The Effects of Uncertainty and Contract Structure in Specialty Grain Markets

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The level of vertical integration in agricultural markets has seen considerable growth over the last decade. Authors have outlined many motivations for this phenomenon including supply-chain organization (Tsoulouhas and Vukina 1999), more discriminating consumers (Barkema 1993), more efficient relationships between buyers and sellers (Drabenstott 1993), information asymmetries (Hennessy 1996), quality control (Hueth and Ligon 1999; Hennessy and Lawrence 1999), procurement considerations specific to the dynamics of agricultural decision making (NASS 2003; Sexton and Zhang 1996), declining commodity prices (Fulton, Pritchett, and Pederson 2003), and the decoupling of farm support outlined in the 1996 farm bill (Coaldrake and Sonka 1993).

While a large proportion of grains and oilseeds are produced under marketing contracts in the United States (NASS 2003), production contracts have been relatively more prevalent in livestock (Goodhue 2000; Lawrence et al. 1997; Johnson and Foster 1994) and specialty grains markets (Ginder et al. 2000; Good, Bender, and Hill 2000; Fulton, Pritchett, and Pederson 2003; Sykuta and Parcell 2003). Specialty crop markets are generally smaller and more centralized than those for commodity crops. Risk management options for specialty grains are also imperfect as crop insurance, and futures and options markets are generally only available for commodity crops. These characteristics make production and procurement in spot markets riskier for farmers and processors, respectively. The risk associated with spot market production and procurement is one of the main reasons given for producers entering into specialty grain contracts in Indiana (Fulton, Pritchett, and Pederson 2003).

Moreover, specialty crops are associated with higher production costs than commodity crops. Higher costs are attributed to factors such as increased labor intensity, storage issues stemming from segregation and identity preservation requirements, and specific or additional input requirements and field operations (Fulton, Pritchett, and Pederson 2003; Ginder et al. 2000). Production of specialty crops may also require the use of specific assets (Lajili et al. 1997; Sporleder 1992), which may be associated with a higher level of equity financing relative to less specific assets (Williamson 1996). Thus, processors must properly structure contract terms to reflect the additional costs and risks associated with the production of specialty crops to induce farmer acceptance of production contracts.

While considerable attention has been given to the effects of contract structures in the livestock industry, less attention has been giving to production contracts for crop production. This paper presents a theoretical model of a monopsonistic processor who procures crop production under contract from a set of producers. The processor sets the structure and terms of the contract as well as the number of producers to whom the contract is offered to maximize expected profits subject to a capacity constraint and producers' decision rules. Risk-neutral producers who are offered the contract then decide to either accept the contract or produce a commodity crop for sale on the commodity market to maximize expected profits. Producer heterogeneity is introduced with respect to production costs for the specialty crop. While the situation is described as one where the processor contracts with producers to grow a specialty crop, the contracting relationship in the model could easily be generalized to other markets.

The contributions of this paper are two-fold. First, the model compares the equilibrium outcomes when contracts are based on acreage (acreage contracts) to when contracts are based on a specified production level (bushel contracts). Authors generally assume that acreage (bushel) contracts will be preferred by producers (processors), because they shift production risk from the producer (processor) to the processor (producer) (Sykuta and Parcell 2003; Lajili et al. 1997). However, the set of assumptions which define the market environment in this analysis lead to a different result. It is shown that under certain conditions, there exists a bushel contract that Pareto dominates the optimal acreage contract. Expected profits for both the processor and producers may be greater when the bushel contract structure is implemented rather than an acreage contract. However, that bushel contract may not be optimal in that it is not the processor's expected profit maximizing bushel contract.

Second, the model recognizes that the processor's total procurement in any period is the sum of random yield realizations on all contracted acres. The spatial correlation structure of yields will affect the processor's ability (or inability) to pool farm level production risk over a large number of contracted producers. This is expected to have an impact on the processor's preferred choice of contract structure (acreage vs. bushel contract). A numerical calibration to the model provides some insight into how the spatial correlation of producer yields may affect the processor's choice of contract type and terms. Equilibrium outcomes with respect to expected processor and producer profits are compared for a range of parameterizations, finding that the processor will, in general, be able to achieve greater expected profits using bushel contracts. Expected producer profits are also shown to be greater under bushel contracts in all scenarios analyzed.

The assumption of a capacity constraint, producer risk-neutrality, and the effects of an *ex post* spot market for the specialty crop under bushel contracts are the main drivers of this result. The relative advantage of bushel contracts to acreage contracts is shown to increase as the level of correlation between farm level yields is increased. Intuitively, as yield risk becomes increasingly systemic in nature, the processor's benefits of placing a larger share of production risk on the producers increase. This result confirms that the choice of contract structure will hinge heavily on the poolability of production risk for specialty crops.

