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Two-echelon Supply Chain Operations under Dual Channels with Differentiated Productivities

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Abstract: This paper examines a two-echelon supply chain with an upstream supplier (she) and a downstream manufacturer (he) transacting an intermediate product via direct bilateral contracting and futures market channels with differentiated productivities. A game model is established to examine the dual-channel supply chain operations. Analytical results reveal that downstream productivity improvement (DPI) through the bilateral interaction is necessary and sufficient for the supply chain members to trade in the bilateral channel in addition to the futures market. We show that, when the price in the futures market increases, the manufacturer would purchase less from the futures market and more from the supplier, which not only increases the supplier's expected profit but also increases her risk (variance of the profit) in equilibrium. Furthermore, we find that when the bilateral channel exhibits stronger DPI, the manufacturer obtains a higher expected profit and bears a higher risk, but the supplier enjoys a higher expected profit without incurring any additional risk.

Keywords: Supply chain relationship; Productivity improvement; Futures market; Contract; Game model

1. INTRODUCTION

With the support of the internet, electronic marketplaces provide competitive secondary (spot) market channels for firms in a supply chain to trade their products. Such spot market channels may help mitigate the double-marginalization problem and, hence, improve supply chain efficiency. At the same time, firms trading in spot markets also bear a great deal of risks associated with volatile spot prices. However, futures markets, such as the Chicago Board of Trade (CBOT), the New York Mercantile Exchange (NYMEX) and the London Metal Exchange (LME), offer firms an alternative market channel to trade various commodities such as crude oil, metals, and plastics. Not only can futures markets enhance supply chain efficiency, but they can also be used to hedge against spot price risks.

Nowadays, the utilization of spot and/or futures markets is widely observed in practice. For example, HP's TradingHubs.com, a web-based secondary market, accommodated transactions of over $45 million of parts and products from July 1999 to April 2000 (Lee and Whang, 2002). As for futures markets, Newman (2009) reports that, in the 2000s, an average of 30%-40% of the total trading activities for the coffee "C" contracts in the New York Board of Trade are made up by commercial traders who, unlike non-commercial traders such as hedgers and speculators conducting only financial trade, engage in physical commodity transactions with actual deliveries. Despite increasing popularity of e-markets, supply chain partners still use bilateral contracts for most transactions in the real business world. According to Electronics Business Network's 2002 poll of 150 original equipment manufacturers and their service providers, 72% of their procurement spending was executed through bilateral contracts and the same level was estimated for the coming year (Dong and Liu, 2007).

Laughlin (2003) reports that 54% of the trading in the electric power market covered by PJM Interconnection was completed through bilateral transactions.

This co-existence of market trading and bilateral contracting arouses researchers in the field of supply chain and operations management to study why firms in a supply chain still transact by bilateral contracts in the presence of the more efficient market trading. They introduce spot market trading to supply chain models and furnish four different interpretations for the need of bilateral contracting to complement spot market trading: risk hedging (Dong and Liu, 2007), potential productivity improvement (Cohen and Agrawal, 1999; Levi et al., 2003), strategic threats under trigger strategies (Tunca and Zenios, 2006), and the price impact of buyers' strategic purchase in the spot market (Mendelson and Tunca, 2007). For more detailed survey on relationship between (spot) market trading and supply chain operations, readers are referred to Haksöz and Seshadri (2007) and Kleindorfer and Wu (2003).

However, little attention is paid to the impact of futures market trading on the negotiation of bilateral contracts in supply chains, although a few authors analyze optimization models where futures trading is assumed to hedge spot price risks (see, for example, Haksöz and Seshadri (2011)). Intuitively, if supply chain members trade in a futures market for actual deliveries, they can make commitments in terms of selling or buying a portion of intermediate products to strategically affect the following negotiation of their bilateral contracts. In this paper, we thus establish a three-stage game model to study the strategic role of committing to futures trading and to explore a new motivation for supply chain members to use the bilateral channel.

In this model, we consider a two-echelon supply chain consisting of an upstream supplier with uncertain unit production cost and a downstream manufacturer with stochastic final market demand. Both members have access to a futures market to trade an intermediate product. In addition to the futures trading channel, the transaction can also be completed by signing a bilateral wholesale price contract. Before negotiating the contract, the supplier (manufacturer) decides her (his) quantity to sell (buy) in the futures market at an observed futures price. After the bilateral contract is signed, the uncertain production cost for the supplier and the uncertain market demand for the manufacturer are realized, and both members fulfill their obligations set by the futures market and the wholesale price contract. Finally, the manufacturer sells the final product to consumers as per the realized demand.

In our model, we assume that the bilateral (contracting) channel improves the manufacturer's productivity compared with the futures market channel. This assumption is consistent with the general idea (as demonstrated in Cohen and Agrawal, 1999, Levi et al., 2003, Ulrich and Barney, 1984) that direct interactions through bilateral contracting rather than market trading help forge a better cooperation link, thereby improving productivities across the supply chain.

By analyzing the subgame perfect equilibrium of this game, we make a four-fold contribution to the literature. Firstly, we find that DPI is a necessary and sufficient condition for the supply chain to transact through bilateral contracting in the presence of the futures market, thereby establishing an alternative DPI interpretation for a positive bilateral transaction on top of Mendelson and Tunca's (2007) strategic price impact explanation and the strategic threats under trigger strategies in a repeated game setting in Taylor and Plambeck (2007a, 2007b). Secondly, it is shown that when DPI exists, *ex ante* commitment to futures market trading allows the equilibrium contract to be independent of the expected downstream market demand and upstream unit production cost. The implication of this independence result is that prior commitment to futures trading helps mitigate double marginalization. Thirdly, with a given DPI level, a higher futures price leads to a higher trading quantity at a heightened wholesale price in the bilateral channel, leading to a lower (higher) expected profit for the manufacturer (supplier) with a lower (higher) variance. This highlights that the futures price can serve as an indicator for supply chain managers to predict the change of bilateral contracting relations and the corresponding performance outcomes. This result is consistent with the price-to-be-fixed contracting practice in coffee supply chains where the contracted price is the futures price plus a quality adjustment (Bargawi and Newman, 2017; Starbucks, 2010) and Adcock's (2006) appeal for (upstream) producers and (downstream) consumers to adopt the (LME) futures price as a benchmark for their (bilateral) price negotiations. Fourthly, for a given futures price, an increased DPI level strengthens the bilateral relation with a higher proportion of final product from the bilateral channel at an elevated wholesale price, and the result yields a win-win performance scenario, in which both the supplier and the manufacturer achieve a higher expected profit with different risk implications. This result furnishes a plausible way to understand the asymmetric reliance on relationship-based collaborations and different motivations for these collaborations observed in the B2B relationship management literature (Collins and Burt, 1999; Allen, 2001; Hingley, 2005; Nyaga et al., 2010).

The remainder of this paper is organized as follows. We briefly review related literature in Section 2. Section 3 presents a three-stage game model to describe our supply chain setting. The corresponding subgame perfect equilibrium is derived in Section 4. Section 5 reports how the futures price and DPI affect supply chain operations and the corresponding implications on profitability and the associated risk. Concluding remarks are summarized in Section 6. All mathematical proofs are provided in

Appendix A.

