conditions are discussed throughout the paper.

3.1 Existence of Market

Proposition 3.1 states that there exists a unique free-entry equilibrium with full access to the futures market as long as the entry cost is not too high to prevent at least one firm from entering the industry. The entry cost must also be not too low to ensure that a finite number of entering firms.

Proposition 3.1. *For $F \in (0, \theta)$, there exists a unique equilibrium with $1 \leq J^* < \infty$ firms in the industry if and only if*

$$\frac{(F-\mu_S)^2}{2\alpha\sigma_S^2} < K \leq \frac{(\theta - F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}. \tag{7}$$

Further, the firms always produce regardless of the type of financial activity, i.e., $q^*(J^*) > 0$.

Proof. See Proposition B.1 in Appendix B. □

Proposition 3.1 is illustrated in Figure 1, where $F \in (0, \theta)$ is on the x-axis, and $K > 0$ is on the $y-$axis.[16] The two convex lines depict the lower and upper bounds in (7). Hence, the darker shaded area between the two curves encompasses the points $\{K, F\}$ for which the equilibrium exists, and, in particular, a finite number of firms enter the industry. Note that entry may occur for all values of F, whether the futures market is normal backwardation ($F \in (0, \mu_S)$), actuarially fair ($F = \mu_S$), or contango ($F > \mu_S$). Note as well

[16] To generate Figure 1, we set $\{\theta, \gamma\} = \{7, 1\}$, and $\{\mu_S, \sigma_S^2, \alpha\} = \{2, 1, 1\}$. While Figure 1 is generated with specific values, the shapes of the curves hold in general. The same comment applies to all figures.

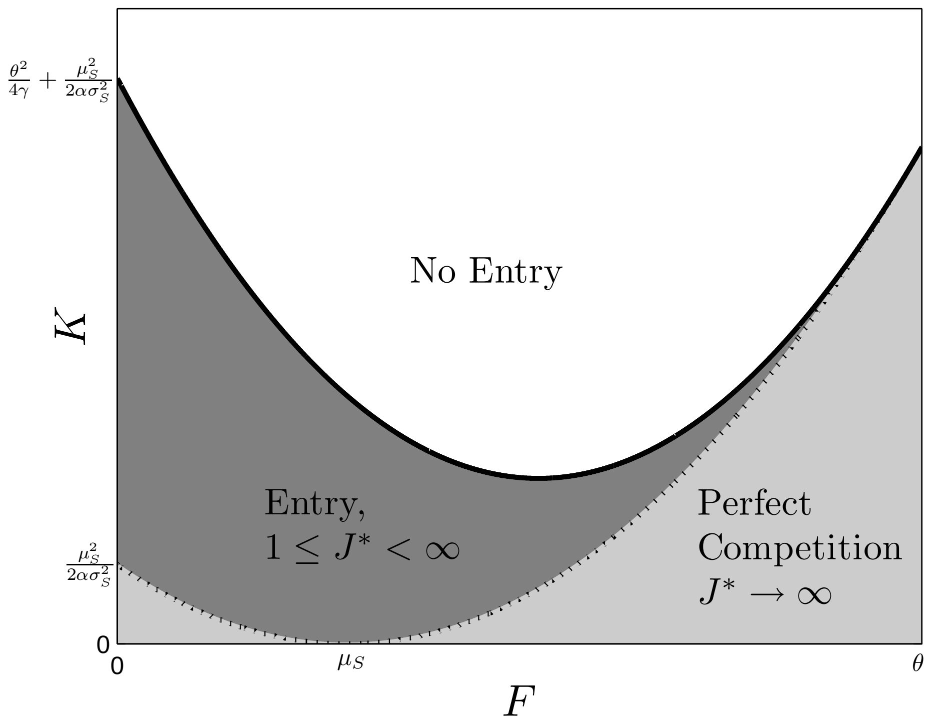

Figure 1: Entry, Full Access to the Futures Market

that, while the upper and lower bounds of (7) decrease along with an increase in the mean and variance of the spot price (and risk aversion), the darker shaded area in-between the two curves,

$$\int_0^\theta \left(\frac{(\theta - x)^2}{4\gamma} + \frac{(x - \mu_S)^2}{2\alpha\sigma_S^2} - \frac{(x - \mu_S)^2}{2\alpha\sigma_S^2} \right) \mathrm{d}x = \frac{\theta^3}{12\gamma} \qquad (8)$$

is unaffected by changes in the mean and variance of the spot price as well as risk aversion. In other words an increase in any of these three parameters does not reduce the possibility of entry. Below the lowest convex curve, there is no equilibrium with a finite number of firms. In other words, all potential entrants have an incentive to enter. Because unlimited entry (with $K > 0$) is due to speculation motives, we delay our discussion about the limiting case (i.e., $J^* \to \infty$).

Having discussed the condition for entry, we provide information about the types of financial activities in which the firms engage in equilibrium. Proposition 3.2 states that, whenever the equilibrium exists, the firms may hedge or speculate (or both) depending on the structure of the futures market and the value of the sunk cost.

Proposition 3.2. *Suppose that* (7) *holds. Then, optimal hedging is*

$$\omega^*(J^*) = 1 - \frac{\sqrt{\gamma}(F-\mu_S)}{\alpha\sigma_S^2\sqrt{K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}}}. \tag{9}$$

Further,

1. *For $F \in (0, \mu_S)$, the firms fully hedge production and, at the same time, speculate by buying in the futures market to sell in the spot market, i.e., $\omega^*(J^*) > 1$.*

2. *For $F = \mu_S$, the firms fully hedge production, i.e., $\omega^*(J^*) = 1$.*

3. *For $F \in (\mu_S, \theta)$, there are three exclusive outcomes.*

   (a) *The firms partially hedge, i.e., $\omega^*(J^*) \in (0, 1)$.*

   (b) *The firms do not access the futures markets, i.e., $\omega^*(J^*) = 0$.*

   (c) *The firms speculate by buying in the spot market to sell in the futures market, i.e., $\omega^*(J^*) < 0$.*

Proof. See Propositions B.1 and B.2 in Appendix B. □

Proposition 3.2 is illustrated in Figure 2.[17] Specifically, Figure 2 provides information about the financial activity in which the firms engage when there is a finite and positive number of firms in the industry. Consistent with Proposition 3.2, the firms fully hedge and speculate when the futures market is normal backwardation. Whenever the futures price is actuarially fair, the firms fully hedge as long as the sunk cost is not too high to prevent entry of at least one firm. See the dashed vertical line in Figure 2.

[17] Figures 1 and 2 are generated using the same parameter values.

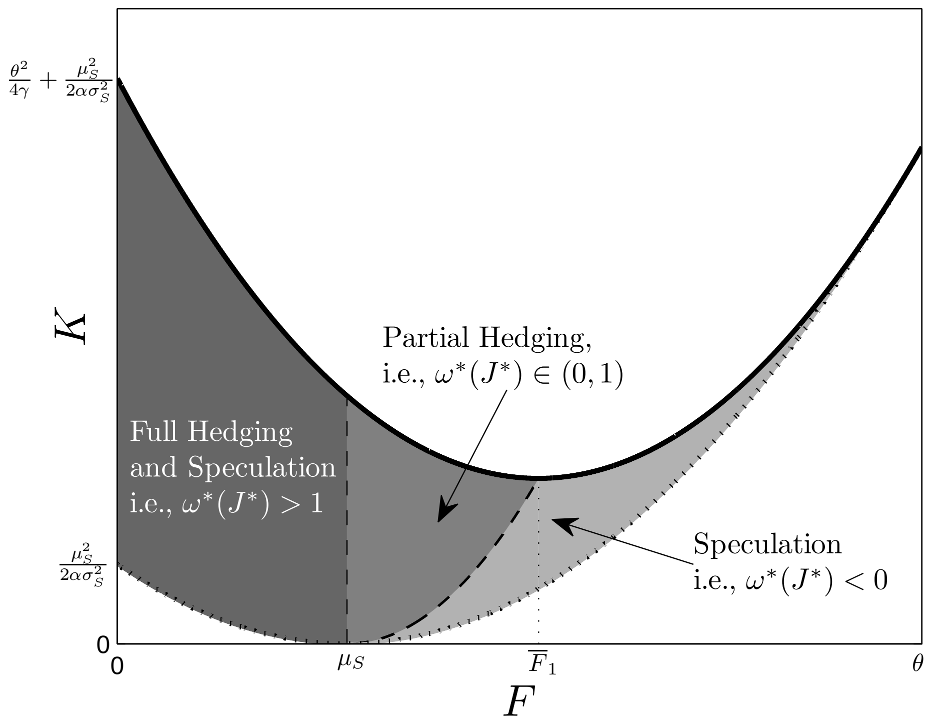

Figure 2: Financial Activity, Full Access to the Futures Market

A contango futures market (i.e., $F > \mu_S$) yields either partial hedging or speculation depending on the value of the sunk cost and the futures price. The division between these two outcomes is depicted by the dashed increasing convex line $K = \frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4}$, intersecting with the minimum of the upper bound for K in (7), i.e., when $F = \overline{F}_1 \equiv \frac{2\gamma\mu_S+\alpha\sigma_S^2\theta}{2\gamma+\alpha\sigma_S^2}$.[18] From Figure 2, in a contango situation, hedging is possible only for lower values of the futures input price, while speculation can occur at any futures input price as long as the sunk cost is low enough.

Remark 3.3. *For $F \in \left[\overline{F}_1, \theta\right)$, hedging is no longer chosen regardless of the value of the sunk cost*

[18]The points $\{K, F\}$ on the dashed increasing line that intersects the upper bound of (7) at its minimum refer to cases for which the firms do not access the futures market, i.e., $\omega^*(J^*) = 0$.