The next two sections provide a brief review of the literature on production contracts in agriculture and a summary of recent survey results from specialty grains markets in the Midwest, respectively. Then the contracting model is presented followed by a section providing some analytical results. A numerical calibration to the theoretical model is then provided with results for a range of parameterizations. The final section concludes and discusses possible extensions to the model and directions for further research.

Literature Review

Considerable attention has been given to the effects of contract structure on the sharing of value and risk in agricultural markets. Goodhue (2000) used an agency theory approach to model production contracts in the broiler industry, finding that contracts outlining relative compensation schemes and strict input control by the processor were optimal responses to grower heterogeneity and risk aversion. Weleschuk and Kerr (1995) used a transactions cost approach to examine contracts for specialty crops in Canada, finding market power on the part of buyers led to reduced competition with respect to the compensation terms of contracts. Goodhue and Hoffman (2006) discuss the technical aspects of contracts, referred to as “boilerplate” in the contracting industry, that are often ignored in theoretical studies but play large roles in actual settings with regards to contract enforcement and liability issues.

Empirical approaches include those of Purcell and Hudson (2003) concerning vertical alliances in the beef industry, and Fraser’s (2005) examination of contracts in the Australian wine grape industry. Purcell and Hudson (2003) use a simulation model of cattle producers, cooperative feedlots, and beef packers to examine the effects of different compensation structures on risk sharing within a vertical beef alliance. Fraser (2005) applies regression analysis to actual contract data to identify the effects of grower and regional characteristics on contract structures. Fraser's results are consistent with Sykuta and Cook's (2001) assertion that producer characteristics have a limited effect in contract design, implying buyer characteristics will more often determine the specific contract terms.

Other authors have used experimental methods to elicit producer preferences for marketing contract attributes in both livestock (Roe, Sporleder, and Belleville 2004) and crop (Lajili et al. 1997) production. Lajili et al. (1997), using survey data, related the levels of asset specificity, production uncertainty, and producer risk aversion to the preferred levels of vertical integration with respect to the sharing of production risk and costs. Roe, Sporleder, and Belleville (2004) used an experimental survey design for marketing contracts in the hog industry, finding that producers strongly preferred contracts offered by cooperative firms, validating a hypothesis by Sykuta and Cook (2001) regarding institutional considerations in agricultural contracting. Wu and Roe (2007) is another example of an experimental approach which illustrates the importance of third-party contract enforcement in contractual relationships when there is buyer concentration (market power).

Considerable attention has also been paid to the interaction between and the co-existence of contract and spot markets in agriculture. Xia and Sexton (2004) present a model of cattle production where buyer concentration leads to reduced *ex post* spot market (price) competition when contract premiums are based on cash market prices. Zhang and Sexton (2000) use a spatial model with high transportation costs to show how processors can use exclusive contracts to create captive supplies to gain monopsony power and reduce price competition on the spot market. However, Carriquiry and Babcock's (2004) model of oligopsony in specialty grain markets shows that if the contract premium is based on a fixed cash market price there will be increased competition on the *ex post* spot market. The recent work by Wang and Jaenicke

(2006) uses a principal-agent framework within a market equilibrium model to show that the introduction of contract markets may cause spot prices and spot price volatility to rise or fall depending on the relative sizes of the contract and spot markets, and the compensation structures outlined in the contracts.

While there have been a number of excellent studies into the effects of contract structures on market equilibriums, authors have mainly focused on livestock markets and the compensation schemes in agricultural contracts. This is most likely due to the importance of price uncertainty relative to production uncertainty in the livestock sector. However, production uncertainty plays a major role in crop production. Therefore, one would expect production uncertainty to play a crucial role in shaping the contract structures in specialty grains markets. This is the main focus of this paper.

Survey Data

In addition to the theoretical and empirical studies on agricultural production contracts, there also exists a collection of recent survey data on specialty grain markets in the Midwest. The survey data reported in Good, Bender, and Hill (2000) for Illinois specialty grain handlers shows that the vast majority of specialty corn (waxy, high oil, white, yellow food grade) and soybeans (tofu, non-GMO) in Illinois are produced and procured under contractual arrangements. Good, Bender, and Hill (2000) report that many firms act as intermediaries between producers and processors by forming contractual relations with both parties. Moreover, the intermediate firms, comprised mainly of country elevators, contract with producers based on acreage but contract with processors based on bushels. This implies that the intermediate firms may be able to pool production risk across producers.

Sykuta and Parcell (2003) provide a survey on contract structures offered by DuPont in their specialty soybean programs. While the contract premiums are generally based on the total bushels delivered, the actual contracts are based on acreage, shifting a portion of the production risk to the processor. Acreage contracts differ from bushel contracts in that the producer does not have to make up yield shortages in poor years or sell surpluses at a potentially lower price on the spot market in good years. The production risk shifted to buyers under acreage contracts creates variability with respect to the amount of premium paid out to contracted producers, as well as serious implications for capacity considerations for processors. Sykuta and Parcell (2003) note that buyers may be able to reduce production risk by pooling across large areas (attempting to eliminate some systemic yield risk), or offer contracts in selective areas or to specific producers with low historical yield variability.