2. LITERATURE REVIEW

Motivated by the electronic marketplace TradingHubs.com, Lee and Whang (2002) triggers an interest to study how competitive market trading complements bilateral contract transactions in supply chains. A central question is why supply chain members still transact by bilateral contracts given that more efficient markets are available to buy or sell intermediate products. Dong and Liu (2007) view a bilateral contract as a forward contract between a supplier and a manufacturer in a supply chain and establish that the risk-hedging benefit justifies the prevalent existence of bilateral contracting within supply chains in the presence of open market trading. Mendelson and Tunca (2007) demonstrate that spot market trading improves supply chain channel profit and consumer surplus. However, due to the strategic impact on the equilibrium price of the spot market, it does not eliminate bilateral fixed-price contracting even if these contracts are signed under inferior information.

Another line of research adopts the concept of the so-called relational contract to understand long-term collaborations among supply chain members. Tunca and Zenios (2006) model an e-market clearing mechanism between multiple suppliers and a set of manufacturers as a price-based auction and reveals conditions for these two venues to coexist and conditions under which one is preferred to the other. The authors point out that the auction-based market trading does not necessarily increase supply chain channel profit or consumer surplus. Without considering market trading, Taylor and Plambeck (2007a) provide two types of simple relational contracts (i.e. price-only and price-and-quantity contracts) and compare their optimal performance from the buyer’s perspective.

From the viewpoint of a supply chain system, Taylor and Plambeck (2007b) derive a general optimal relational contract that specifies a lump-sum transfer and a quantity-contingent payment from the buyer to the seller, a demand-dependent order, and the seller's capacity investment. They show with two simpler versions of relational contracts (i.e. no-monitoring and capacity- inspection contracts) that both contracts perform well for a broad range of parameters.

A different body of literature explores some "physical" aspects of bilateral contracting relations in supply chains. Cohen and Agrawal (1999) study a buyer's trade-off between short-term (spot trading) and long-term contracts, where the latter possesses productivity improvement opportunities. The contracting market model of Levi et al. (2003) indicates that low relationship-specific investment leads to extensive use of contract trading. Both Cohen and Agrawal (1999) and Levi et al. (2003) recognize that long-term contracting requires some specific investment, which in turn leads to operational cost savings at one or more firms in a supply chain. This cost saving may take different forms such as rekeying cost and clerical expenses under EDI (Dearing, 1990), monitoring costs due to a reduction of opportunistic behavior by reducing the investor's bargaining power (Ulrich and Barney, 1984), and maintenance and smoothing costs (Levi et al., 2003). Cost savings via bilateral contracting can be interpreted as increased production efficiency or productivity.

Our paper has the following major differences from the aforementioned literature. Firstly, our model is different from the problem considered by Cohen and Agrawal (1999) as their research is essentially an optimization model from the buyer's perspective. Secondly, our exposition differs from that reported by Levi et al. (2003) as they investigate how the contracting market equilibrium is reached with competitive contract offers. Thirdly, our main concern here is how supply chain operations are affected by potential productivity improvement resulted from bilateral contracting instead of strategic threats under trigger strategies (Taylor and Plambeck, 2007a; 2007b). Fourthly, Dong and Liu (2007) reveal the risk hedging motivation of bilateral contracting. We focus on the strategic role of futures market trading in the bilateral contract negotiation. Finally, but more importantly, the endogenously determined spot price in equilibrium in Mendelson and Tunca (2007) validates the price impact of strategic spot market trading on fixed-price contracting and a high enough level of the price impact leads to a positive contract transaction. In contrast, the model here assumes that supply chain members are engaged in futures trading and the quantities herein do not have any (futures) price impact on bilateral contract negotiation. This makes downstream productivity improvement (DPI) a potential factor for explaining a positive contracting transaction

3. THE MODEL

Consider a two-echelon supply chain consisting of an upstream supplier and a downstream manufacturer. The two members use a wholesale price contract to trade an intermediate product. The manufacturer may also purchase the intermediate product from the futures market, and the supplier may also sell her intermediate product via the futures market. The manufacturer uses the intermediate product to produce his final product with an uncertain market demand. The market price of the manufacturer's final product, defined as *p*, is characterized by an inverse demand function

$$p = a + \varepsilon - bQ_m \tag{1}$$

where $\varepsilon \sim N(0, \sigma_\varepsilon^2)$ representing market uncertainty, and Q_m is the total output quantity of the manufacturer's final product demanded in the final market.

Since the manufacturer procures the intermediate product from two different channels, i.e., the bilateral contract with the supplier and the futures market. We use q_s to denote the manufacturer's procurement quantity from the supplier and q_{mf} to represent the manufacturer's procurement quantity from the future market, respectively. Additionally, we assume that bilateral contracting facilitates downstream productivity improvement (DPI). Therefore, the total output quantity of the manufacturer's final product, Q_m, can be described as

$$Q_m = kq_s + q_{mf} \tag{2}$$

where $k \geq 1$ measures the manufacturer's relative productivity improvement for the procured intermediate products from the bilateral contracting channel compared to those obtained from the futures market. When $k = 1$, bilateral contracting does not have any productivity enhancement for the manufacturer and a higher k indicates a higher improvement level. The productivity improvement in bilateral contracting is usually attributed to long-term relationship-specific investment that has been made through repeated transactions in the past and is often assumed sunk. For instance, Cohen and Agrawal (1999) and Levi et al. (2003) treat this cost saving as an exogenous and, thus, sunk, prior to contract negotiation.

Dong and Liu (2007) have identified the risk-hedging benefits for bilateral contracts against the volatile spot market. In this paper, we aim to show that DPI alone induces bilateral contracts. To exclude spot price risks, we assume that the supplier (manufacturer) obtains a fixed unit revenue (cost), i.e., $F(< a)$ in the futures market channel. Note that in our model, we assume that the supplier sells and the manufacturer buys at the same futures price. In reality, the manufacturer and the supplier may trade in the futures market at different physical time points and, thus, at different futures prices. To cope with this, without loss of generality, we assume that the supplier sells at $F + \Delta F$ while the manufacturer buys at F, where ΔF can be positive or negative. Under this alternative assumption, we can still prove that the game has a unique subgame perfect equilibrium and derive it in a closed form. Furthermore, we can show that there exists a threshold, $\overline{\Delta F}$, such that for all $\Delta F \in (-\overline{\Delta F}, \overline{\Delta F})$, all the managerial implications (in Section 5) still hold. For more details, please refer to Appendix B.

Let w be the unit wholesale price charged by the supplier to the manufacturer for the intermediate product. Thus, the manufacturer's profit function can be written as

$$\pi_m = [a + \varepsilon - b(kq_s + q_{mf})](kq_s + q_{mf}) - wq_s - Fq_{mf}$$

As in Dong and Liu (2007), we assume that both the supplier and the manufacturer are risk-averse and have mean-variance preference over their risky profits. Risk-averse decision-makers are empirically observed in the literature (e.g. Cramer et al., 2002; Willebrands et al., 2012; Cucculelli and Ermini, 2013), and, as suggested by Kirkwood's (2004) simulation results, an exponential utility function is an appropriate choice to represent risk-averse decision-makers' preferences. In theory, a mean-variance preference can be justified by the certainty equivalence of the expected utility with an exponential utility function and a normally distributed uncertainty (Mascell et al. 1995). Therefore, we use certainty equivalence as the objective functions for both the manufacturer and the supplier. More specifically, we below assume both firms have exponential utility functions with Arrow-Pratt absolute risk measures of ρ_s and ρ_m (where subscripts "s" and "m" represent the supplier and the manufacturer, respectively) and the uncertainties of the manufacturer's demand and the supplier's cost follow normal distributions.