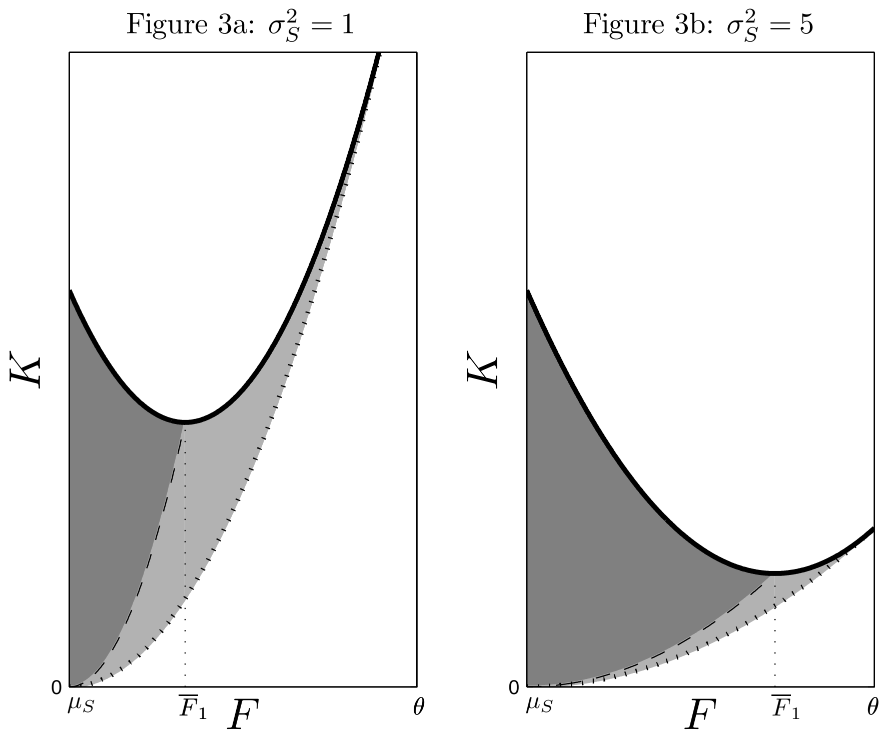

Figure 3: Financial Activity, Hedging vs. Speculation

The entry cost influences the type of financial activity. In Figure 2, consider a point $\{K, F\}$ in the area for partial hedging (i.e., $\omega^*(J^*) \in (0, 1)$). A decrease in the sunk cost while keeping the futures input price constant eventually leads to a switch from hedging to speculation. This is due to the fact that a lower K yields more entry, which reduces profit from selling the output, and, thus, raises the opportunity cost of hedging (instead of speculating) under contango.

Remark 3.4. *For $F \in (\mu_S, \overline{F}_1]$, a lower sunk cost can induce the firms not to hedge, and engage in speculation.*

Finally, hedging becomes more likely under contango along with an increase in the variance of the spot input price or risk aversion. This is illustrated in Figure 3, which shows that an increase in the variance of the spot input price moves $\overline{F}_1 \equiv \frac{2\gamma\mu_S + \alpha\sigma_S^2\theta}{2\gamma+\alpha\sigma_S^2}$ to the right, which increases the darker shaded area (partial hedging) and reduces the lighter shaded area (speculation).[19]

Remark 3.5. *For $F \in [\mu_S, \theta)$, an increase (decrease) in σ_S^2 or α makes it more likely for hedging (speculation) to occur.*

We now discuss the limiting case below the lowest convex curve in Figure 1. Specifically, the lighter shaded area in Figure 1 combines the points $\{K, F\}$ for which entry is always beneficial regardless of the number of firms active in the market. In other words, the stage-2 certainty equivalent is high enough to cover the sunk cost for any number of firms, which yields the case of perfect competition. Due to unlimited entry, the profit from the output sector approaches zero (i.e., the perfect competition outcome drives the output price to the marginal cost), while the firms engage in speculation to generate revenue from the financial sector. Consistent with Figure 1, this is only possible when the futures price is not actuarially fair. From Figure 1, there are two outcomes under the limiting case of perfect competition (i.e., in the lighter shaded area). The firms speculate by selling futures contracts under contango (i.e., $F > \mu_S$), while buying them under normal backwardation (i.e., $F < \mu_S$). Although $K > 0$, speculation on the financial market makes it possible for the output market to approach perfect competition in the limit.

Proposition 3.6. *For $F \in (0, \theta), F \neq \mu_S$, and $0 < K \leq \frac{(F-\mu_S)^2}{2\alpha\sigma^2}$, $J^* \to \infty$ yielding the perfectly competitive outcome in the output sector. Firms always engage in speculation in the futures market.*

Proof. Suppose that $F \in (0, \theta), F \neq \mu_S$ and $0 < K \leq \frac{(F-\mu_S)^2}{2\alpha\sigma^2}$. From (43), $CE^*(J) = \frac{(\theta-F)^2}{(1+J)^2\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2} > K$ for any J. Hence, $J^* \to \infty$. From (38) and (39), $\lim_{J^*\to\infty} x^*(J^*) = \frac{F-\mu_S}{\alpha\sigma_S^2}$ and $\lim_{J^*\to\infty} y^*(J^*) = -\frac{F-\mu_S}{\alpha\sigma_S^2}$, while, from (40) and (42) $\lim_{J^*\to\infty} q^*(J^*) = 0$, and $\lim_{J^*\to\infty} p^*(J^*) = F$.[20] □

[19] To generate Figure 3, we set $\{\theta, \gamma\} = \{10, 1\}$ and $\{\mu_S, \alpha\} = \{5, 1\}$.

[20] Recall that $q^*(J^*) = x^*(J^*) + y^*(J^*)$ where $x^*(J^*)$ is the amount of input purchased (or sold) in the spot market and $y^*(J^*)$ is the amount of input purchased (or sold) in the futures market.

3.2 Separation

Before examining the effect of financial access on the equilibrium, we discuss the effect of entry on the separation property between production and uncertainty (and risk preferences). We first define separation as used in the literature. See Holthausen (1979), Feder et al. (1980), and Viaene and Zilcha (1998), for instance.

Definition 3.7. *There is separation when production and output price are independent of uncertainty and risk preferences.*

We show that, whenever the free-entry equilibrium exists and the futures price is not actuarially fair, entry renders production and output price dependent on the distribution of the spot price as well as risk aversion. To show this, we proceed in two steps. We first show that the separation property holds at the second stage of the game, i.e., for a given number of firms. We then show that, once the number of firms is endogenized, the separation property no longer holds because uncertainty and risk preferences affect market concentration.

Proposition 3.8 provides the production and output price in the Cournot equilibrium at the second stage of the game, i.e., for a given number of firms.[21]

Proposition 3.8. *Suppose that J firms have full access to the futures market. Given an industry with J firms, each firm produces*

$$q^*(J) = \frac{\theta - F}{(1+J)\gamma} \tag{10}$$

at output price

$$p^*(J) = \frac{\theta + JF}{1+J}. \tag{11}$$

Proof. The proof is immediate from the Cournot solution of the second stage of the game stated in the proof of Proposition B.1 in Appendix B. In particular, see (40) and (42). □

[21] Appendix C.1 provides a formal definition of the static Cournot equilibrium.

Proposition 3.9 follows immediately. The separation property is consistent with the case of perfect competition either when there is uncertainty about the output price (Ethier, 1973; Danthine, 1973; Holthausen, 1979; Feder et al., 1980) or the input price (Holthausen, 1979; Katz and Paroush, 1979; Paroush and Wolf, 1992). The futures price is the sole driving force for production because, in equilibrium, the marginal revenue of output is equal to the futures price, and, thus, is independent of the distribution of the spot price and risk aversion. See expression (36) in Appendix B.[22]

Proposition 3.9. *From* (10) *and* (11), $\partial q^*(J)/\partial \mu_S, \partial q^*(J)/\partial \sigma_S^2, \partial q^*(J)/\partial \alpha = 0$ *and* $\partial p^*(J)/\partial \mu_S, \partial p^*(J)/\partial \sigma_S^2, \partial p^*(J)/\partial \alpha = 0$.

Having shown that complete separation occurs when there is no entry, we next show that, when the firms make a decision on entry, the futures price is no longer the driving force for the production decision. In fact, there is always nonseparation because the distribution of $\tilde{S}$ and risk aversion have an effect on the production decision (and, thus, the output price) *through* the number of firms entering the industry.

Propositions 3.10 and 3.11 states that market concentration does depend on uncertainty and risk aversion. In particular, a higher mean or variance of the spot input price reduces the number of firms in the industry. An increase in risk aversion yields the same result. The reason is that an increase in any of these three parameters decreases the equilibrium second-stage certainty equivalent, which induces less firms to enter the industry. See expression (43).

Proposition 3.10. *In the free-entry equilibrium with full access to the futures market,*

$$J^* = \frac{\theta - F}{\sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)\gamma}} - 1 \tag{12}$$

[22]In the case of no entry (or at stage 2 of the game), the separation property holds unconditionally because firms may either hedge or engage in speculation. Appendix C.2 shows that, if firms can only hedge, (i.e., have partial access to the futures market), production and output price are only conditionally independent of uncertainty and risk preferences. In other words, the upper bound of the range of futures input prices yielding hedging is increasing in the mean and variance of the spot input price as well as risk aversion. This, in turn, increases the likelihood of hedging, thus dampening the effect of uncertainty on production.

firms enter the industry.

Proof. See Proposition B.1 in Appendix B. □

Proposition 3.11. *Suppose that $F \neq \mu_S$. From* (12)*,* $\frac{\partial J^*}{\partial \mu_S}, \frac{\partial J^*}{\partial \sigma_S^2}, \frac{\partial J^*}{\partial \alpha} < 0$.

Proposition 3.12 provides the equilibrium variables for production and output price. Note that (13) and (14) are equal to (10) and (11), respectively, evaluated at J^* defined by (12), Hence, the distribution of $\tilde{S}$ and risk preferences influence production and output price *through* the number of firms entering the industry.

Proposition 3.12. *In the free-entry equilibrium with full access to the futures market, each firm produces*

$$q^*(J^*) = \sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)/\gamma} \tag{13}$$

at output price

$$p^*(J^*) = \sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)\gamma} + F. \tag{14}$$

Proof. See Proposition B.1 in Appendix B. □

Proposition 3.13 states that as long as the futures price is not actuarially fair, the separation property does not hold.

Proposition 3.13. *Suppose that the futures price is not actuarially fair, i.e., $F \neq \mu_S$. Then, from* (13) *and* (14)*, production and output price depend on the distribution of $\tilde{S}$ and the risk aversion coefficient α.*

The result stated in Proposition 3.13 is in sharp contrast to the separation result obtained in the literature in the absence of another source of uncertainty (e.g., uncertainty in production, basis risk). In other words, once firms are allowed to make entry decisions, the futures price is no longer the driving force for the production decision (even with one source of uncertainty). Indeed, conditional on the number of firms, each firm is able to fully adjust production in such a way that it is independent of uncertainty and preferences. When firms also make entry decisions, production decisions becomes less flexible. Hence, the endogenization of the number of firms in an industry with sunk cost $K > 0$ yields nonseparation.[23]

The negative effect of risk, mean, or risk aversion on the number of firms implies that the remaining firms can exercise more market power. Specifically, when there is access to the futures market, higher risk induces each firm to produce more. However, while per-firm production increases along with more risk, the number of firms decreases, which is the dominant effect, and the equilibrium output price unambiguously increases along with an increase in the variance of the spot input price. The result also holds for an increase in the mean of the spot price or an increase in risk aversion.