The survey data from over 2,800 producers in Ginder et al. (2000) reports that the majority (60%) of specialty corn contracts in Iowa are structured to pay a premium over a reference price, referred to as “market price plus a premium”. The reference price can either be a fixed price or pegged to a specified cash market price, such as a local spot market or a futures price. The surveys conducted by Good, Bender, and Hill (2000) and Fulton, Pritchett, and Pederson (2003) imply the same type of compensation structures for specialty grain contracts in Illinois and Indiana, respectively. Sykuta and Parcell’s (2003) survey also reported the use of a premium above a market price in DuPont’s specialty soybean programs.

The premiums are motivated by higher production costs, segregation and identity preservation, possible yield drags, and documentation and certifications costs (Ginder et al. 2000). The magnitude of these additional costs will depend on the characteristics of the specialty crop as well as characteristics of the individual farm operation. Storage capacity, farm size, financing constraints, and the management ability of the producer are just a few examples of heterogeneity with respect to specialty crop production costs across farming operations.

The survey conducted by Fulton, Pritchett, and Pederson (2003) reports that higher variable production costs, higher investment costs, and managerial time requirements were three of the top four reasons why Indiana producers chose not to grow any specialty crops. The number one reason for not producing specialty crops was the lack of a market for sale of the specialty crop. For surveyed producers who did produce specialty crops under contract, revenue enhancement and market access were the top two reasons reported for contracting.

Contract Model

The terms "specialty" and "commodity" are used to differentiate the contracted crop and the alternative cash market crop in the model. Examples would include high oil, white, or waxy corn (specialty) and #2 yellow corn (commodity). Soybean production would be another example in commodity form, with the specialty crop being DuPont's STS® or tofu soybeans. Moreover, the non-GMO or organic forms of any general commodity crop would be another example of what is referred to as a specialty crop. For simplicity, bushels will be used as the production unit measure for the specialty and commodity crop. However, the model could easily be generalized to other types of crops whose production is measured in other units (i.e. tons or lbs.). In the sections that follow, subscripts denote differentiation unless otherwise noted.

Overview

The modeled contracting scenario is a familiar one in agriculture. Consider a profit-maximizing (risk-neutral) monopsonistic processor who procures specialty crop production from a group of producers by way of a production contract[1]. In stage I, the processor offers a contract for the specialty crop to producers. The producers then decide to either accept the contract to produce the specialty crop, or to reject the contract and produce the commodity crop. Producers who accept the contract then move into stage II where production of the specialty crop takes place per specific management guidelines outlined in the contract[2]. If the contract guidelines are followed the processor "verifies" the specialty crop for each contracted farmer through costly monitoring, acknowledging that his production carries the specialty trait. Thus, there is no quality or trait uncertainty in the model. Furthermore, it is assumed that the processor will not purchase any amount of unverified specialty crop production. This assumption precludes the possibility of producers choosing to grow the specialty crop speculatively (i.e. there is no *ex ante* spot market for the specialty crop)[3]. Moreover, given the management guidelines outlined in the contract and the intensive monitoring done by the processor, producers do not have the ability to "shirk" and attempt to pass off the commodity crop as having the specialty trait.

In stage III the farmers harvest the specialty crop and yields are realized on each farm. Each farmer's actual yield is private information (informational asymmetry). In stage IV *ex post* spot market transactions for the specialty crop may take place between producers, depending on the type of contract offered (acreage vs. bushel) and yield realizations (supply and demand). There will not be an *ex post* spot market under acreage contracts because producers deliver all specialty bushels produced to the processor. However, if the processor offers a bushel contract an *ex post* spot market for the specialty crop may exist as contracted farmers realizing low yields, in an effort to fulfill their bushel contracts, may purchase bushels from contracted farmers who realized high yields. The processor may also enter the *ex post* spot market for the specialty crop to purchase additional specialty crop production up to his capacity constraint. The prevailing price on the specialty crop spot market will depend on the aggregate yield over contracted acres. This will be explained further in the following sections.

In stage V the contracts are settled by the farmers delivering contracted production to the processor and receiving the compensation outlined in the contract. Finally in stage VI, processing takes place and the processor sells output to a downstream user earning a processing return on each bushel processed up to the plant capacity. The processor sells any excess (above his capacity constraint) contracted specialty crop at its salvage value on the commodity market. Figure 1 summarizes the timing of all decisions and actions in the modeled contracting scenario.

The Processor

The processor earns a net processing return *R* for each unit of the specialty crop processed *Y*, up to an exogenous capacity constraint *Q*[4]. Thus, processing is modeled as a fixed proportions technology where each unit processed results in one unit of output (by appropriately specifying the unit of measure for the processed crop) (Carriquiry and Babcock 2004).