With the normality assumption of ε, the exponential utility function and a large enough a (for instance, $a > 3\sigma_\varepsilon$, such that p and π_m are negative with negligible probabilities), the manufacturer's certainty equivalence is expressed as

$$CV_m = E\pi_m - \frac{1}{2}\rho_m \operatorname{var}\pi_m = [a - b(kq_s + q_{mf})](kq_s + q_{mf}) - wq_s - Fq_{mf} - \frac{1}{2}\rho_m \sigma_\varepsilon^2 (kq_s + q_{mf})^2 \quad (3)$$

Assume that the supplier has a sufficiently large capacity and her unit production cost c is stochastic and $c \sim N(c_0, \sigma_c^2)$ where $0 < c_0 < F$ and σ_c^2 is sufficiently small relative to $F - c_0$ (for example, $3\sigma_c < F - c_0$). The assumption of random unit cost for the supplier reflects the uncertainty in her procurement process of raw materials. The supplier can sell her intermediate product to the manufacturer directly or to the futures market. Hence, the supplier's profit function is

$$\pi_s = wq_s + Fq_{sf} - c(q_s + q_{sf})$$

where q_s and q_{sf} are the quantities that the supplier sells to the manufacturer at the unit wholesale price w and to the futures market at unit price F, respectively.

The corresponding certainty equivalence is

$$CV_s = E\pi_s - \frac{1}{2}\rho_s \operatorname{var}\pi_s = wq_s + Fq_{sf} - c_0(q_s + q_{sf}) - \frac{1}{2}\rho_s \sigma_c^2 (q_s + q_{sf})^2 \quad (4)$$

In our model, the decision sequence is as follows. In stage 0, based on an observed futures price F, the manufacturer and the supplier choose q_{mf} and q_{sf} simultaneously. Then the supplier decides w in stage 1. In stage 2, the manufacturer determines q_s as per the wholesale price w selected by the supplier. Finally, the supplier's unit cost c is realized, the supplier produces $q_s + q_{sf}$, and the manufacturer receives $q_s + q_{mf}$ from the supplier and the futures market. The final market uncertainty ε is realized and the manufacturer sells his full production $kq_s + q_{mf}$ in the final market at the market-clearing price according to the inverse demand function (1).

The futures market makes it possible for the supplier and the manufacturer to engage in market trading prior to negotiating their bilateral contract. The decision sequence that q_{mf} and q_{sf} are chosen prior to determining w and q_s in the bilateral contract allows us to examine the impact of futures commitments on bilateral contract relations and supply chain operations.

Finally, all mathematical notations are listed in Table 1.

Table 1 Summary of Notations

Symbol	Description
ρ_s, ρ_m	The supplier's and the manufacturer's Arrow-Pratt absolute risk measure
ε	The normally distributed random shock of the final market demand with an expected value of zero
σ_ε^2	The variance of the random shock of the final market demand
a, b	The market size and the slope of the (expected) final market demand
p, Q_m	The market-clearing price and the total output quantity of the manufacturer's product in the final market
c	The normally distributed random unit cost of the supplier
c_0, σ_c^2	The expected value and variance of the supplier's random unit cost
k	The parameter indicating the downstream productivity improvement (DPI)
q_s	The quantity of intermediate products transacted between the supplier and the manufacturer
w	The supplier's unit wholesale price for the intermediate product sold to the manufacturer
q_{sf}, q_{mf}	The supplier's and the manufacturer's respective quantity traded in the futures market
F	The futures price for the intermediate product
π_s, π_m	The supplier's and the manufacturer's profit
CV_s, CV_m	The supplier's and the manufacturer's certainty equivalence

4. THE EQUILIBRIUM

As specified in the sequence of events in Section 3, our model is a three-stage game including stages 0, 1, and 2. Following backward induction, we solve the last stage first. In stage 2, the manufacturer chooses q_s to maximize CV_m given in (3). Since it is straightforward to show CV_m is concave in q_s, the first-order condition immediately implies that the manufacturer's optimal response (in terms of an optimal order quantity) can be characterized in Lemma 1. For notational convenience, let $B \overset{\text{def}}{=} 2b + \rho_m \sigma_\varepsilon^2$.

Lemma 1: *In stage 2, given* q_{mf}, q_{sf}, *and* w, *the manufacturer's optimal order quantity from the supplier is*

$$q_s(w) = \frac{1}{k}\left(\frac{a - w/k}{B} - q_{mf}\right) \tag{5}$$

In stage 1, the supplier determines w to maximize CV_s in (4). Substituting (5) into (4), one can easily rewrite CV_s and confirm its concavity in w. Thus, the first-order condition of the supplier's maximization problem directly implies that the supplier's optimal response (in terms of an optimal wholesale price) can be given in Lemma 2. For notational convenience, let $A \overset{\text{def}}{=} \rho_s \sigma_c^2$.

Lemma 2: *In stage 1, given* q_{mf} *and* q_{sf}, *anticipating the manufacturer's optimal response (5), the supplier's optimal wholesale price is*

$$w = \frac{\left(k + \frac{A}{kB}\right)a - \left(kB + \frac{A}{k}\right)q_{mf} + c_0 + Aq_{sf}}{2 + \frac{A}{k^2 B}} \tag{6}$$

Lemma 2 indicates that the wholesale price decreases in q_{mf} but increases in q_{sf}. That is, if the manufacturer strategically purchases more of the intermediate product from the futures market, the supplier has to lower her unit wholesale price charged to the manufacturer, benefiting the manufacturer; on the other hand, if the supplier strategically sells more in the futures market, the supplier can charge a higher unit wholesale price in the bilateral channel, resulting in a benefit for the supplier. Therefore, both the manufacturer and the supplier have incentives to trade in the futures market prior to their contract negotiation, and their commitments to a higher quantity in the futures market trading will enhance their respective positions in the wholesale price contract negotiation.

Now, we turn to stage 0 of our model, in which the manufacturer and the supplier play a simultaneous-move game by selecting q_{mf} and q_{sf}, respectively. With (5) and (6), the manufacturer's and the supplier's certainty equivalence can be rewritten as $CV_m(q_{mf}, q_s(w(q_{mf}, q_{sf})), w(q_{mf}, q_{sf}))$ and $CV_s(q_{sf}, q_s(w(q_{mf}, q_{sf})), w(q_{mf}, q_{sf}))$, respectively. One can directly verify that CV_m is concave in q_{mf} and CV_s is concave in q_{sf}. Then it is sufficient to use the first-order conditions to characterize the stage-0 interaction.