Proposition 3.14. *From* (13) *and* (14), $\frac{\partial q^*(J^*)}{\partial \mu_S}, \frac{\partial q^*(J^*)}{\partial \sigma_S^2}, \frac{\partial q^*(J^*)}{\partial \alpha} > 0$ *and* $\frac{\partial p^*(J^*)}{\partial \mu_S}, \frac{\partial p^*(J^*)}{\partial \sigma_S^2}, \frac{\partial p^*(J^*)}{\partial \alpha} > 0$.

Some of the results stated in Proposition 3.14 show how access to the futures market alters the comparative analysis. To see this, Proposition 3.15 provides the same comparative analysis in the absence of access to the futures input market. The hat sign is used on equilibrium values when there is no access to the futures market.

Proposition 3.15. *Suppose that firms have no access to the futures market, i.e., the constraint* $\omega_j = 0$ *holds for all* j*. Then,* $\frac{\partial \hat{q}^*(\hat{J}^*)}{\partial \mu_S} = 0$*, while* $\frac{\partial \hat{q}^*(\hat{J}^*)}{\partial \sigma_S^2}, \frac{\partial \hat{q}^*(\hat{J}^*)}{\partial \alpha} < 0$*. Further,* $\frac{\partial \hat{p}^*(\hat{J}^*)}{\partial \mu_S}, \frac{\partial \hat{p}^*(\hat{J}^*)}{\partial \sigma_S^2}, \frac{\partial \hat{p}^*(\hat{J}^*)}{\partial \alpha} > 0$.

Proof. From Proposition D.1 in Appendix D, taking derivatives of (61) and (62) yields the comparative analysis stated in Proposition 3.15. $\square$

Two comments are warranted. First, while an increase in risk increases production under access to the futures market (i.e., $\partial q^*(J^*)/\partial \sigma_S^2 > 0$), an increase in risk induces the firms to produce less without financial access

[23] If entry were not costly, the number of firms would be infinity in our case. In the limit, total production and output price would be independent of the distribution of the spot price and risk aversion.

(i.e., $\partial \hat{q}^*(\hat{J}^*)/\partial \sigma_S^2 < 0$).[24] In other words, financial access reverses the effect of risk on per-firm production. Second, an increase in the mean of the spot input price has no effect on production under no financial access (i.e., $\partial \hat{q}^*(\hat{J}^*)/\partial \mu_S = 0$). While an increase in μ_S decreases production directly, it also increases production indirectly via a decrease in the number of firms. In our model with a linear demand and linear technology, these two opposite effects cancel each other out, and, thus, a higher expected cost has no effect on production.

4 The Effect of Access to Futures Market

In this section, we study the effect of access to the futures market first on entry, then on production and output price. To that end, we compare our equilibrium values under full access and under no access to the futures market. The full characterization of the benchmark model of no access to the futures market is relegated to Appendix D, to which we refer throughout this section. To clarify the analysis, the hat sign is used on equilibrium values when there is no access to the futures market.

4.1 Entry

Proposition 4.1 states that there exists a unique free-entry equilibrium with no access to the futures market as long as the entry cost is not so high that it prevents at least one firm from entering the industry.[25]

Proposition 4.1. *Suppose that firms have no access to the futures market, i.e., the constraint $\omega_j = 0$ holds for all j. There exists a unique equilibrium with $1 \leq \hat{J}^* < \infty$ firms in the industry if and only if*

$$0 < K \leq \frac{(\theta - \mu_S)^2}{2(2\gamma + \alpha\sigma_S^2)}. \tag{15}$$

[24] The result without financial access is consistent with classical results obtained in a static environment (i.e., without entry decision) for perfect competition (Sandmo, 1971; Batra and Ullah, 1974) and quantity-setting monopoly (Leland, 1972).

[25] An equilibrium with a finite number of firms exists as long as the sunk cost is strictly greater than zero, otherwise an infinite number of potential firms would enter the industry.

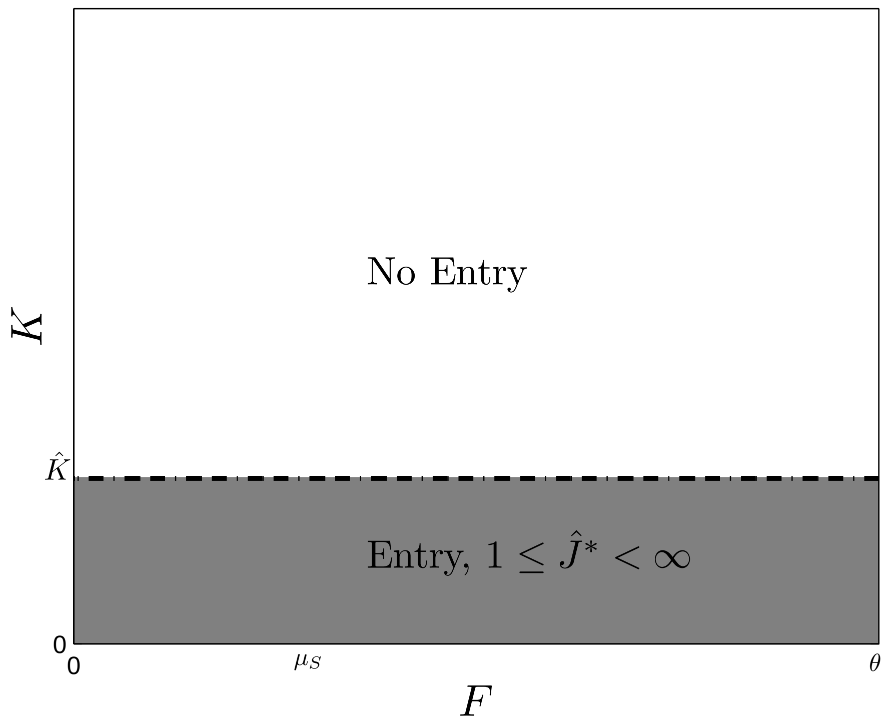

Figure 4: Entry, No Access to the Futures Market

Proof. See Proposition D.1 in Appendix D. □

The condition stated in (15) is depicted in Figure 4, where $F \in (0, \theta)$ is on the x-axis, and $K > 0$ is on the $y-$axis. Given that the firms do not access the futures market, the condition is independent of F and the firms enter as long as $K \leq \hat{K} \equiv \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S^2)}$.[26]

Combining the information of Figures 1 and 4 into Figure 5 illustrates that access to the futures input market facilitates entry. Specifically, for futures prices $F \in (0, \overline{F}_1], \overline{F}_1 \equiv \frac{2\gamma\mu_S+\alpha\sigma_S^2\theta}{2\gamma+\alpha\sigma_S^2}$, hedging (with speculation when $F \in (0, \mu_S)$) allows firms to enter for a sunk cost above $\hat{K}$ (area A in Figure 5)

[26] Unlike the case of full access to the futures market, an increase in the mean or variance of the spot input price, or an increase in risk aversion reduces the possibility of entry. See (8) for the case of full access to the futures market. Indeed, from (15), $\partial\hat{K}/\partial\mu_S, \partial\hat{K}/\partial\sigma_S^2, \partial\hat{K}/\partial\alpha < 0$.

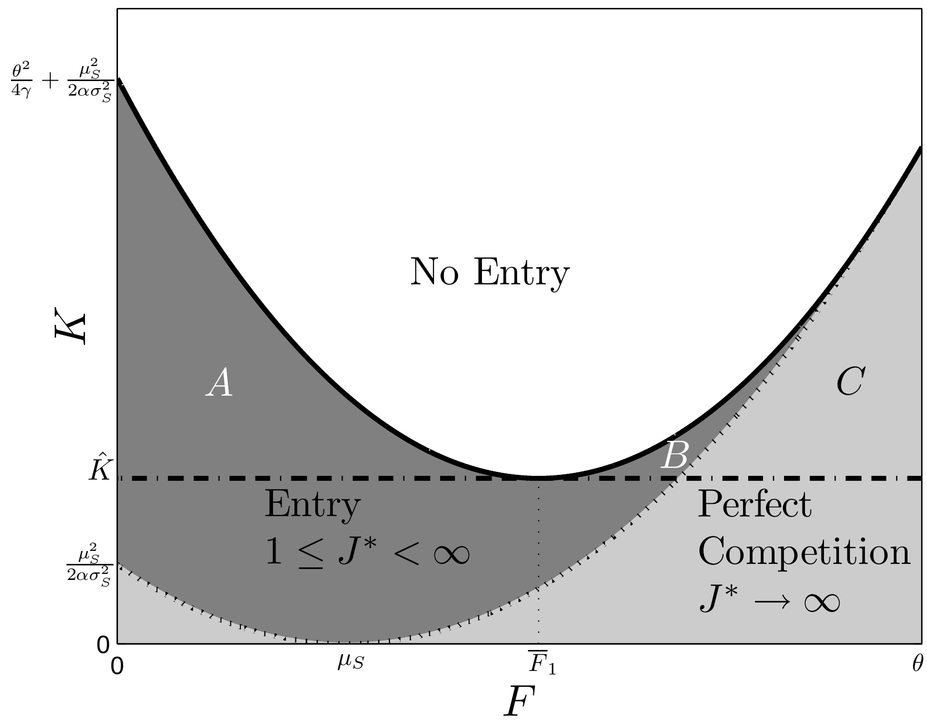

Figure 5: Entry, Full Access vs. No Access to the Futures Market

which would had been otherwise impossible without access to the futures input market. Under speculation, for futures prices $F \in (\overline{F}_1, \theta)$, speculation induces firms to enter for a sunk cost above $\hat{K}$ (area B in Figure 5).

Proposition 4.2. *Access to the futures market allows firms to bear a higher sunk cost, i.e., entry of at least one firm is possible for* $K > \hat{K}$.

While the industry can bear a higher sunk cost, the effect of access to the futures input market on the number of firms is ambiguous. To see this, recall that (12) defines the number of firms under full access, while, from (60),

$$\hat{J}^* = \frac{(\theta - \mu_S)\sqrt{2\gamma + \alpha\sigma_S^2}}{\gamma\sqrt{2K}} - \frac{\alpha\sigma_S^2}{\gamma} - 1 \tag{16}$$

firms enter the industry under no access to the futures market.