The "price" received by the processor (*R*) is assumed to be net of any variable production and operating costs for the processing plant. The capacity constraint *Q* could be thought of as a physical constraint on the technology, or due to contractual arrangements between the processor and downstream buyers (Good, Bender, and Hill 2000). Each unit of the specialty crop procured above capacity is "dumped" on the commodity market at its salvage value[5] which is assumed to equal the price on the commodity market *r* less a percentage handling charge δ[6]. The handling charge includes storage and transportation costs incurred by the processor on contracted specialty crop production that cannot be processed due to his capacity constraint.

$$(1) \qquad R(Y;Q) = \begin{array}{l} RY \text{ for } Y \le Q \\ RQ + (r-\delta)(Y-Q) \text{ for } Y > Q \end{array}$$

where $Y = \sum_i y_i$ for all contracted farmers *i*

$$\delta \in [0, r]$$

To induce production of the specialty crop the processor offers a contract to producers either based on acreage or on total bushels to be delivered. The acreage contract is defined by a premium level p, above a reference price, that the processor will pay the producer for each bushel grown on contracted acres. The bushel contract is defined by a premium p above the reference price, the size of the contract in bushels y^B, and an "underage" penalty p^u that the farmer must pay to the processor if he cannot fulfill his contract in bushels of the specialty crop (because his yield fell below the contracted amount and there was not any additional production from other contracted producers available on the spot market). In addition to choosing the terms (premium and state contingent penalty) and structure (acreage or bushel) of the contract offered, the processor chooses the size of the contracting region, defined by the number of producers N within the region, where he will offer the contract[7].

In the case of either contract type, the contract also outlines specific guidelines for the management practices that the producer must follow. These guidelines may include requirements for input use (i.e. a specific seed, fertilizers, or chemicals), storage and segregation, and timing of any production tasks. The processor enforces the management terms of the contract through costly monitoring. The costs of monitoring $m(N)$ are assumed to be an increasing convex function of the size of the contracting region, with $m_N, m_{NN} > 0$. It is assumed that as contracted farmers become spread out over a larger region it becomes increasingly difficult (costly) for the processor to monitor their management actions.

The Producers

Upon receiving the contract offer, the set of N profit maximizing (risk-neutral) producers within the contracting region choose to either accept the contract and produce the specialty crop, or produce the commodity crop for sale in the commodity market. Each producer is assumed to farm one acre and face a farm-level yield distribution for both the specialty and commodity crops, $y_i \sim f(y) \in [0, y_{max}]$ for $\forall i \in N$ (i.e. it is assumed there is no yield drag for the specialty crop) where $E[y_i] = \bar{y}$ and $Var[y_i] = \sigma_y^2$ for $\forall i$. Furthermore, the joint distribution of farm level yields is characterized by a spatial correlation structure where the correlation between yields on any two farms *i* and *j* is equal to $\rho_{i,j} \geq 0$ for $\forall i \neq j$.

Commodity crop production costs *c* are also assumed to be homogeneous across all producers within any contracting region. Production costs for the commodity crop are equal to the sum of *J* variable and (annualized) fixed production costs that include labor, fertilizers, chemicals, land, machinery, fuels, storage etc. Expected profits for commodity crop production π_i^C are equal to the expected yield times the commodity price *r* minus production costs. The commodity price is assumed to be constant so that the analysis is focused on the effects of production uncertainty[8].

(2) $$E\left[\pi_i^C\right] = r\bar{y} - c \text{ for } \forall i, \text{ where } c = \sum_j x_j \text{ for } \forall i$$

Given the management guidelines outlined in the contract, production of the specialty crop will result in higher production costs (i.e. seed with special genetics, more intensive labor and management, the use of additional inputs or specific assets) than the commodity crop. Furthermore, it is assumed that these costs may vary by farm so that producers are heterogeneous with respect to specialty crop production costs under contract. The additional costs above those for the commodity crop are denoted by a non-negative additive term $\tau_{j,i}$.

(3) $$c_i^s = \sum_j (x_j + \tau_{j,i}), \text{ where } \tau_{j,i} \geq 0 \text{ for } \forall i, j$$

Thus, specialty crop production costs are higher than for the commodity crop $c_i^s \geq c_i = c$ for all farmers. It is also assumed that transportation and marketing costs are such that producers, given equal prices, are indifferent between delivering bushels to the processor, selling on the specialty crop spot market, or selling on the commodity market[9].

While each producer knows his specialty crop production cost with certainty, the processor views production costs for the specialty crop as being randomly distributed, on a non-negative and bounded support, across producers within the contracting region $c_i^s \sim \hat{h}(c^s) \in [c, c + c^u],\ \forall i \in N$ for $\forall N$. The distribution of specialty crop production costs across producers in any region is also common knowledge to each of the producers.