The first-order condition for the manufacturer is

$$\begin{aligned}
\frac{\mathrm{d}CV_m}{\mathrm{d}q_{mf}} &= \left(\frac{\partial CV_m}{\partial q_s}\frac{\partial q_s}{\partial w} + \frac{\partial CV_m}{\partial w}\right)\frac{\partial w}{\partial q_{mf}} + \frac{\partial CV_m}{\partial q_{mf}} \\
&= \left[\frac{w(q_{mf}, q_{sf})}{k} - q_s(w(q_{mf}, q_{sf}))\frac{\partial w}{\partial q_{mf}}\right] - F \qquad (7) \\
&= \frac{(k^2B + A)(3k^2B + A)a - B(k^2B + A)(3k^2B + A)q_{mf} + k^3B^2c_0 + k^3B^2Aq_{sf}}{(2k^2B + A)^2} - F \qquad (8) \\
&= 0
\end{aligned}$$

where the second equality holds since the manufacturer's first-order condition $\partial CV_m / \partial q_s = 0$ holds (or equivalently (5) holds).

In (7), F is the manufacturer's cost of buying an extra unit of the intermediate product in the futures market while the bracketed terms represent a cost saving in the purchase in the bilateral channel. Thus the manufacturer's optimal decision of his futures market trading quantity is determined by a trade-off between these two terms. By solving the manufacturer's first-order condition, we obtain Lemma 3.

Lemma 3: *Anticipating the optimal responses (5) and (6), for any* q_{sf} *chosen by the supplier, the manufacturer's optimal order quantity from the futures market in stage 0 is*

$$q_{mf} = \frac{k^3 BAq_{sf}}{(k^2B+A)(3k^2B+A)} + \frac{a}{B} + \frac{k^3 Bc_0}{(k^2B+A)(3k^2B+A)} - \frac{(2k^2B+A)^2 F}{B(k^2B+A)(3k^2B+A)} \quad . \tag{9}$$

Lemma 3 directly implies that q_{mf} decreases in *F*. Intuitively, when the price of the intermediate product in the futures market (*F*) increases, the manufacturer tends to order less from the futures market.

Similarly, the supplier's first-order condition in stage 0 is

$$\frac{\mathrm{d}CV_s}{\mathrm{d}q_{sf}} = F - \left[c_0 + A(q_s(w(q_{mf}, q_{sf})) + q_{sf})\right] \tag{10}$$

$$= F - \frac{2k^2Bc_0 + kAa - kBAq_{mf} + 2k^2BAq_{sf}}{2k^2B+A} \tag{11}$$

$$= 0$$

In (10), F is the supplier's revenue of selling an extra unit of the intermediate product in the futures market while the bracketed terms represent the supplier's increased cost of producing the extra unit. Thus, the supplier's optimal sales quantity to the futures market is induced by a trade-off between her marginal revenue and marginal cost of producing an extra unit. Based on the supplier's first-order condition, we reach Lemma 4.

Lemma 4: *Anticipating the optimal responses (5) and (6), for any* q_{mf} *chosen by the manufacturer, the supplier's optimal quantity sold to the futures market in stage 0 is*

$$q_{sf} = \frac{q_{mf}}{2k} - \frac{a}{2kB} - \frac{c_0}{A} + \frac{(2k^2B+A)F}{2k^2BA} \tag{12}$$

Lemma 4 indicates that q_{sf} increases in *F*. Intuitively, when the price of the intermediate product in the futures market (*F*) increases, the supplier would like to sell more to the futures market.

Here, we focus on the case in which $q_{mf} \geq 0$ and $q_{sf} \geq 0$ in equilibrium so that the supplier only sells her intermediate product to the futures market but never purchases from it and the manufacturer only procures his input from the futures market but never sells to it. These conditions imply that the supplier and the manufacturer are "real" business entities (or commercial traders) that produce and deliver physical goods and do not participate as arbitrageurs in the futures market.

With Lemmas 1-4, we are now ready to present the subgame perfect equilibrium by solving (9) and (12) for non-negative q_{mf}^* and q_{sf}^*, which are subsequently plugged into (5) and (6) to solve for w^* and q_s^*. These results are summarized in Proposition 1.

Proposition 1: *Keeping other parameters constant, there exist thresholds $B^\#$ and $a^\#(B)$ for each $B(\geq B^\#)$ such that if $B \geq B^\#$ and $a \geq a^\#(B)$, our three-stage game has a unique subgame perfect equilibrium as follows:*

$$q_{mf}^* = \frac{a-F}{B} + \frac{k(1-k)F}{3k^2B+2A}, \quad q_{sf}^* = \frac{F-c_0}{A} - \frac{(k-1)(2k^2B+A)F}{k^2B(3k^2B+2A)}$$

$$w^* = \frac{\left[k^2B(1+2k)+A(1+k)\right]F}{3k^2B+2A}, \quad q_s^* = \frac{(k-1)(2k^2B+A)F}{k^2B(3k^2B+2A)},$$

where all these decisions in equilibrium are non-negative.

The threshold conditions in Proposition 1 simply ensure that neither the supplier nor the manufacturer is a hedger or a speculator who just uses the futures market trading as a financial instrument, instead, they are commercial traders who settle the futures contract with actual delivery. With the definition of $B \overset{\text{def}}{=} 2b + \rho_m \sigma_\varepsilon^2$, the condition $B \geq B^\#$ represents a non-trivial operational scenario where the final market demand is inelastic enough, the manufacturer is risk-averse enough, or the final market is risky enough. The condition $a \geq a^\#(B)$ simply means that the expected market size is large enough. For the remainder of this paper, we assume that these two conditions are satisfied.

Proposition 1 indicates that the wholesale price (w^*) and the supplier's selling quantity to the manufacturer (q_s^*) in equilibrium are independent of the manufacturer's expected market demand (a) and the supplier's expected unit production cost (c_0). However, if there does not exist the futures market trading channel for the intermediate product, it is straightforward to show that the equilibrium wholesale price increases in both a and c_0, whereas the equilibrium trading quantity between the manufacturer and the supplier increases in a but decreases in c_0. When the futures market trading channel exists, based on an observed futures price, the *ex ante* (stage-0) committed trading in the futures market eliminates the impact of the expected downstream market demand and upstream production cost on the *ex post* (stage-1 and stage-2) bilateral contract relation between the manufacturer and the supplier.

This independence result can be explained by examining the manufacturer's and the supplier's behavioral motivations in a more detailed fashion. For an increase of Δa in a, as both the manufacturer's and the supplier's reaction curves shift upwards to the same degree ($\Delta a / B$), the manufacturer's purchase in the futures market increases by $\Delta q_{mf} = \Delta a / B$ with a constant supplier's sales to the futures market. These *ex ante* strategic commitments to the futures market trading of the manufacturer and the supplier lead to an unchanged *ex post* bilateral transaction between them. When the expected final market demand increases by Δa and the manufacturer increases its futures market purchase by $\Delta q_{mf} = \Delta a / B$, the manufacturer's order quantity from the supplier remains the same for any wholesale price w ($\Delta q_s(w) / \Delta a = 0$ from (5)). This further eliminates the supplier's motivation to raise the wholesale price ($\Delta w / \Delta a = 0$ from (6)). Thus, the trading quantity and wholesale price in the bilateral channel are independent of a. Given this unchanged bilateral contract transaction, the supplier's marginal cost of producing an extra unit for selling in the futures market will not be affected by a. Thus, the supplier has no incentive to change her futures market sales, resulting in no impact on the contract negotiation (cf. (6)). In a similar way, one can explain why the equilibrium wholesale price contract is independent of the supplier's expected cost (c_0). A higher c_0 reduces the supplier's *ex ante* commitment to futures market trading quantity and this lower futures market sales buffers the supplier's *ex post* motivation to raise the wholesale price (cf. (6)) in the bilateral contract negotiation stage, leading to a constant wholesale price. The unchanged wholesale price subsequently leaves the supplier with the same sales quantity in the bilateral channel.