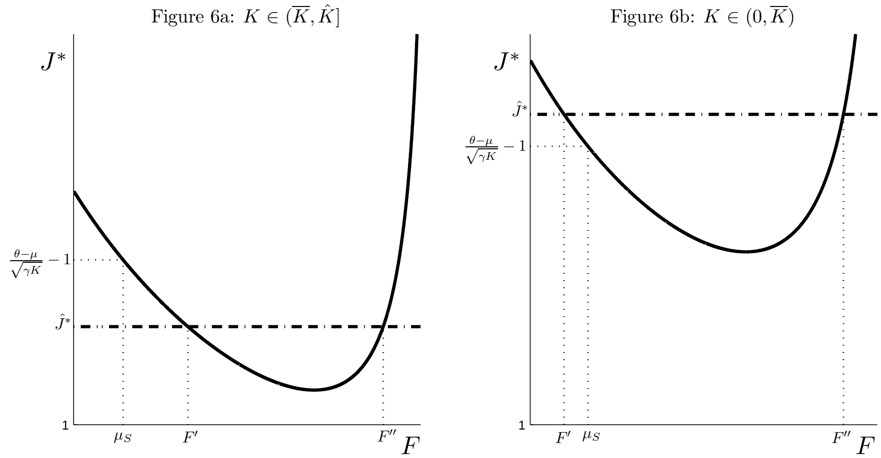

Figure 6: Number of Firms

We begin by comparing the number of firms under an actuarially fair futures input price with the number of firms when there is no access to the futures market. Proposition 4.3 states that the number of firms is greater with an actuarially fair futures input price as long as the sunk cost is high for $K \in (0, \hat{K})$.

Proposition 4.3. *Suppose that* $0 < K < \hat{K} \equiv \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S)}$*. Then,* $J^*|_{F=\mu_S} > \hat{J}^*$ *if and only if*

$$\frac{(\theta-\mu_S)^2}{2(\sqrt{2\gamma+\alpha\sigma_S^2}+\sqrt{2\gamma})^2} < K \leq \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S^2)}. \tag{17}$$

Proof. From (12) and (16), $J^*|_{F=\mu_S} > \hat{J}^*$ if and only if $K > \frac{(\sqrt{2\gamma+\alpha\sigma_S^2}-\sqrt{2\gamma})^2(\theta-\mu_S)^2}{2\alpha^2\sigma_S^4}$, which is the same as the lower bound in (17). The inequality $\frac{(\theta-\mu_S)^2}{2(\sqrt{2\gamma+\alpha\sigma_S^2}+\sqrt{2\gamma})^2} < \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S)}$ always holds. □

To see what happens when the futures input price is not actuarially fair, consider Figure 6, where $F \in [\mu_S, \theta)$ is on the x-axis, while $J^* > 0$ is on the y-axis. The convex solid line plots J^* as a function of F, which is the general shape of (12). The straight dash-dot line is the number of firms under no access to the futures market. From (16), $\hat{J}^*$ is independent of F. When the convex curve intersects the straight line from below at $F = F''$ in Figure 6a, the firms switch from hedging to speculation, i.e., from $\omega^*(J^*) \in (0, 1)$ to $\omega^*(J^*) < 0$.[27]

Consider first the case in which $J^*|_{F=\mu_S} > \hat{J}^*$ as depicted in Figure 6a. Here, the sunk cost is *high* in the sense that $K \in (\overline{K}, \hat{K}], \overline{K} \equiv \frac{(\theta-\mu_S)^2}{2(\sqrt{2\gamma+\alpha\sigma_S^2}+\sqrt{2\gamma})^2}$, as in (17). Note that, as long as the futures input price is close enough to μ_S, hedging yields more firms in the industry. Consider next the case in which $J^*|_{F=\mu_S} < \hat{J}^*$ as depicted in Figure 6b. Here, the sunk cost is *low*, i.e., $K \in (0, \overline{K})$. Regardless of the futures input price, hedging always yields fewer firms in the industry. While access to the futures market may increase or decrease the number of firms when hedging occurs, it is clear from Figures 6a and 6b that speculation always yields more firms.

Consistent with Figure 6, Proposition 4.4 states that the equilibrium number of firms is convex in the futures input price. Hence, an increase in F can lead to a higher number of firms in the industry.

Proposition 4.4. *Suppose that firms have access to the futures market. Then,*

1. *For* $F \in (0, \mu_S)$, $\frac{\partial J^*}{\partial F} < 0$.
2. *For* $F \in [\mu_S, \theta)$, $\frac{\partial J^*}{\partial F} > 0$ *if and only if* $F > \mu_S + \frac{2\alpha\sigma_S^2}{\theta-\mu_S}$.

Proof. Differentiating (12) yields

$$\frac{\partial J^*}{\partial F} = \frac{-\sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)\gamma} + \frac{(F-\mu_S)}{2\alpha\sigma_S^2}(\theta - F)\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)^{-\frac{1}{2}}\sqrt{\gamma}}{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)\gamma}, \quad (18)$$

which yields the cases stated in Proposition 4.4. □

Before proceeding with a detailed explanation of this result, note that the positive relationship between the futures price and the number of firms

[27]Hence, F'' is the largest value of the futures price such that (12) and (16) are equal and $\partial J^*/\partial F > 0$. From (9), $\omega^*(J^*)|_{F=F''} = 0$.

entering the industry may occur not only when firms speculate, but also when firms hedge in a contango futures market. See conditions (46) and (48).[28]

Having stated and discussed Proposition 4.4, we now provide an explanation for the positive relationship between the futures price and the number of firms entering the industry. Due to strategic interactions, an increase in F might increase payoffs for given J, which enables more firms to cover the sunk cost, and, thus, enter the industry.[29] To show this, we study the effect of F on the equilibrium certainty equivalent for a given number of firms in the industry $CE^*(J) \equiv CE(J, q^*(J), \omega^*(J), (J-1)q^*(J))$. Indeed, if F increases $CE^*(J)$, then J^* implicitly defined by $CE^*(J^*) = K$ increases as well.

Proposition 4.5. *Suppose that firms have access to the futures market. Then, in the Cournot equilibrium,*

$$CE^*(J) = \frac{(\theta - F)^2}{(1+J)^2\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}. \tag{21}$$

Proof. See (43) in the proof of Proposition B.1 in Appendix B. □

Proposition 4.6 states that the firms might not necessarily benefit from a lower futures input price due to a more competitive financial market.[30] In other words, the firms' payoffs are not necessarily decreasing in the futures input price. In fact, $CE^*(J)$ is convex in F, so that a lower futures input price may lead to a lower certainty equivalent. This effect occurs sometimes when firms hedge, and always when firms speculate. Further, it can only

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[28] To obtain $\frac{\partial J^*}{\partial F} > 0$ when the firms hedge, the following must hold

$$\frac{(F-\mu_S)(\theta-\mu_S)}{2\alpha\sigma_S^2} > \frac{(2\gamma + \alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4}. \tag{19}$$

Rearranging (19) yields

$$F < \frac{2\gamma\mu_S + \alpha\sigma_S^2\theta}{2\gamma + \alpha\sigma_S^2} \equiv \overline{F}_1, \tag{20}$$

which, from Remark 3.3, is a necessary condition on the value of the futures price for hedging to occur. See also Figure 2.

[29] Here, the term payoff refers to the equilibrium certainty equivalent.

[30] A more competitive financial market might arise in the presence of risk-neutral speculators.

occur in a contango situation. In other words, $CE^*(J)$ is decreasing in F under normal backwardation and actuarially-fair pricing.

Proposition 4.6. *Suppose that firms have access to the futures market. Then, $CE^*(J)$ is strictly increasing in F if and only if*

$$\frac{(1+J)^2\gamma\mu_S + 2\alpha\sigma_S^2\theta}{(1+J)^2\gamma + 2\alpha\sigma_S^2} < F < \theta, \tag{22}$$

Proof. Differentiating (21) with respect to F yields (22). $\square$

The positive relationship between payoff and F when the firms hedge, i.e., $\frac{(1+J)^2\gamma\mu_S+2\alpha\sigma_S^2\theta}{(1+J)^2\gamma+2\alpha\sigma_S^2} < F < \frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2}$, is due to the fact that an increase in the cost of hedging induces firms to decrease output, which can mitigate the effect of increasing output due to the strategic interaction of the firms. Specifically, the effect of an increase in the futures input price on the firms' payoffs is two-fold. First, an increase in F directly decreases the payoffs. Second, there is an indirect effect through the behavior of the firms, i.e., an increase in F induces firms to decrease production. This, in turn, mitigates the externality that the firms have on one another, which may increase their payoffs. Both effects pull in opposite directions and the overall effect is ambiguous. See Appendix E for a formal exposition.

Figure 7 depicts the effect of the futures input price on the equilibrium certainty equivalent resulting from the strategic interaction of the firms in a non-cooperative game. Specifically, Figures 7a and 7b depict the equilibrium certainty equivalent of a firm with contango for an industry with $J = 3$ firms and $J = 4$ firms, respectively.[31] For *low* futures input prices, the firm hedges. For prices greater than $\overline{F}_J \equiv \frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2}$, the firm produces without hedging its random cost, but speculates.

For the case in which there is no speculation in equilibrium (i.e., $F \in [\mu_S, \overline{F}_J]$), we make an additional comment. In Figure 7a, with $J = 3$, each firm attains his highest payoffs in a Cournot equilibrium when the price of hedge coverage is actuarially fair, $F = \mu_S$. Here, hedging results in higher payoffs as long as $\mu_S \leq F \leq F'$. However, in Figure 7b, with $J = 4$,

[31] The values of the remaining parameters of the model are $\theta = 10$, $\gamma = \mu_S = \sigma_S^2 = \alpha = 1$.