Contract Supply

Given the assumptions on the specialty grain production costs, the processor must offer premiums above the commodity price to induce farmers to accept specialty crop production contracts. By making the compensation terms of the contract more favorable the processor increases the total number of farmers in a given contracting region who will accept the contract N^c, a shift up his "contract supply curve" for a given contract region. By increasing the size of the contracting region the processor induces an outward shift to his contract supply curve increasing the number of farmers who will accept the contract for any compensation structure.

The effects of the compensation terms of the contract and the size of the region on the number of contracts accepted is given in figure 2. The left panel provides a spatial interpretation[10] of the effects of increasing the size of the contract region from N_1 to N_2 ($N_2 > N_1$) on the number of accepted contracts. The right panel in figure 2 plots two conditional contract supply curves for the two contracting region sizes. The contract premium is plotted on the vertical axis. Increasing the premium for a given contract size induces a move up the supply curve. Increasing the size of the contract region from N_1 to N_2 causes a rightward rotation in the processor's contract supply curve.

In equilibrium, the processor optimally chooses the contract terms to maximize expected profits given knowledge about the profit-maximizing behavior of producers.

The following subsections outline the processor and producers' problems and market equilibrium in detail under acreage and bushel contracts, respectively.

Acreage Contracts

Under acreage contracts, farmer *i*'s profit π_i^A is equal to his yield times the sum of the reference (commodity) price and the contract premium *p* less specialty crop production costs.

(4) $$\pi_i^A = (r+p)y_i - c_i^s$$

Farmer *i* accepts the contract if expected profits from contracting are greater than expected profits from producing the commodity crop.

(5) $$E\left[\pi_i^A\right] \geq E\left[\pi_i^C\right] \Rightarrow (r+p)\overline{y} - c_i^s \geq r\overline{y} - c \Rightarrow c_i^s - c = \hat{c}_i \leq p\overline{y}$$

Equation (5) defines the marginal producer with specialty production cost "premium" $\hat{c}^A = p\overline{y}$, where all farmers with a specialty crop production cost premium below (above) $\hat{c}^A$ will accept (reject) the contract. Using a change of measure, the distribution of specialty crop production cost premiums within any contracting region *N* is given by

$\hat{c}_i \sim h(\hat{c}_i) \in \left[0, c^u\right],$ where $h(\hat{c}_i) = h(c_i^s - c) = \hat{h}(c_i^s)$. Also, let $H(c) = \int_0^c h(x)dx = \Pr\left[\hat{c} \leq c\right]$

denote the cumulative distribution function of the specialty crop production cost premium.

The processor offers a premium *p* above the commodity reference price, that will be paid for each bushel of the specialty crop grown on the N^c contracted acres, within the chosen contracting region *N*. Under acreage contracts there will be no *ex post* spot market for the specialty crop because each farmer delivers all bushels produced on contracted acres to the processor. The processor's profit is equal to processing returns less procurement and diversification costs. For each bushel of the specialty crop dumped on the commodity spot market the processor incurs a handling fee δ that is expressed as a percentage of the spot price. The processor chooses the premium and the size of the contracting region to maximize expected profits, subject to each producer's decision rule[11] and given his information on the farm-level yield and specialty crop production cost premium distributions.

$$\max_{p,N} E\left[\Pi^A\left(p,N\right)\right] = \begin{array}{l} \int_0^Q RYdG(Y) + \int_Q^{N^c y_{max}} \left[RQ + \left(r - \delta\right)\left(Y - Q\right)\right] dG(Y) \\ -\int_0^{N^c y_{max}} (r+p) YdG(Y) - m(N) \end{array} \tag{6}$$

subject to $p \geq 0,\ N \geq 0$, and

$$Y = \sum (y_i \mid E\left[\pi_i^A\right] \geq E\left[\pi_i^C\right]) \sim g(Y; p, N) \in \left[0, N^c y_{max}\right]$$

where $\hat{c}_i \sim h(\hat{c})$, $y_i \sim f(y)\ \forall i$

Total procurement for the processor *Y* is equal to the sum of the yield realizations for each contracted producer. Therefore, the distribution of total procurement *g*, with cumulative distribution function *G*, is a function of the farm level yield distribution *f* and the number of farmers who accept the contract, which in turn is a function of the premium offered and the size of the contracting region[12]. Formally, $N^c = H(p\bar{y})N$ with $N_p^c = h(p\bar{y})N\bar{y} \geq 0$ and $N_N^c = H(p\bar{y}) \geq 0$. Thus, $G(Y; p+dp, N) \leq G(Y; p, N)$ and $G(Y; p, N+dN) \leq G(Y; p, N)$ for $\forall dp, dN \geq 0$. This implies that increasing the premium or size of the contracting region induces a shift of first-order stochastic dominance in *G*.