The independence result suggests that *ex ante* commitments to futures market trading of supply chain members automatically suppress their opportunistic tendency to modify the *ex post* wholesale contract relative to any change in the supplier's expected production cost and/or the manufacturer's expected final market demand. Note that each of these two factors influences the supplier's wholesale price marginalization in a standard wholesale price contract setting. In contrast, in our current model setting, the price marginalization is immune to any change in the supplier's expected production cost and/or the manufacturer's expected final market demand. Thus, the independence result indicates that prior commitments to futures trading help mitigate double marginalization between the two supply chain members.

Furthermore, one can verify that $w^* \in (F, kF)$ for all $k > 1$. The inherent rationale is that both parties' *ex ante* commitment to futures market trading results in an equilibrium wholesale price that allows both parties to trade via the bilateral channel: $w^* > F$ implies that the supplier is willing to sell to the manufacturer and $w^* < kF$ gives the manufacturer a motivation to buy from the supplier. Together with the mitigation of double marginalization, the use of the bilateral channel with higher productivity shall presumably lead to a higher operational efficiency for the supply chain. The allocation of such efficiency gains depends on the futures price (*F*) and the level of productivity improvement (*k*).

Corollary 1: *If* $k=1$ *, the subgame perfect equilibrium reduces to* $q_{mf}^{*}=(a-F)/B$ *,* $q_{sf}^{*}=(F-c_0)/A$ *,* $w^{*}=F$ *and* $q_s^{*}=0$.

Corollary 1 shows that the futures market trading channel for the intermediate product completely overrides bilateral channel if $k=1$. In this case, the equilibrium trading quantity in the bilateral channel (q_s^{*}) becomes zero. Recall that $k=1$ means that there is no relative DPI for the manufacturer based on his bilateral interactions with the supplier. Therefore, Proposition 1 and Corollary 1 jointly indicate that the existence of DPI, i.e., $k > 1$, is a necessary and sufficient condition for the bilateral contracting to arise as a viable channel in the supply chain and DPI can be viewed as an effective indicator for explaining when a positive bilateral transaction arises in the presence of dual channels in the supply chain.

5. MANAGERIAL IMPLICATIONS

In this section, we derive managerial insights based on comparative statics with regard to the futures price and DPI in a one-at-a-time manner. When there is no DPI in the bilateral channel (i.e., $k=1$), the supplier and the manufacturer would stop using the bilateral channel to trade the intermediate product in equilibrium (i.e., $q_s^{*}=0$) and the comparative statics in this case becomes trivial. Therefore, we will focus on the interesting case $k>1$ in this section.

5.1 Impact of the Futures Price

We first consider the impact of the futures price on supply chain operations in equilibrium.

Proposition 2: *If the futures price (F) increases, then for all $k > 1$, the equilibrium wholesale price (w^*) and the equilibrium quantity (q_{sf}^*) that the supplier sells to the futures market increase, but the equilibrium quantity (q_s^*) that the supplier sells to the manufacturer and the equilibrium quantity (q_{mf}^*) that the manufacturer purchases from the futures market decrease.*

Proposition 2 is generally consistent with our conventional wisdom. That is, when the futures price (F) of the intermediate product increases, the supplier would like to sell more to the futures market (i.e., q_{sf}^* increases), and the manufacturer tends to purchase less from the futures market (i.e., q_{mf}^* decreases). Facing a higher unit revenue (F) from the futures market, the supplier has stronger motivation to raise her wholesale price (w^*) charged to the manufacturer, which induces the manufacturer to order less from the supplier (i.e., q_s^* decreases). Our result is aligned with the price-to-be-fixed contract used in transacting coffee of bulk grades between international traders and Tanzanian exporters. The contracted price in this bilateral channel equals to the futures price of the coffee at a particular point in time, plus or minus an agreed differential for quality difference (Bargawi and Newman, 2017). Moreover, a trader in this coffee supply chain, interviewed by Bargawi and Newman, acknowledged that "the futures price is the determinant all along the chain." Similar price-to-be-fixed contract is also adopted by Starbucks (Starbucks 2010). Underpinned by the practices in coffee supply chains, Proposition 2 provides a theoretical support for Adcock's (2006) appeal that the futures prices in the London Metal Exchange (LME) is ready to be used as benchmarks for both (upstream) producers and (downstream) consumers in their bilateral contract negotiations.

The next proposition illustrates the impact of the futures price on the equilibrium performance of the supply chain members whose expected profits and variances are as follows:

$$E\pi_m^* = [a - b(kq_s^* + q_{mf}^*)](kq_s^* + q_{mf}^*) - w^* q_s^* - Fq_{mf}^*\,, \quad \operatorname{var}\pi_m^* = \sigma_\varepsilon^2 (kq_s^* + q_{mf}^*)^2$$

$$E\pi_s^* = w^* q_s^* + Fq_{sf}^* - c_0(q_s^* + q_{sf}^*)\,, \quad \operatorname{var}\pi_s^* = \sigma_c^2 (q_s^* + q_{sf}^*)^2\,.$$

Proposition 3: *If the futures price (F) increases, then for all $k > 1$, the manufacturer's expected profit ($E\pi_m^*$) and the corresponding variance ($\operatorname{var}\pi_m^*$) of his profit in equilibrium decrease, but for the supplier, her expected profit ($E\pi_s^*$) and the variance ($\operatorname{var}\pi_s^*$) of her profit in equilibrium increase.*

Proposition 3 shows that an increase in the futures price leads to a decrease in the manufacturer's expected profit and risk (as captured by the variance), but it increases the supplier's expected profit and risk. Intuitively, when the futures price increases, the manufacturer's opportunity cost (buying in the futures market) increases, so the supplier would take advantage of this chance to charge the manufacturer a higher wholesale price. Therefore, an increased futures price drives the manufacturer's procurement costs higher in both channels, thereby reducing his order quantities in the two channels. Thus, the manufacturer would have a lower profit and a lower risk. In contrast, an increase in the futures price leads to higher marginal revenues for the supplier in both channels which stimulates the supplier to expand her production, resulting in a higher profit with a higher risk. This suggests that in terms of expected profits, a change in the futures price does not induce a win-win situation for both supply chain members. Such asymmetric impacts on supply chain members' profitability shed some light on supply chain relationship management: although the competitive futures market trading helps improve supply chain efficiency, it also brings possibilities for one supply chain member to take advantage of the other in negotiating the bilateral contract. A practical response to this issue is that about 2/3 of US companies have implicit contracts for prices or implicit understanding with their customers to guard against such opportunistic behaviors in the presence of volatile prices (Grey et al., 2005).

5.2 Impact of Downstream Productivity Improvement

Now, we consider the impact of DPI on supply chain operations. For ease of discussion, we define, $Q_m^* = kq_s^* + q_{mf}^*$ and $Q_s^* = q_s^* + q_{sf}^*$ to represent the total equilibrium output volume of the manufacturer and the supplier, respectively. Then we have the following proposition.