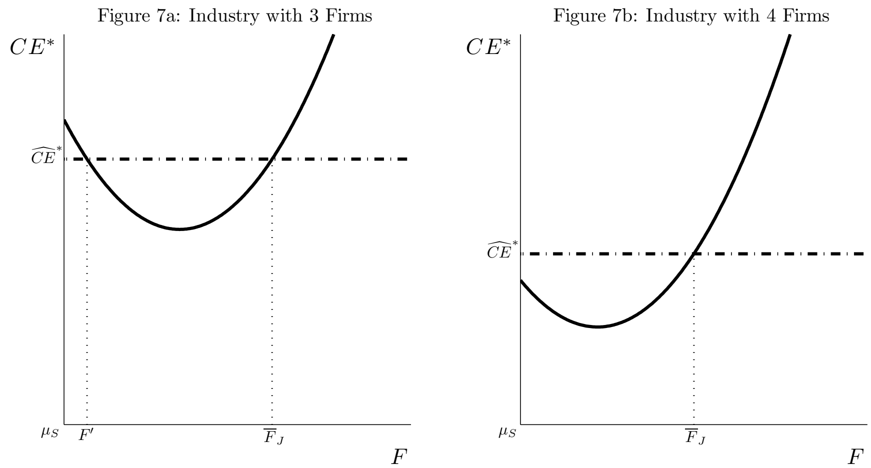

Figure 7: The Effect of F on $CE^*(J)$

$CE^*|_{F=\mu_S}$ is not the highest value. The ambiguous effect of the cost of hedging on the firms' payoffs implies that a more competitive financial market due in part to risk-neutral speculators might actually have a detrimental effect on payoffs.

4.2 Production and Output Price

We next turn to the effect of access to the futures market on production and output price. Proposition 4.7 states that if firms hedge, then access to the futures input market leads to an increase in production. However, if firms only speculate, then production decreases with access to the futures input market. Hence, access to the futures market dampens the effect of uncertainty on production when the firms hedge, but exacerbates the effect of uncertainty when firms speculate. In addition, when the firms hedge, the result for Cournot markets stated in Proposition 4.7 is consistent with Holthausen (1979) and Feder et al. (1980) for competitive markets.

Proposition 4.7. *Suppose that firms have full access to the futures market. In equilibrium, if firms hedge (i.e., $\omega^*(J^*) > 0$),*[32] *then $\hat{q}^*(\hat{J}^*) < q^*(J^*)$ while*

[32]The result holds whether the firms partial hedge (i.e., $\omega^*(J^*) \in (0,1)$), fully hedge (i.e., $\omega^*(J^*) = 1$), or fully hedge and speculate simultaneously (i.e., $\omega^*(J^*) > 1$).

if firms only speculate (i.e., $\omega^*(J^*) < 0$), then $\hat{q}^*(\hat{J}^*) > q^*(J^*)$.

Proof. The proof is immediate from comparing (13) with (61). □

An important implication from Remark 3.4 and Proposition 4.7 is that a decrease in the sunk cost makes it more likely that the dampening effect does not occur.

Remark 4.8. *Suppose that firms have full access to the futures market. In equilibrium, in a contango futures market, a decrease in the sunk cost can induce the firms to speculate, which exacerbates the effect of uncertainty on production.*

Next, we turn to the effect of F on production. Proposition 4.9 states that, depending on the structure of the futures market, per-firm production decreases or increases with a higher futures price.

Proposition 4.9. *Suppose that firms have full access to the futures market. Then,*

1. *For $F \in (0, \mu_S)$, $\frac{\partial q^*(J^*)}{\partial F} > 0$.*
2. *For $F = \mu_S$, $\frac{\partial q^*(J^*)}{\partial F} = 0$.*
3. *For $F \in (\mu_S, \theta)$, $\frac{\partial q^*(J^*)}{\partial F} < 0$.*

Proof. Differentiating (13) yields

$$\frac{\partial q^*(J^*)}{\partial F} = -\frac{(F-\mu_S)}{2\alpha\sigma_S^2\sqrt{\gamma}}\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)^{-\frac{1}{2}}. \tag{23}$$

Given (7), the sign of (23) depends on $F \in (0, \theta)$. □

While Proposition 4.7 states that hedging always increases output, the effect of access to the futures market on output price is more complicated because the number of firms entering the industry also depends on whether the firms have access to the futures market. In particular, while hedging increases output, it may also decrease the number of firms. The overall effect on total output, and, thus, output price is then ambiguous. However, Proposition 4.10 states that when the futures price is actuarially fair, access to the futures market reduces the output price.

Proposition 4.10. *Suppose that firms have full access to the futures market. If the futures price is actuarially fair, then* $\hat{p}^*(\hat{J}^*) > p^*(J^*)$.

Proof. Evaluating (14) and (62) at $F = \mu_S$ yields $\hat{p}^*(\hat{J}^*) > p^*(J^*)$. $\square$

In addition, if firms have full access to the futures market, the overall effect of the futures price on the output price is ambiguous as well. On the one hand, an increase in F might decrease per-firm production, which increases the output price. On the other hand, an increase in F might increase the number of firms, which decreases the output price. Proposition 4.11 states that an increase in F might result in a lower output price only when the firms engage in speculation.

Proposition 4.11. *Suppose that firms have access to the futures market. Then* $\frac{\partial p^*(J^*)}{\partial F} < 0$ *if and only if* $\omega^*(J^*) < 0$.

Proof. From (14),

$$\frac{\partial p^*(J^*)}{\partial F} = \underbrace{-\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)^{-\frac{1}{2}} \frac{(F-\mu_S)}{2\alpha\sigma_S^2}\sqrt{\gamma}}_{\text{Negative Effect through Entry}} + 1. \tag{24}$$

From (24), $\frac{\partial p^*(J^*)}{\partial F} < 0$ if and only if

$$K < \frac{(F-\mu_S)^2(2\alpha\sigma_S^2 + \gamma)}{4\alpha^2\sigma_S^4}, \tag{25}$$

which implies, from (46), that $\frac{\partial p^*(J^*)}{\partial F} < 0$ if and only if $\omega^*(J^*) < 0$. $\square$

5 Final Remarks

This paper provides an analysis of the firms' production and hedging decisions under imperfect competition with potential entry. Entry is shown to remove the separation result, i.e., although the firms have access to the futures market, their production decisions depend on risk and risk aversion through the determination of the number of firms in the industry. We also show that the use of futures contracts have an ambiguous effect on the market structure of the industry. For instance, when the futures input price is actuarially fair, access to the futures market increases or decreases the number of entering firms depending on the value of the sunk cost.

To study the interaction between entry and the futures market, we have assumed that the spot and futures prices were exogenous. However, these prices are determined by markets as well, which, in turn, affects resources allocation, production decisions, and risk-taking. Extending the model to include suppliers of the input along with speculators is an avenue for future research. While the determination of spot and futures prices has already been studied by Turnovsky (1983), the output producers are assumed to be passive, i.e., their demand for the input is given. In fact, output producers are active and forward-looking and, as shown in this paper, their output and input decisions are entwined.

Another extension would be to test the model in the airline industry or any industry with similar characteristics facing Cournot competition. Recent empirical tests on hedging were limited to the effect of different determinants such as CEO risk aversion, convexity of tax function, corporate governance, distress costs, information asymmetry, and the effect of hedging on firm value. To our knowledge, no study has analyzed the effect of hedging on entry. The main empirical question would be: Do airline companies that hedge (or speculate) enter different routes more aggressively? Our theoretical results are ambiguous on this question and an empirical prediction from the model is that airline companies produces less in different routes when futures prices are high, which induces more firms to enter and hedge their fuel cost.

A The Certainty Equivalent

The certainty equivalent is implicitly defined by

$$\mathbb{E}u\left(\pi\left(J, q_j, \omega_j, \sum\nolimits_{k\neq j} q_k, \tilde{S}, F\right)\right) = u\left(CE\left(J, q_j, \omega_j, \sum\nolimits_{k\neq j} q_k\right)\right), \quad (26)$$

so that, given (1) and Assumptions 2.1 and 2.3,

$$\begin{aligned} CE\left(J, q_j, \omega_j, \sum\nolimits_{k\neq j} q_k\right) &= \mathbb{E}\pi\left(J, q_j, \omega_j, \sum\nolimits_{k\neq j} q_k, \tilde{S}, F\right) \\ &\quad - \alpha\mathbb{V}\pi\left(J, q_j, \omega_j, \sum\nolimits_{k\neq j} q_k, \tilde{S}, F\right)/2, \end{aligned} \quad (27)$$

which yields (3). Here, $\mathbb{E}$ is the expectation operator and $\mathbb{V}$ is the variance operator over $\tilde{S}$.

B Free-Entry Equilibrium with Full Access to Futures Market

This appendix provides a full characterization of the free-entry equilibrium with full access to the futures market. Proposition B.1 states the unique free-entry equilibrium with full-access to the futures market, while Proposition B.2 states conditions for the different types of financial activity.[33] Proposition B.1 and B.2 are the basis for Propositions 3.1 and 3.2.

Proposition B.1. *For $F \in (0, \theta)$, there exists a unique equilibrium with $1 \leq J^* < \infty$ firms in the industry if and only if*

$$\frac{(F-\mu_S)^2}{2\alpha\sigma_S^2} < K \leq \frac{(\theta-F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}. \quad (28)$$

[33]Because the second-stage equilibrium certainty equivalent is strictly decreasing in J, we simplify the characterization of the expressions for production and output price by ignoring the fact that J^* is an integer. The number of potential firms is assumed to be large enough so that there is no corner solution for the equilibrium number of firms.

In equilibrium,

$$J^* = \frac{\theta - F}{\sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)\gamma}} - 1 \tag{29}$$

firms enter the industry. Each firm produces

$$q^*(J^*) = \sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)/\gamma} \tag{30}$$

at output price

$$p^*(J^*) = \sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)\gamma} + F. \tag{31}$$

Hedge coverage is

$$\omega^*(J^*) = 1 - \frac{\sqrt{\gamma}(F-\mu_S)}{\alpha\sigma_S^2\sqrt{K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}}}. \tag{32}$$

Proof. We first solve the Cournot equilibrium at stage 2 for a given number of firms J. We then determine the number of firms entering the industry. We finally derive the condition for existence.