Using Leibniz rule and noting that $\int_0^{N^c y_{max}} YdG(Y) = E(Y) = H(p\bar{y})N\bar{y}$, where $H(\cdot)$ is the cumulative distribution function for the specialty crop production cost premium, the solution to the processor's problem (p^{A*}, N^{A*}) satisfies the following first order conditions. All functions are evaluated at the optimum unless otherwise noted.

$$\begin{aligned}(7)\qquad \partial E\left[\Pi^{A}\right]\Big/\partial p = & \int_{0}^{Q} RYdG_{p} + \int_{Q}^{N^{c}y_{max}} \left[RQ + (r-\delta)\left(Y-Q\right)\right]dG_{p} \\ & + \left[RQ + \left(r-\delta\right)\left(N^{c}y_{max} - Q\right)\right]g\left(N^{c}y_{max}\right)N_{p}^{c}y_{max} \\ & -(r+p^{A*})N_{p}^{c}\overline{y} - N^{c}\overline{y} \leq 0,\ p^{A*} \geq 0\end{aligned}$$

$$\begin{aligned}(8)\qquad \partial E\left[\Pi^{A}\right]\Big/\partial N = & \int_{0}^{Q} RYdG_{N} + \int_{Q}^{N^{c}y_{max}} \left[RQ + (r-\delta)\left(Y-Q\right)\right]dG_{N} \\ & + \left[RQ + (r-\delta)\left(N^{c}y_{max} - Q\right)\right]g(N^{c}y_{max})N_{N}^{c}y_{max} \\ & -(r+p^{A*})N_{N}^{c}\overline{y} - m_{N} \leq 0,\ N^{A*} \geq 0\end{aligned}$$

Note that both non-negativity constraints must be non-binding in any equilibrium with contracting so that the first order conditions will be strictly equal to zero. Equations (7) and (8) equate the marginal benefits to the marginal costs of increasing the premium *p* and the size of the contracting region *N*, respectively. The marginal benefits of increasing the premium are equal to the increase in processing returns, given by the first three terms in equation (7). Similarly, the net benefits of increasing N are given in the first three terms of equation (8). The third term, in both cases, reflects the fact that the upper bound of the aggregate yield distribution is increasing in the number of acres contracted by the processor (i.e. $Y_{max} = N^{c}y_{max}$).

The marginal costs of increasing the premium in (7) are equal to the increased cost on each contracted acre plus the additional cost of increasing the amount of contract acres from increasing the premium. The marginal costs of increasing the size of the contract region in (8) are equal to the increase in procurement costs as more contracts will be accepted for any given premium, plus the increase in monitoring costs from expanding the size of the contracting region.

The second order sufficient conditions for a maximum are assumed to hold and are available from the authors upon request.

Bushel Contracts

Given a bushel contract offer, farmer *i*'s profit π_i^B is equal to the reference price plus the premium times the size of the contract y^B, less production costs for the specialty crop. For simplicity, the analysis is limited to bushel contracts where $y^B = \overline{y}$. This of course implies that aggregate contracted bushels will equal $N^c\overline{y} = \overline{Y}$. When actual yield is less than the size of the contract the farmer must either pay a fixed underage penalty (specified in the contract offer) on each unit below the contracted amount, or enter the specialty crop spot market (if there is positive supply) to purchase excess production from other contracted farmers to fulfill his contract obligation. When farmer *i*'s yield is greater than the contract size he can sell the excess specialty crop production at its salvage value on the commodity market or sell it on the specialty crop spot market (if demand exists).

$$\begin{aligned}\pi_i^B &= (r+p)\overline{y} + I\left(y_i\right)p^s\left(Y, p^u, r \mid y_i > \overline{y}\right)\left(y_i - \overline{y}\right) \\ &\quad + \left[1 - I\left(y_i\right)\right]p^s\left(Y, p^u, r \mid y_i \le \overline{y}\right)\left(y_i - \overline{y}\right) - c_i\end{aligned} \tag{9}$$

where $I(y_i) = \begin{matrix} 1 \text{ if } y_i > \overline{y} \\ 0 \text{ otherwise} \end{matrix}$

The prevailing price on the specialty crop spot market p^s will depend on the underage penalty p^u set by the processor in the bushel contract, the salvage value *r*, and the aggregate specialty crop production *Y* across all contracted farmers. At the time of contract signing, producers use their knowledge of the distribution of production cost premiums for the specialty crop and their information on the joint distribution of yields within the contracting region to formulate an expectation for the *ex post* specialty crop spot market price. There are two possible scenarios. The aggregate yield realization will either be equal to or below the total contracted by the processor $Y \leq \bar{Y}$, or greater than the contracted amount $Y > \bar{Y}$. If $Y \leq \bar{Y}$, excess demand on the specialty crop spot market will bid the spot price up to the underage penalty[13], $p^s = p^u$. If $Y > \bar{Y}$ there will be excess supply on the specialty crop spot market and the prevailing spot price will equal the salvage value of the commodity market price, $p^s = r$.

In either aggregate yield case, farmer *i*'s yield could be greater than or less than the individual contract size, $y_i > \bar{y}$ or $y_i \leq \bar{y}$, creating four possible *ex post* spot market scenarios under bushel contracts. Farmer *i*'s expectations for the prevailing specialty crop spot price conditional on his yield falling above or below the contract size are given below.