Proposition 4: *If DPI (k) increases, then (i) the equilibrium quantity (q_{mf}^*) that the manufacturer purchases from the futures market decreases; (ii) the equilibrium wholesale price (w^*) increases; (iii) the manufacturer's equilibrium total output volume (Q_m^*) increases, and (iv) the supplier's equilibrium total output volume (Q_s^*) remains unchanged.*

Proposition 4 indicates that when the manufacturer enjoys a higher DPI from the bilateral channel, he becomes less dependent on the futures market, so he has a tendency to purchase less from the futures market. When the manufacturer becomes more dependent on the bilateral channel, the supplier can use it as a leverage to charge a higher wholesale price for each unit sold to the manufacturer. Due to the higher productivity improvement from the bilateral channel, the manufacturer's total output volume is expected to increase. However, the supplier would keep her total output volume unchanged. Such asymmetric reliance of supply chain members on relationship-based productivity improvements are empirically observed in the B2B relationship management literature (Hingley, 2005; Nyaga et al., 2010). When the manufacturer shifts more of his production of the final product from the futures market to the bilateral channel, it makes his demand for the intermediate product from the bilateral channel less elastic: for any change in the wholesale price set by the supplier, the change in the manufacturer's order quantity becomes smaller. This reduced elasticity then enables the supplier to benefit from a higher wholesale price rather than from production expansion. Therefore, it is best for the supplier to charge a higher wholesale price but keep her total production volume unchanged.

Proposition 5 below summarizes how the performances of the manufacturer and the supplier respond to a change in DPI.

Proposition 5: *If DPI (k) increases, then the manufacturer's expected profit ($E\pi_m^*$) and the corresponding variance (* $\mathrm{var}\,\pi_m^*$ *) of his profit in equilibrium increase, but for the supplier, her equilibrium expected profit (* $E\pi_s^*$ *) increases with a constant variance (* $\mathrm{var}\,\pi_s^*$ *).*

Proposition 5 demonstrates that the asymmetric reliance of the manufacturer and the supplier on the bilateral channel leads to different "wins" for them when DPI increases (i.e., k increases). As expected, both the manufacturer and the supplier achieve higher expected profits. However, the changes in the risks of their profits are quite different. As the bilateral-channel productivity improvement increases, the more powerful player, the supplier (the first mover in the bilateral contract negotiation), does not bear any additional risk, but the less powerful player, the manufacturer (the second mover), bears a higher risk. The reason is intuitive. The supplier can take the advantage of the less elastic demand from the bilateral channel to charge a higher wholesale price while keep her total output volume unchanged and, thus, she can avoid any additional risk. However, in response to the higher DPI in the bilateral channel, the manufacturer needs to procure less from the futures market and expand his total output volume and, thus, bears more risk facing uncertain final market demand. Our result is consistent with the imbalanced power structure explanation for the inequity in B2B relationship-based collaborations furnished by Collins and Burt (1999), Allen (2001), and Hingley (2005). In particular, Collins and Burt (1999) and Allen (2001) demonstrate that the more or less powerful members in food supply chains bear different levels of risks.

6. CONCLUDING REMARKS

Based on the assumption that direct interactions through the simple wholesale price contract in the bilateral channel may improve productivity for supply chain partners, we consider a two-echelon supply chain with an upstream supplier and a downstream manufacturer both engaging in dual channel (i.e., the bilateral channel and the futures market) transactions. In this paper, we first build a three-stage game to analyze the strategic interactions between the supplier and the manufacturer, then we derive a unique subgame perfect equilibrium in closed-form for the game. Finally, we discuss managerial implications obtained from comparative statics analysis. Our major findings are summarized below.

The first finding establishes DPI as a necessary and sufficient condition to trigger and maintain the bilateral contracting relation between the two supply chain partners. This result furnishes an alternative productivity explanation for positive contract transactions on top of the strategic price impact of the spot market trading in Mendelson and Tunca (2007) and the strategic threats under trigger strategies in a repeated game setting in Taylor and Plambeck (2007a, 2007b).

The second finding reveals that the prior commitments to futures market trading allow the equilibrium trading quantity and wholesale price in the bilateral channel to be independent of the downstream market size and the upstream unit cost (Proposition 1). Compared to the case without the futures market, this result demonstrates that the futures market trading effectively buffers the impact of any change in the downstream market demand and upstream unit cost on the bilateral contracting relation. This independence result implies that prior commitments in the futures market help mitigate the double marginalization problem.

The third finding demonstrates that an increase in the futures price increases the supplier's expected profit and her associated risk, but it decreases the manufacturer's expected profit and his associated risk. Therefore, the observed futures price can work as a valid indicator for supply chain managers to forecast the change of bilateral contracting relations and corresponding performance outcomes.

The fourth finding indicates that an increase in DPI of the bilateral channel makes the manufacturer shift more of his procurement from the futures market to the bilateral channel. As a result, the manufacturer would have a higher expected profit together with a higher risk, while the supplier is able to seize a higher expected profit without incurring any additional risk.

There exist a few directions to extend this research. For instance, our model here essentially takes a static view towards futures market movement. Once a futures price F is observed, it remains constant during the wholesale price contract negotiation. It is worthwhile to introduce a dynamic framework to examine how futures price evolution affects supply chain operations, especially when the wholesale price contract is subject to renegotiation. Another direction is to incorporate information asymmetry regarding supply chain members' futures market trading activities.

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APPENDICES: PROOFS OF PROPOSITIONS AND A ROBUSTNESS CHECK

Appendix A: Proofs of propositions

Proof of Proposition 1.

We first calculate the stage-0 equilibrium. (9) can be rewritten as

$$q_{sf}=\frac{(k^2B+A)(3k^2B+A)q_{mf}}{k^3BA}-\frac{(k^2B+A)(3k^2B+A)a}{k^3B^2A}-\frac{c_0}{A}+\frac{(2k^2B+A)^2F}{k^3B^2A} \tag{A1}$$

Substituting (A1) into (12), we have

$$\begin{aligned}0&=\left(\frac{1}{2k}-\frac{(k^2B+A)(3k^2B+A)}{k^3BA}\right)q_{mf}+\left(\frac{-1}{2kB}+\frac{(k^2B+A)(3k^2B+A)}{k^3B^2A}\right)a\\&\quad+\left(\frac{2k^2B+A}{2k^2BA}-\frac{(2k^2B+A)^2}{k^3B^2A}\right)F\\&=\frac{(2k^2B+A)\left[(3k^2B+2A)a+(kB-4k^2B-2A)F-B(3k^2B+2A)q_{mf}\right]}{2k^3B^2A}\end{aligned}$$

Then we have

$$q_{mf}^*=\frac{a}{B}+\frac{(kB-4k^2B-2A)F}{B(3k^2B+2A)}=\frac{a}{B}+\left(\frac{k-k^2}{3k^2B+2A}-\frac{1}{B}\right)F=\frac{a-F}{B}+\frac{k(1-k)F}{3k^2B+2A}$$

Substituting q_{mf}^* into (12), (6) and (5), it is easy to verify the other equilibrium variables q_{sf}^*, w^* and q_s^*.