1. **Cournot equilibrium at stage 2.**

   We perform a change of variables. Let $x_j + y_j \equiv q_j$, where $x_j \equiv (1-\omega_j)q_j$ is the units of output for which firm j does not hedge, and $y_j \equiv \omega_j q_j$ is the units of output for which firm j hedges (or speculates). Hence, (3) is rewritten as

$$\begin{aligned} CE\left(J, q_j, \omega_j, \sum\nolimits_{k\neq j} q_k\right) = {} & \left(\theta - \gamma \sum\nolimits_{k=1}^{J}(x_k + y_k)\right)(x_j + y_j) \\ & - \mu_S(x_j + y_j) - (F-\mu_S)y_j - \alpha\sigma_S^2 x_j^2/2. \end{aligned} \tag{33}$$

   Using (33) and given that the optimal policies of firm $k \neq j$ are $q^*(J)$

and $\omega^*(J)$, the maximization problem of firm j is[34]

$$\max_{x_j,y_j\geq 0}(\theta-\gamma(J-1)(x^*(J)+y^*(J))-\gamma(x_j+y_j))(x_j+y_j)$$
$$-\mu_S(x_j+y_j)-(F-\mu_S)y_j-\alpha\sigma_S^2x_j^2/2. \tag{34}$$

From (34), the first-order conditions are

$$\frac{\partial}{\partial x_j}:\theta-\gamma(J-1)(x^*(J)+y^*(J))-2\gamma(x_j+y_j)-\mu_S-\alpha\sigma_S^2x_j=0, \tag{35}$$

$$\frac{\partial}{\partial y_j}:\theta-\gamma(J-1)(x^*(J)+y^*(J))-2\gamma(x_j+y_j)-\mu_S-F+\mu_S=0, \tag{36}$$

evaluated at $x_j=x^*(J)$ and $y_j=y^*(J)$.[35] Solving (35) and (36) for $x^*(J)$ and $y^*(J)$ yields

$$x^*(J)=\frac{F-\mu_S}{\alpha\sigma_S^2}, \tag{38}$$
$$y^*(J)=\frac{\theta-F}{(1+J)\gamma}-\frac{F-\mu_S}{\alpha\sigma_S^2}. \tag{39}$$

Hence, from (38) and (39), $q^*(J)=x^*(J)+y^*(J)$ and $\omega^*(J)=y^*(J)/q^*(J)$, i.e.,

$$q^*(J)=\frac{\theta-F}{(1+J)\gamma}>0, \tag{40}$$
$$\omega^*(J)=1-\frac{(1+J)\gamma(F-\mu_S)}{\alpha\sigma_S^2(\theta-F)}. \tag{41}$$

[34]Uniqueness is immediate from the assumption of linear demand and convex cost.
[35]The Hessian matrix

$$H=\begin{bmatrix}-2\gamma-\alpha\sigma_S^2 & -2\gamma\\ -2\gamma & -2\gamma\end{bmatrix} \tag{37}$$

satisfies the second-order conditions.

Plugging (40) into (2) yields

$$p^*(J) = \frac{\theta + JF}{1+J}. \tag{42}$$

Finally, plugging (40) and (41) into (3) yields the certainty equivalent $CE^*(J) \equiv CE\,(J, q^*(J), \omega^*(J), (J-1)q^*(J))$,

$$CE^*(J) = \frac{(\theta - F)^2}{(1+J)^2\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}. \tag{43}$$

2. **Entry decision at stage 1:** Setting (43) equal to K and solving for $J = J^*$ yields (29). Plugging (29) into (40), (41), and (42) yields (30), (32), and (31), respectively.

3. **Derivation of expression** (28)**.** From (29), $J^* \geq 1$ implies that

$$K \leq \frac{(\theta - F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}, \tag{44}$$

while, from (43), $J^* < \infty$ as long as $CE^*(J) > K$ does not hold for all $J \geq 1$, i.e.,

$$K > \lim_{J\to\infty} CE^*(J) = \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}. \tag{45}$$

Combining (44) and (45) yields (28).

□

Proposition B.2 provides conditions for the firms' financial activities.

Proposition B.2. *Suppose that* (28) *holds. We obtain:*

1. *If $F \in (0, \mu_S)$, then $\omega^*(J^*) > 1$.*

2. *If $F = \mu_S$, then $\omega^*(J^*) = 1$.*

3. *If $F > \mu_S$ and*

$$\frac{(2\gamma + \alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4} \leq K \leq \frac{(\theta - F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}, \tag{46}$$

then $\omega^*(J^*) \in (0,1)$.

4. *If* $F \in (\mu_S, \overline{F}_1), \overline{F}_1 \equiv \frac{2\gamma\mu_S + \alpha\sigma_S^2\theta}{2\gamma+\alpha\sigma_S^2}$ *and*

$$K = \frac{(2\gamma + \alpha\sigma_S^2)(F - \mu_S)^2}{2\alpha^2\sigma_S^4}, \tag{47}$$

then $\omega^*(J^*) = 0$.

5. *If* $F \in (\mu_S, \theta)$ *and*

$$\frac{(F-\mu_S)^2}{2\alpha\sigma_S^2} < K < \min\left\{\frac{(2\gamma + \alpha\sigma_S^2)(F - \mu_S)^2}{2\alpha^2\sigma_S^4}, \frac{(\theta - F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right\}, \tag{48}$$

then $\omega^*(J^*) < 0$.

Proof. Using (28) and (32) yields the conditions stated in Proposition B.2. □

C Cournot Equilibrium with No Entry

In this appendix, we formally define the static Cournot equilibrium in Section C.1 We then show in Section C.2 that, in the static Cournot equilibrium, if firms have partial access to the futures market, i.e., hedging but no speculation, then production and output price are only conditionally independent of uncertainty and risk preferences.

C.1 Definition

The symmetric static Cournot equilibrium consists of the strategies $\{q^*(J), \omega^*(J)\}$ and the price $p^*(J)$ when there are J firms in the industry. Note that Conditions 1 and 2 in Definition C.1 are identical to Conditions 1 and 2 in Definition 2.5.

Definition C.1. *The tuple* $\{q^*(J), \omega^*(J), p^*(J)\}$ *is an equilibrium if*

1. *For all j, given the strategies $\{q^*(J), \omega^*(J)\}$ of firm $k \neq j$, $q^*(J)$ and $\omega^*(J)$ solve*

$$\max_{q_j \geq 0, \omega_j \in \mathbb{R}} CE\left(J, q_j, \omega_j, (J-1)q^*(J)\right). \tag{49}$$

2. *Given $q^*(J)$, $p^*(J) = D\left(Jq^*(J)\right)$.*

C.2 Partial Access to the Futures Market, No Entry

Consider the case in which firms have partial access to the futures market, i.e., the constraint $\omega_j \in [0,1]$ holds for all j. The subscript H stands for hedging, and no speculation.

Proposition C.2. *Suppose that J firms have access to the futures market, but cannot speculate, i.e., the constraint $\omega_j \in [0,1]$ holds for all j. Then, in equilibrium, each firm supplies*

$$q_H^*(J) = \begin{cases} \frac{\theta - F}{(1+J)\gamma}, & 0 < F < \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2} \\ \frac{\theta - \mu_S}{(1+J)\gamma + \alpha\sigma_S^2}, & \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2} \leq F < \theta \end{cases}, \tag{50}$$

and hedges a fraction

$$\omega_H^*(J) = \begin{cases} 1, & 0 < F \leq \mu_S \\ 1 - \frac{(1+J)\gamma(F-\mu_S)}{\alpha\sigma_S^2(\theta - F)}, & \mu_S < F < \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2} \\ 0, & \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2} \leq F < \theta \end{cases} \tag{51}$$

of its random cost. The equilibrium output price is

$$p_H^*(J) = \begin{cases} \frac{\theta + JF}{1+J}, & 0 < F < \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2} \\ \frac{(\gamma + \alpha\sigma_S^2)\theta + J\gamma\mu_S}{(1+J)\gamma + \alpha\sigma_S^2}, & \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2} \leq F < \theta \end{cases}. \tag{52}$$

Proof. Financial participation: $\omega_j \in (0,1]$. From (34), the first-order conditions are

$$\frac{\partial}{\partial x_j} : \theta - \gamma(J-1)(x_H^*(J) + y_H^*(J)) - 2\gamma(x_j + y_j) - \mu_S - \alpha\sigma_S^2 x_j = 0, \quad (53)$$

$$\frac{\partial}{\partial y_j} : \theta - \gamma(J-1)(x_H^*(J) + y_H^*(J)) - 2\gamma(x_j + y_j) - \mu_S - F + \mu_S = 0, \quad (54)$$

evaluated at $x_j = x_H^*(J)$ and $y_j = y_H^*(J) \neq 0$.[36] Solving (53) and (54) for $x_H^*(J)$ and $y_H^*(J)$ yields

$$x_H^*(J) = \frac{F - \mu_S}{\alpha\sigma_S^2}, \quad (56)$$

$$y_H^*(J) = \frac{\theta - F}{(1+J)\gamma} - \frac{F - \mu_S}{\alpha\sigma_S^2} \neq 0, . \quad (57)$$

if and only if $0 < F < \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2} < \theta$ when speculation is not allowed. Hence, from (56) and (57), $q_H^*(J) = x_H^*(J) + y_H^*(J)$ as in (50) when $0 \leq F < \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2}$. Moreover, as in (51) $\omega_H^*(J) = y_H^*(J)/q_H^*(J)$ for $\mu_S < F < \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2}$ and $\omega_H^*(J) = 1$ for $0 < F \leq \mu_S$.

No Financial Participation: $\omega_j = 0$. We next consider corner solutions, i.e., $\omega_H^*(J) = 0$. From (57), $y_H^*(J) = 0$ if and only if $\frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2} \leq F < \theta$. Hence, from (34), the first-order condition for x_j is

$$\frac{\partial}{\partial x_j} : \theta - \gamma(J-1)(x_H^*(J) + y_H^*(J)) - 2\gamma(x_j + y_j) - \mu_S - \alpha\sigma_S^2 x_j = 0, \quad (58)$$

evaluated at $x_j = x_H^*(J)$ and $y_j = y_H^*(J) = 0$, so that, for $\frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2} \leq F < \theta$, $q_H^*(J) = x^*(J)$ and $\omega_H^*(J) = 0$ as in (50) and (51). $\square$

In view of Proposition C.2, we now provide two results regarding separation. First, when speculation is excluded, we obtain a conditional separation result. That is, Proposition C.3 states that, conditional on hedging (i.e., the futures input price is not too high), production and output price are

[36] The Hessian matrix

$$H = \begin{bmatrix} -2\gamma - \alpha\sigma_S^2 & -2\gamma \\ -2\gamma & -2\gamma \end{bmatrix} \quad (55)$$

satisfies the second-order condition.

independent of risk and risk aversion.

Proposition C.3. *From* (50) *and* (52), $q_H^*(J)$ *and* $p_H^*(J)$ *are conditionally independent of uncertainty and risk preferences. That is, conditional on hedging, i.e.,* $0 < F < \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2}$, $\partial q_H^*(J)/\partial\mu_S, \partial q_H^*(J)/\partial\sigma_S^2, \partial q_H^*(J)/\partial\alpha = 0$ *and* $\partial p_H^*(J)/\partial\mu_S, \partial p_H^*(J)/\partial\sigma_S^2, \partial p_H^*(J)/\partial\alpha = 0$.