(10) $$E\left[p^s \mid y_i \leq \bar{y} \right] = p^{s,u} = \theta_1 p^u + (1-\theta_1) r \leq p^u$$

(11) $$E\left[p^s \mid y_i > \bar{y} \right] = p^{s,o} = \theta_2 p^u + (1-\theta_2) r \geq r$$

where $$\begin{aligned} \theta_1 &= \Pr\left[Y \leq \bar{Y} \mid y_i \leq \bar{y} \right] \\ \theta_2 &= \Pr\left[Y \leq \bar{Y} \mid y_i > \bar{y} \right] \end{aligned}$$

The conditional probabilities θ_1 and θ_2 will depend on how farmer yields are jointly distributed across the contracting region (i.e. the spatial correlation), with $\theta_1 \geq (\leq) \theta_2$ when yields are positively (negatively) correlated. If yields are perfectly correlated there will not be an *ex post* spot market because farmers will either pay the underage penalty p^u to the processor when (all) yields are below the mean, or sell the excess specialty crop on the commodity market at the salvage value *r* when (all) yields are above the mean (i.e. $\theta_1 = 1$, $\theta_2 = 0$). If yields are independent, $\theta_1 = \theta_2 = 1/2$ and the expected spot price is $1/2 \left(p^u + r \right)$ in both the underage and overage scenarios. This implies that if yields are independent, the magnitude of the underage penalty has no effect on farmer participation because the expected cost of the penalty when farmer *i's* yield is below the mean is exactly equal to the benefits of the penalty when his actual yield is above average. This is purely a result of farmer expectations for the *ex post* specialty crop spot price.

Given farmer *i*'s expectation for the *ex post* specialty crop spot market price, expected profit for the bushel contract is given below in equation (12).

$$
\begin{aligned}
E\left[\pi_i^B\right] &= (r+p)\bar{y} - c_i^s - p^{s,u}\int_0^{\bar{y}}(\bar{y}-y)dF(y) + p^{s,o}\int_{\bar{y}}^{y_{max}}(y-\bar{y})dF(y) \\
&= (r+p)\bar{y} - c_i^s - \left\{\theta_1 p^u + (1-\theta_1)r\right\}\Delta y + \left\{\theta_2 p^u + (1-\theta_2)r\right\}\Delta y \\
&= (r+p)\bar{y} - c_i^s + \left(r - p^u\right)\left(\theta_1 - \theta_2\right)\Delta y
\end{aligned}
\quad , \tag{12}
$$

where $\Delta y = \int_0^{\bar{y}}(\bar{y}-y)dF(y) = \int_{\bar{y}}^{y_{max}}(y-\bar{y})dF(y)$ by the definition of $\bar{y}$. Thus, if yields are positively correlated, the farmer will pay less (in expectation) than p^u in the case of an individual underage and will receive a price greater (in expectation) than the salvage value *r* in the case of an individual overage[14].

Equation (12) defines the marginal production cost premium for the specialty crop $\hat{c}^B$, where all producers with $\hat{c}_i \leq (>)\ \hat{c}^B$ will accept (reject) the bushel contract offered by the processor. Comparing this to the marginal producer under acreage contracts, defined by $\hat{c}^A$, any underage penalty that is greater than the commodity price will require a greater bushel contract premium to induce the same level of farmer contract acceptance relative to the acreage contract (for a given *N*).

$$
\hat{c}^B = p\bar{y} + \left(r - p^u\right)\left(\theta_1 - \theta_2\right)\Delta y \tag{13}
$$

Given the profit-maximizing decision rule of the producers, the processor chooses the premium level *p* and the underage penalty p^u to maximize expected profits. In equilibrium there must be some constraints on the values of the underage penalty. If the processor sets the underage penalty to a value below the commodity price, each contracted producer has an incentive to report zero yield (private information) to the processor and pay the underage fee while selling the specialty crop on the commodity market. This nets each producer the reference price plus premium times the contract size (a sort of lump sum payment), plus the difference between the underage penalty and reference price for each bushel produced up to the contract size (or actual yield if it is below the mean), plus the reference price for each unit produced above the mean. The maximum underage penalty that the processor can charge is assumed to be equal to his net processing return R[15]. For any underage penalty greater than the net processing margin, the processor would be better off collecting the underage than accepting delivery of contracted bushels for processing. As an arbitrage condition, it is assumed producers would simply not accept such a contract.