Second, we explore conditions to ensure q_{sf}^* and q_{mf}^* to be non-negative. Since q_{sf}^* given in Proposition 1 is continuous and strictly increases in B with $q_{sf}^*\to-\infty$ as $B\to0$ and $q_{sf}^*\to(F-c_0)/A>0$ as $B\to+\infty$, thus there exists a critical $B^{\#}$ such that $q_{sf}^*\geq0$ for all $B\geq B^{\#}$. Furthermore, since q_{mf}^* given in Proposition 1 is continuous and strictly increases in a, then $q_{mf}^*\geq0$ is equivalent to

$$a \geq \left[1 + \frac{k(k-1)B}{3k^2B + 2A}\right] F \equiv a^{\#}(B)$$

Finally, w^* and q_s^* are clearly non-negative. Proposition 1 is thus proved. □

Proof of Proposition 2.

For $k > 1$, we first calculate $\partial w^* / \partial F$, $\partial q_s^* / \partial F$ and $\partial q_{mf}^* / \partial F$ as follows:

$$\frac{\partial w^*}{\partial F} = \frac{k^2B(1+2k) + A(1+k)}{3k^2B + 2A} > \frac{k^2B(1+2) + A(1+1)}{3k^2B + 2A} = 1$$

$$\frac{\partial q_s^*}{\partial F} = \frac{(k-1)(2k^2B + A)}{k^2B(3k^2B + 2A)} > 0, \quad \frac{\partial q_{mf}^*}{\partial F} = \frac{-1}{B} + \frac{k(1-k)}{3k^2B + 2A} < 0$$

Note that $q_{sf}^* \geq 0$ and $c_0 > 0$ implies

$$\frac{F - c_0}{A} - \frac{k-1}{k^2} \frac{(2k^2B + A)F}{B(3k^2B + 2A)} \geq 0 \Rightarrow \frac{1}{A} - \frac{k-1}{k^2} \frac{(2k^2B + A)}{B(3k^2B + 2A)} > 0$$

We thus have

$$\frac{\partial q_{sf}^*}{\partial F} = \frac{1}{A} - \frac{k-1}{k^2} \frac{(2k^2B + A)}{B(3k^2B + 2A)} > 0. \square$$

Proof of Proposition 3.

For the first part, with the equilibrium variables given in Proposition 1, we have

$$\begin{aligned}
\frac{\partial E\pi_m}{\partial F} &= \left[a - 2b(kq_s^* + q_{mf}^*)\right] \frac{\partial (kq_s^* + q_{mf}^*)}{\partial F} - q_s^* \frac{\partial w^*}{\partial F} - w^* \frac{\partial q_s^*}{\partial F} - F \frac{\partial q_{mf}^*}{\partial F} - q_{mf}^* \\
&= \rho_m \sigma_\varepsilon^2 \frac{\partial (kq_s^* + q_{mf}^*)}{\partial F} + \frac{F}{B} \times \left(\frac{k-1}{k}\right)^2 \times \frac{3k^2B + A}{3k^2B + 2A} \times \frac{k^2B + A}{3k^2B + 2A} - \frac{a - F}{B} \\
&< \rho_m \sigma_\varepsilon^2 \frac{\partial (kq_s^* + q_{mf}^*)}{\partial F} + \frac{F}{B} \left[\left(\frac{k-1}{k}\right)^2 \times \frac{3k^2B + A}{3k^2B + 2A} \times \frac{k^2B + A}{3k^2B + 2A} - \frac{1}{3}\right] \\
&< \rho_m \sigma_\varepsilon^2 \frac{\partial (kq_s^* + q_{mf}^*)}{\partial F}
\end{aligned}$$

where the first inequality follows from $q_{mf}^* \geq 0$ when $k \to \infty$, the second inequality is derived from the fact that $(k-1)^2/k^2<1$ and $(3k^2B+A)(k^2B+A)/(3k^2B+2A)^2<1/3$.

Moreover, (5) implies

$$\frac{\partial(kq_s^*+q_{mf}^*)}{\partial F}=-\frac{1}{Bk}\frac{\partial w^*}{\partial F}<0 \tag{A2}$$

Therefore, we have $\partial E\pi_m/\partial F<0$. Further, with (A2) and $\operatorname{var}\pi_m=\sigma_\varepsilon^2(kq_s+q_{mf})^2$, it implies

$$\frac{\partial \operatorname{var}\pi_m}{\partial F}=2\sigma_\varepsilon^2(kq_s^*+q_{mf}^*)\frac{\partial(kq_s^*+q_{mf}^*)}{\partial F}<0$$

For the second part, $\partial E\pi_s/\partial F$ is calculated as

$$\begin{aligned}\frac{\partial E\pi_s}{\partial F}&=(F-c_0)\frac{\partial q_{sf}^*}{\partial F}+q_{sf}^*+(w^*-c_0)\frac{\partial q_s^*}{\partial F}+\frac{\partial w^*}{\partial F}q_s^*\\&=(F-c_0)\left(\frac{\partial q_{sf}^*}{\partial F}+\frac{\partial q_s^*}{\partial F}\right)+(w^*-F)\frac{\partial q_s^*}{\partial F}+q_{sf}^*+\frac{\partial w^*}{\partial F}q_s^*\\&=(F-c_0)\frac{1}{A}+(w^*-F)\frac{\partial q_s^*}{\partial F}+q_{sf}^*+\frac{\partial w^*}{\partial F}q_s^*>0\end{aligned}$$

where the inequality is due to $w^*>F>c_0$, $\partial q_s^*/\partial F>0$, and $\partial w^*/\partial F>0$.

Finally, we have

$$\frac{\partial \operatorname{var}\pi_s}{\partial F}=2\sigma_c^2(q_s^*+q_{sf}^*)\frac{\partial(q_s^*+q_{sf}^*)}{\partial F}=2\sigma_c^2(q_s^*+q_{sf}^*)\left(\frac{\partial q_{sf}^*}{\partial F}+\frac{\partial q_s^*}{\partial F}\right)=\frac{2\sigma_c^2(q_s^*+q_{sf}^*)}{A}>0.\square$$

Proof of Proposition 4.

Firstly, $\partial q_{mf}^*/\partial k$, $\partial w^*/\partial k$ and $\partial Q_m/\partial k$ are derived as

$$\frac{\partial q_{mf}^*}{\partial k}=\frac{\left[-3k^2B+2A(1-2k)\right]F}{(3k^2B+2A)^2}<0,\quad \frac{\partial w^*}{\partial k}=\frac{\left[6k^4B^2+kAB(9k-2)+2A^2\right]F}{(3k^2B+2A)^2}>0$$

$$\frac{\partial q_m}{\partial k}=\frac{\left[6k^4B^3+(2k^3+5k^2)AB^2+2A^2B\right]F}{\left[kB(3k^2B+2A)\right]^2}>0$$

Secondly, $\partial Q_s/\partial k=0$ follows from $Q_s=q_{sf}^*+q_s^*=(F-c_0)/A$ (see Proposition 1).