Second, Proposition C.4 states that there is no unconditional separation. Indeed, production depends indirectly on α and σ_S^2 via the range of futures input prices that induce access to the futures market for hedging. Specifically, from Proposition C.2, the upper bound of the range of futures input prices yielding hedging is increasing in the variance of the spot input price and risk aversion. This, in turn, increases the likelihood of hedging, and thus dampens the effect of uncertainty on production.

Proposition C.4. *From* (50) *and* (52), $q_H^*(J)$ *and* $p_H^*(J)$ *are unconditionally dependent of the distribution of the spot price and risk preferences.*

D No Access to the Futures Market, Entry

Suppose that firms have no access to the futures market. Proposition D.1 characterizes the unique equilibrium. There exists a unique equilibrium as long as the entry cost is not too high to prevent at least one firm from entering the industry.[37]

Proposition D.1. *Suppose that no firm has access to the futures market, i.e., the constraint* $\omega_j = 0$ *holds for all* j. *Then, there exists a unique equilibrium with* $1 \leq \hat{J}^* < \infty$ *if and only if*

$$0 < K \leq \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S^2)}. \tag{59}$$

In equilibrium,

$$\hat{J}^* = \frac{(\theta-\mu_S)\sqrt{2\gamma+\alpha\sigma_S^2}}{\gamma\sqrt{2K}} - \frac{\alpha\sigma_S^2}{\gamma} - 1 \tag{60}$$

[37] An equilibrium with a finite number of firms exists as long as the sunk cost is strictly greater than zero, otherwise an infinite number of potential firms would enter the industry.

firms enter the industry. Each firm produces

$$\hat{q}^*(\hat{J}^*) = \frac{\sqrt{2K}}{\sqrt{2\gamma + \alpha\sigma_S^2}} \tag{61}$$

at output price

$$\hat{p}^*(\hat{J}^*) = \mu_S + \frac{\sqrt{2K}(\gamma + \alpha\sigma_S^2)}{\sqrt{2\gamma + \alpha\sigma_S^2}}. \tag{62}$$

Proof. Suppose that $\omega_j = 0$ holds for all j, Then, from (34) evaluated at $y^*(J) = y_j = 0$, the first-order condition is

$$\frac{\partial}{\partial x_j} : \theta - \gamma(J-1)\hat{x}^*(J)) - 2\gamma x_j - \mu_S - \alpha\sigma_S^2 x_j = 0. \tag{63}$$

Solving (63) for $\hat{x}^*(J) = \hat{q}^*(J)$ yields

$$\hat{q}^*(J) = \frac{\theta - \mu_S}{(1+J)\gamma + \alpha\sigma_S^2}. \tag{64}$$

Plugging (64) into (2) yields

$$\hat{p}^*(J) = \frac{(\gamma + \alpha\sigma_S^2)\theta + J\gamma\mu_S}{(1+J)\gamma + \alpha\sigma_S^2}. \tag{65}$$

Finally, plugging (64) into (3) yields the certainty equivalent $\widehat{CE}^*(J) \equiv \widehat{CE}(J, \hat{q}^*(J), 0, (J-1)\hat{q}^*(J))$,

$$\widehat{CE}^*(J) = \frac{(2\gamma + \alpha\sigma_S^2)(\theta - \mu_S)^2}{2((1+J)\gamma + \alpha\sigma_S^2)^2}. \tag{66}$$

Setting (66) equal to K and solving for $J = \hat{J}^*$ yields (60). Plugging (60) into (64) and (65) yields (61) and (62), respectively. Finally, we derive the existence condition defined by (59). From (60), $\hat{J}^* \geq 1$ implies that

$$K \leq \frac{(\theta - \mu_S)^2}{2(2\gamma + \alpha\sigma_S^2)} \tag{67}$$

as in (59). □

E The Effect of Futures Price on Certainty Equivalent

In this appendix, we study the ambiguous effect of F on $CE^*(J)$ in a contango structure (i.e., $F > \mu_S$). Recall that, for $F < \mu_S, \partial CE^*(J)/\partial F < 0$. To that end, rewrite (21) as revenue minus cost, i.e.,

$$CE^*(J) = R^*(J) - \Psi^*(J), \tag{68}$$

where

$$\begin{aligned} R^*(J) &= p^*(J)q^*(J), & (69) \\ &= \frac{\theta + JF}{1+J}\frac{\theta - F}{\gamma(1+J)} & (70) \end{aligned}$$

is the revenue and

$$\begin{aligned} \Psi^*(J) &= \mu_S q^*(J) + (F-\mu_S)\omega^*(J)q^*(J) + \alpha\sigma^2(1-\omega^*(J))^2 q^{*2}/2, & (71) \\ &= \underbrace{\mu_S\frac{\theta - F}{\gamma(1+J)}}_{\text{cost of production}} + \underbrace{(F-\mu_S)\left(\frac{\theta - F}{(1+J)\gamma} - \frac{F-\mu_S}{\alpha\sigma_S^2}\right)}_{\text{cost of hedging}} + \underbrace{\frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}}_{\text{risk premium}} & (72) \end{aligned}$$

is the equilibrium cost. Therefore,

$$\frac{\partial CE^*(J)}{\partial F} = \frac{\partial R^*(J)}{\partial F} - \frac{\partial \Psi^*(J)}{\partial F}, \tag{73}$$

where

$$\frac{\partial R^*(J)}{\partial F} = \frac{(J-1)\theta - 2JF}{\gamma(1+J)^2} \tag{74}$$

and

$$\frac{\partial \Psi^*(J)}{\partial F} = \underbrace{-\frac{\mu_S}{\gamma(1+J)}}_{\text{cost of production}} + \underbrace{\frac{\theta + \mu_S - 2F}{(1+J)\gamma} - \frac{2(F-\mu_S)}{\alpha\sigma_S^2}}_{\text{cost of hedging}} + \underbrace{\frac{(F-\mu_S)}{\alpha\sigma_S^2}}_{\text{risk premium}}. \tag{75}$$

Consider first the effect of F on revenue $R^*(J)$. A higher cost of hedging induces the firms to reduce production, which, in turn, reduces the market externality due to the strategic interaction of the firms. In other words, $\frac{\partial p^*(J)}{\partial F}q^*(J) + p^*(J)\frac{\partial q^*(J)}{\partial F} > 0$, or the percentage increase in the equilibrium output price is greater than the percentage decrease in the output. This has the effect of increasing revenue. Formally, from (74), $\frac{\partial R^*(J)}{\partial F} > 0$ if and only if $(J-1)\theta > 2JF$.

Consider next the effect of F on cost $\Psi^*(J)$. The cost may decrease with a higher cost of hedging. Specifically, from (75), the cost of production unambiguously decreases in F because the firm reduces production. See the fist term in (75). The total cost of hedge coverage decreases in F if and only if $(\theta - 2F + \mu_S)\alpha\sigma_S^2 < 2(1+J)\gamma(F-\mu_S)$. See the second term in (75). Finally, the cost of bearing risk (through the risk premium in (75)) unambiguously increases in F. In general, the cost decreases in F when $(\theta - 2F)\alpha\sigma_S^2 < (1+J)\gamma(F-\mu_S)$. The overall effect is stated in Proposition 4.6.

As noted, if $J = 1$, then condition (22) is not satisfied. Indeed, the positive relation between the certainty equivalent and the futures input price is only possible when the firms exercise a negative externality on one another.

F Partial Access to the Futures Market, Entry

In this appendix, we consider an intermediate benchmark model in which access to the futures input market is restricted to hedging, i.e., no speculation. As in Appendix C.2, we use the subscript H to indicate that firms may hedge, but cannot speculate. Proposition F.1 states that an equilibrium exists as long as the entry cost is not *too* high to prevent at least one firm from entering the industry.

Proposition F.1. *Suppose that firms have access to the futures market, but cannot speculate, i.e., the constraint $\omega_j \in [0,1]$ holds for all j. There exists* *a unique equilibrium with* $1 \le J_H^* < \infty$ *firms in the industry if and only if*

$$0 < K \le \max\left\{\frac{(\theta - F)^2}{4\gamma}, \frac{(\theta - F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}, \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S^2)}\right\}. \tag{76}$$

Further, the firms hedge, i.e., $\omega_H^*(J_H^*) \in (0,1]$ *when* $F \in [0, \overline{F}_1], \overline{F}_1 \equiv \frac{2\gamma\mu_S + \alpha\sigma_S^2\theta}{2\gamma+\alpha\sigma_S^2}$ *and*

$$0 < K \le \frac{(\theta - F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}, \tag{77}$$

and do not hedge, i.e., $\omega_H^*(J_H^*) = 0$*, when*

$$0 < K \le \min\left\{\frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4}, \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S^2)}\right\}. \tag{78}$$

Proposition F.2 characterizes the equilibrium under partial access to the futures market. Note that the equilibrium when the firms may only hedge is a hybrid between no access to the futures input market and full access to the futures input market. For instance, (80) combines both (30) and (61). Hence, all results under hedging (i.e., $\omega_H^*(J_H^*), \omega^*(J^*) \in (0,1)$) hold regardless of the possibility of speculating.

Proposition F.2. *Suppose that firms have access to the futures market, but cannot speculate, i.e., the constraint* $\omega_j \in [0,1]$ *holds for all* j*. In equilibrium,*

$$J_H^* = \begin{cases} \frac{\theta-F}{\sqrt{K\gamma}} - 1, & F \in (0,\mu_S), 0 < K \le \frac{(\theta-F)^2}{4\gamma} \\ \frac{\theta-F}{\sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)\gamma}} - 1, & F \in [\mu_S, \overline{F}_1], \frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4} < K \le \frac{(\theta-F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2} \\ \frac{(\theta-\mu_S)\sqrt{2\gamma+\alpha\sigma_S^2}}{\gamma\sqrt{2K}} - \frac{\alpha\sigma_S^2}{\gamma} - 1, & 0 < K \le \min\left\{\frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4}, \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S^2)}\right\} \end{cases} \tag{79}$$

firms enter the industry. Each firm supplies

$$q_H^*(J_H^*) = \begin{cases} \sqrt{K/\gamma}, & F \in (0,\mu_S), 0 < K \le \frac{(\theta-F)^2}{4\gamma} \\ \sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)/\gamma}, & F \in [\mu_S, \overline{F}_1], \frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4} < K \le \frac{(\theta-F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2} \\ \frac{\sqrt{2K}}{\sqrt{2\gamma+\alpha\sigma_S^2}}, & 0 < K \le \min\left\{\frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4}, \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S^2)}\right\} \end{cases}, \tag{80}$$

and hedges a fraction

$$\omega_H^*(J_H^*) = \begin{cases} 1, & F \in (0, \mu_S), 0 < K \le \frac{(\theta-F)^2}{4\gamma} \\ 1 - \frac{\sqrt{\gamma}(F-\mu_S)}{\alpha\sigma_S^2\sqrt{\left(K-\frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)}}, & F \in [\mu_S, \overline{F}_1], \frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4} < K \le \frac{(\theta-F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2} \\ 0, & 0 < K \le \min\left\{\frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4}, \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S^2)}\right\} \end{cases} \tag{81}$$

of its random cost. The equilibrium output price is

$$p_H^*(J_H^*) = \begin{cases} \sqrt{K\gamma} + F, & F \in (0, \mu_S), 0 < K \le \frac{(\theta-F)^2}{4\gamma} \\ \sqrt{\left(K - \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)\gamma} + F, & F \in [\mu_S, \overline{F}_1], \frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4} < K \le \frac{(\theta-F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2} \\ \frac{\sqrt{2\gamma K}(\alpha\sigma_S^2+\gamma)}{\sqrt{2\gamma+\alpha\sigma_S^2}} + \mu_S, & 0 < K \le \min\left\{\frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4}, \frac{(\theta-\mu_S)^2}{2(2\gamma+\alpha\sigma_S^2)}\right\} \end{cases} . \tag{82}$$

We now provide a detailed proof of Propositions F.1 and F.2.