Thirdly, from Proposition 1, we have

$$\frac{\partial W_m}{\partial k}=\frac{\left(-3B^2k^4+2ABk^3-7ABk^2-2A^2\right)F}{\left[k(3k^2B+2A)\right]^2}$$

Let $g(k)=-3B^2k^4+2ABk^3-7ABk^2-2A^2$. Then we have $g(1)=-3B^2-5AB-2A^2<0$ and $g'(k)=-12B^2k^3+6ABk^2-14ABk$. Clearly, $g'(1)=-12B^2-8AB<0$. To show that $g'(k)<0$ for all $k>1$, we need only to show that $g'(k)=0$ has no real solution on $(1,+\infty)$. Assume that there exists a solution to $g'(k)=0$ on $(1,+\infty)$. We must have $A\geq 56B/3$. However, from Proposition 1, since $(k-1)/k^2<1/4$ and $(2k^2B+A)/(3k^2B+2A)<2/3$ for all $k>1$, then $q_{sf}^*\geq 0$ for all $k>1$ and $c_0>0$ implies $6B\geq A$. We thus have $56B/3\geq 28A/9>A$, leading to a contradiction.

Finally, (5) implies that

$$\frac{\partial Q_m}{\partial k}=\frac{\partial(kq_s^*+q_{mf}^*)}{\partial k}=-\frac{1}{B}\times\frac{\partial W_m}{\partial k}>0\,.\square$$

Proof of Proposition 5.

For the first part, with the equilibrium solution given in Proposition 1, we have

$$\begin{aligned}\frac{\partial E\pi_m}{\partial k}&=\left[a-2b(kq_s^*+q_{mf}^*)\right]\frac{\partial(kq_s^*+q_{mf}^*)}{\partial k}-q_s^*\frac{\partial w^*}{\partial k}-w^*\frac{\partial q_s^*}{\partial k}-F\frac{\partial q_{mf}^*}{\partial k}\\&=\left[\frac{w^*}{k}+\rho_m\sigma_\varepsilon^2(kq_s^*+q_{mf}^*)\right]\frac{\partial(kq_s^*+q_{mf}^*)}{\partial k}-q_s^*\frac{\partial w^*}{\partial k}-w^*\frac{\partial q_s^*}{\partial k}-F\frac{\partial q_{mf}^*}{\partial k}\\&=\rho_m\sigma_\varepsilon^2(kq_s^*+q_{mf}^*)\frac{\partial(kq_s^*+q_{mf}^*)}{\partial k}+\left(\frac{w^*}{k}-F\right)\frac{\partial q_{mf}^*}{\partial k}-kq_s^*\frac{\partial W_m}{\partial k}\end{aligned}\qquad\text{(A3)}$$

where the second equality is due to (5).

Then $\partial \operatorname{var}\pi_m/\partial k$ is computed as

$$\frac{\partial \operatorname{var}\pi_m}{\partial k}=2\rho_m\sigma_\varepsilon^2(kq_s^*+q_{mf}^*)\frac{\partial(kq_s^*+q_{mf}^*)}{\partial k}\qquad\text{(A4)}$$

Thus, $\partial W_m / \partial k < 0$ implies $\partial(kq_s^* + q_{mf}^*) / \partial k = \partial Q_m / \partial k > 0$ (see Proposition 4). By (A4), we have $\partial \operatorname{var} \pi_m / \partial k > 0$. Furthermore, the first and third terms in the last equality of (A3) are positive, and the second term is also positive, since for all $k > 1$, we have $\partial q_{mf}^* / \partial k < 0$ and

$$\frac{w^*}{k} - F = \frac{(1-k)(k^2B + A)F}{k(3k^2B + 2A)} < 0$$

For the second part, we can directly calculate $\partial E\pi_s / \partial k$ as

$$\frac{\partial E\pi_s}{\partial k} = w^* \frac{\partial q_s^*}{\partial k} + q_s^* \frac{\partial w^*}{\partial k} + F \frac{\partial q_{sf}^*}{\partial k} - c_0 \frac{\partial(q_s^* + q_{sf}^*)}{\partial k} = (w^* - F)\frac{\partial q_s^*}{\partial k} + q_s^* \frac{\partial w^*}{\partial k} \tag{A5}$$

where the last equality is derived from the fact that $\partial Q_s / \partial k = \partial(q_s^* + q_{sf}^*) / \partial k = 0$ (see Proposition 4).

Further,

$$\frac{\partial q_s^*}{\partial k} = \frac{kB\left[-6k^5B^2 + 12k^4B^2 - 5k^3AB + 12k^2AB - 2kA^2 + 4A^2\right]F}{\left[k^2B(3k^2B + 2A)\right]^2} \tag{A6}$$

Substituting (A6) and $\partial w^* / \partial k$ in Proposition 4 into (A5), we have

$$\frac{\partial E\pi_s}{\partial k} = \frac{2(k-1)(2k^2B + A))\left[6k^5B^3 + k^3(2k+5)AB^2 + 2kA^2B\right]F^2}{(k^2B)^2(3k^2B + 2A)^3} > 0$$

Finally, $\partial \operatorname{var} \pi_s / \partial k = 0$ follows from the fact that $\partial Q_s / \partial k = \partial(q_s^* + q_{sf}^*) / \partial k = 0$. □

Appendix B: The robustness of Propositions 1-5 to a setting of different futures prices

In this appendix, we show that the results obtained with the assumption that the manufacturer (the supplier) buys (sells) at a same futures price are robust to the setting with different futures prices. Assume that the supplier sells at $F + \Delta F$ with $\Delta F \in (-F, (k-1)F)$ while the manufacturer buys at F where $\Delta F > -F$ simply implies that the supplier sells at a positive futures price and $\Delta F < (k-1)F$ ensures the possibility for the supplier and the manufacturer to trade via the bilateral channel (It will be more profitable for the supplier to sell all of its product to the futures market if it observes a futures price larger than *kF*, which is the highest wholesale price that the manufacturer can accept). Under this assumption, we re-calculate all equilibrium variables as

$$q_{mf}^{'} = q_{mf}^{*} + \frac{k(2k^2B + A)\Delta F}{3k^2B + 2A},\ \ q_{sf}^{'} = q_{sf}^{*} + \frac{(k^2B + A)(2k^2B + A)(3k^2B + A)\Delta F}{k^2BA(3k^2B + 2A)}$$

$$w^{'} = w^{*} + \frac{(k^2B + A)(2k^2B + A)\Delta F}{3k^2B + 2A},\ \ q_{s}^{'} = q_{s}^{*} - \frac{(2k^2B + A)\Delta F}{k^2B(3k^2B + 2A)}$$

where "*" represents the "equilibrium" solutions in Proposition 1.

Clearly, these equilibrium solutions are continuous in ΔF. This in turn implies that the continuity of the equilibrium expected profits and their variances in ΔF. With this continuity, one can easily check that all the partial derivatives in the comparative statics analyses in Section 5 are continuous in ΔF. Thus, there must exist a neighborhood $(-\overline{\Delta F}, \overline{\Delta F})$ of $\Delta F = 0$ ($\overline{\Delta F} > 0$) such that for all $\Delta F \in (-\overline{\Delta F}, \overline{\Delta F})$, the signs of all our partial derivatives keep unchanged. Therefore, our results can be applied to situations where the futures-price differences are not too large (i.e. $\Delta F \in (-\overline{\Delta F}, \overline{\Delta F})$).