Proof. Interior Solutions. We first consider interior solutions to (34), i.e., $x_H^*(J), y_H^*(J) > 0$ or $\omega_H^*(J) \in (0,1)$. From (34), the first-order conditions are

$$\frac{\partial}{\partial x_j} : \theta - \gamma(J-1)(x_H^*(J) + y_H^*(J)) - 2\gamma(x_j + y_j) - \mu_S - \alpha\sigma_S^2 x_j = 0, \tag{83}$$
$$\frac{\partial}{\partial y_j} : \theta - \gamma(J-1)(x_H^*(J) + y_H^*(J)) - 2\gamma(x_j + y_j) - \mu_S - F + \mu_S = 0, \tag{84}$$

evaluated at $x_j = x_H^*(J)$ and $y_j = y_H^*(J)$.[38] Solving (83) and (84) for $x_H^*(J)$ and $y_H^*(J)$ yields

$$x_H^*(J) = \frac{F-\mu_S}{\alpha\sigma_S^2}, \tag{86}$$
$$y_H^*(J) = \frac{\theta-F}{(1+J)\gamma} - \frac{F-\mu_S}{\alpha\sigma_S^2} > 0, . \tag{87}$$

[38] The Hessian matrix

$$H = \begin{bmatrix} -2\gamma-\alpha\sigma_S^2 & -2\gamma \\ -2\gamma & -2\gamma \end{bmatrix} \tag{85}$$

satisfies the second-order condition.

if and only if $\mu_S \leq F < \frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2} < \theta$ when speculation is not allowed. Hence, from (86) and (87), $q_H^*(J) = x_H^*(J) + y_H^*(J)$ and $\omega_H^*(J) = y_H^*(J)/q_H^*(J)$ as in (50) and (51) when $\mu_S \leq F < \frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2}$.

Corner Solutions. We next consider corner solutions, i.e., $\omega_H^*(J) = 0$ and $\omega_H^*(J) = 1$. We consider the case $\omega_H^*(J) = 0$ first. From (57), $y_H^*(J) = 0$ if and only if $\frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2} \leq F < \theta$. Hence, from (34), the first-order condition for x_j is

$$\frac{\partial}{\partial x_j} : \theta - \gamma(J-1)(x_H^*(J) + y_H^*(J)) - 2\gamma(x_j + y_j) - \mu_S - \alpha\sigma_S^2 x_j = 0, \quad (88)$$

evaluated at $x_j = x_H^*(J)$ and $y_j = y_H^*(J) = 0$, so that, for $\frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2} \leq F < \theta$, $q_H^*(J) = x_H^*(J)$ and $\omega_H^*(J) = 0$ as in (50) and (51). Plugging (50) into (2) yields

$$p_H^*(J) = \frac{\theta + JF}{1+J}. \quad (89)$$

Next, we consider the case $\omega_H^*(J) = 1$. Following appendix C.2, $\omega_H^*(J) = 1$ if and only if $0 < F \leq \mu_S$ when speculation is not allowed. From (34), the first-order condition for y_j is

$$\frac{\partial}{\partial y_j} : \theta - \gamma(J-1)(x_H^*(J) + y_H^*(J)) - 2\gamma(x_j + y_j) - \mu_S - F + \mu_S = 0 \quad (90)$$

evaluated at $x_j = x_H^*(J) = 0$ and $y_j = y_H^*(J)$, so that for $0 < F < \mu_S$, $q_H^*(J) = y_H^*(J)$ and $\omega_H^*(J) = 1$. Solving (90) for $y_H^*(J)$ yields

$$y_H^*(J) = \frac{\theta - F}{(1+J)\gamma}. \quad (91)$$

Plugging (91) into (2) yields the same equilibrium price as in (89).

Plugging (50) and (51) into (3) yields the certainty equivalent $CE_H^*(J) \equiv CE\left(J, q_H^*(J), \omega_H^*(J), (J-1)q_H^*(J)\right)$,

$$CE_H^*(J) = \begin{cases} \frac{(\theta-F)^2}{(1+J)^2\gamma}, & 0 < F < \mu_S \\ \frac{(\theta-F)^2}{(1+J)^2\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}, & \mu_S \leq F < \frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2} \\ \frac{(2\gamma+\alpha\sigma_S^2)(\theta-\mu_S)^2}{2((1+J)\gamma+\alpha\sigma_S^2)^2}, & \frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2} \leq F < \theta \end{cases}, \quad (92)$$

Setting (92) equal to K and solving for $J = J_H^*$ yields (79). Plugging (79) into (50), (51), and (52) yields (80), (81), and (82), respectively.

Next, we derive the inequalities in Proposition F.1. First, note, from Proposition C.2, that partial hedging, i.e. $\omega_H^*(J) \in (0,1)$, occurs when $\mu_S \leq F < \frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2}$. From (79), plugging $J_H^* = \frac{\theta-F}{\sqrt{\left(K-\frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}\right)\gamma}} - 1$ into $F < \frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2}$ and rearranging yields

$$K > \frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4}. \tag{93}$$

In addition, when there is partial hedging, from (79), $J_H^* \geq 1$ implies that

$$K \leq \frac{(\theta-F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}. \tag{94}$$

Hence, from (93) and (94), there exists an equilibrium with entry and partial hedging when

$$\frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4} < K \leq \frac{(\theta-F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}, \tag{95}$$

as stated in Proposition F.2.[39]

Second, from Proposition C.2, there is full hedging, i.e., $\omega_H^*(J) = 1$, when $0 < F \leq \mu_S$. Furthermore, with full hedging, from (79), $J_H^* \geq 1$ implies that

$$K \leq \frac{(\theta-F)^2}{4\gamma}. \tag{97}$$

Hence, from (97), there exists an equilibrium with entry and full hedging

[39] Note that the set of K satisfying (95) is nonempty. Indeed, hedging occurs when $F < \frac{(1+J)\gamma\mu_S+\alpha\sigma_S^2\theta}{(1+J)\gamma+\alpha\sigma_S^2} < \frac{2\gamma\mu_S+\alpha\sigma_S^2\theta}{2\gamma+\alpha\sigma_S^2}$, which implies that

$$\frac{(2\gamma+\alpha\sigma_S^2)(F-\mu_S)^2}{2\alpha^2\sigma_S^4} < \frac{(\theta-F)^2}{4\gamma} + \frac{(F-\mu_S)^2}{2\alpha\sigma_S^2}. \tag{96}$$

when

$$0 < K \leq \frac{(\theta - F)^2}{4\gamma}. \tag{98}$$

Third, from Proposition C.2, there is no hedging when $F \geq \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2}$. From (79), plugging $J_H^* = \frac{(\theta-\mu_S)\sqrt{2\gamma+\alpha\sigma_S^2}}{\gamma\sqrt{2K}} - \frac{\alpha\sigma_S^2}{\gamma} - 1$ into $F \geq \frac{(1+J)\gamma\mu_S + \alpha\sigma_S^2\theta}{(1+J)\gamma + \alpha\sigma_S^2}$, and rearranging yields

$$K \leq \frac{(2\gamma + \alpha\sigma_S^2)(F - \mu_S)^2}{2\alpha^2\sigma_S^4}. \tag{99}$$

In addition, when there is no hedging, from (79), $J_H^* \geq 1$ implies that

$$K \leq \frac{(\theta - \mu_S)^2}{2(2\gamma + \alpha\sigma_S^2)}. \tag{100}$$

Hence, from (99) and (100), there exists an equilibrium with entry and no hedging when

$$0 < K \leq \min\left\{\frac{(2\gamma + \alpha\sigma_S^2)(F - \mu_S)^2}{2\alpha^2\sigma_S^4}, \frac{(\theta - \mu_S)^2}{2(2\gamma + \alpha\sigma_S^2)}\right\}, \tag{101}$$

as stated in Proposition F.1.

Finally, there exists a Cournot equilibrium with $J_H^* \geq 1$ as long as (94), (98) or (100) hold, i.e.,[40]

$$\begin{aligned} K &\leq \max\left\{\frac{(\theta - F)^2}{4\gamma}, \frac{(\theta - F)^2}{4\gamma} + \frac{(F - \mu_S)^2}{2\alpha\sigma_S^2}, \frac{(\theta - \mu_S)^2}{2(2\gamma + \alpha\sigma_S^2)}\right\}, && (103)\\ &= \frac{(\theta - F)^2}{4\gamma} + \frac{(F - \mu_S)^2}{2\alpha\sigma_S^2}, && (104) \end{aligned}$$

as stated in Proposition F.1.[41]

□

[40] Note that

$$\frac{(\theta - F)^2}{4\gamma} + \frac{(F - \mu_S)^2}{2\alpha\sigma_S^2} > \frac{(\theta - \mu_S)^2}{2\left(2\gamma + \alpha\sigma_S^2\right)}, \tag{102}$$

simplifies to $\left(\alpha\sigma_S^2\theta - (2\gamma + \alpha\sigma_S^2)F + 2\gamma\mu_S\right)^2 > 0$, which is always true.

[41] Uniqueness is immediate from the assumption of linear demand and convex cost.

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