The processor's maximization problem for bushel contracts is presented formally below in (14). The first order conditions are obtained by differentiating the processor's constrained objective function using Leibniz rule, and are presented in (15)-(19) where λ and μ are the Lagrange (L) multipliers for the inequality constraints on the underage penalty. The second order sufficient conditions for the processor's problem with bushel contracts are assumed to hold and are available from the authors upon request.

$$(14) \qquad \max_{p,N,p^u} E[\Pi^B(p,N,p^u)] = \begin{array}{l} \int_0^Q (R-r)YdG(Y) + \int_Q^{N^c y_{max}} (R-r)QdG(Y) - pN^c\overline{y} \\ + \int_0^{N^c\overline{y}} p^u \left(N^c\overline{y} - Y\right) dG(Y) - m(N) \end{array}$$

subject to $\quad p, N \geq 0,\ \mathrm{r} \leq p^u \leq R$, and

$$Y = \sum (y_i \mid E\left[\pi_i^B\right] \geq E\left[\pi_i^C\right]) \sim g(Y; p, N)$$

where $\hat{c}_i \sim h(\hat{c})$, $y_i \sim f(y)\ \forall i$

(15)
$$\partial L \big/ \partial p = \int_0^Q (R-r)YdG_p + \int_Q^{N^c y_{max}} (R-r)QdG_p + (R-r)Qg(N^c y_{max})N_p^c y_{max}$$
$$-p^{B*}N_p^c\overline{y} - N^c\overline{y} + p^{u*}\left\{\int_0^{N^c\overline{y}} \left(N^c\overline{y} - Y\right)dG_p + \int_0^{N^c\overline{y}} N_p^c\overline{y}dG\right\} \le 0,\ p^{B*} \ge 0$$

(16)
$$\partial L \big/ \partial N = \int_0^Q (R-r)YdG_N + \int_Q^{N^c y_{max}} (R-r)QdG_N + (R-r)Qg(N^c y_{max})N_N^c y_{max}$$
$$-p^{B*}N_N^c\overline{y} - m_N + p^{u*}\left\{\int_0^{N^c\overline{y}} \left(N^c\overline{y} - Y\right)dG_N + \int_0^{N^c\overline{y}} N_N^c\overline{y}dG\right\} \le 0,\ N^{B*} \ge 0$$

(17)
$$\partial L \big/ \partial p^u = \int_0^Q (R-r)YdG_{p^u} + \int_Q^{N^c y_{max}} (R-r)QdG_{p^u}$$
$$+(R-r)Qg(N^c y_{max})N_{p^u}^c y_{max} - p^{B*}N_{p^u}^c\overline{y} + \int_0^{N^c\overline{y}} \left(N^c\overline{y} - Y\right)dG$$
$$+p^{u*}\left\{\int_0^{N^c\overline{y}} \left(N^c\overline{y} - Y\right)dG_{p^u} + \int_0^{N^c\overline{y}} N_{p^u}^c\overline{y}dG\right\} + \lambda^* - \mu^* = 0$$

(18) $\partial L \big/ \partial \lambda = R - p^{u*} \ge 0,\ \lambda^* \ge 0$, and $\lambda^*\left[R - p^{u*}\right] = 0$

(19) $\partial L \big/ \partial \mu = p^{u*} - r \ge 0,\ \mu^* \ge 0$, and $\mu^*\left[p^{u*} - r\right] = 0$

As in the acreage contract solution, both of the non-negativity constraints on p and N will not bind for any interior solution with contracting. Conditions (15)-(17) equate the marginal benefits of increasing the premium, size of the contracting region, and the underage penalty to their marginal costs. The marginal benefits of increasing the premium and size of the contracting region are equal to the expected marginal increases in revenues from processing returns, while the marginal costs are equal to the expected increases in procurement and monitoring costs. The marginal benefits of increasing the underage penalty are equal to the expected increase in underage penalties and the reduction in procurement costs due to lower farmer acceptance. The marginal costs of increasing the underage penalty are equal to the expected reduction in processing returns due to lower farmer acceptance of the contract. Conditions (18) and (19) ensure that the constraints are satisfied at the optimal solution.

Analytic Results

While the generality of the model precludes the derivation of explicit analytical solutions for the optimal acreage and bushel contract equilibriums, some claims can still be made regarding the two contract structures. The first result shows that bushel contracts can Pareto dominate acreage contracts.

> *Proposition 1: There exists a bushel contract which Pareto dominates the optimal acreage contract, although that bushel contract may not be the processor's optimal bushel contract.*

Proof:

Consider a bushel contract where the premium and size of the contract region are set equal to the values of the optimal solution for the acreage contract, and the underage penalty is set equal to the salvage value *r*. Note that farmer acceptance of the two contracts will be equal under these conditions, so that expected farmer profits are the same for the optimal acreage and proposed bushel contracts (i.e. farmers are no worse off)[16]. Given equal contract acceptance, the aggregate distribution of contracted production will be the same so that the processor's expected profits can be compared under the two contract specifications. Subtracting the processor's expected profit under the optimal acreage contract from expected profits under the proposed bushel contract yields the desired result that the processor is at least as well off under the proposed bushel contract than the optimal acreage contract. Formally,

$$E\left[\Pi^B\left(p^{A*}, N^{A*}, p^u = r\right)\right] - E\left[\Pi^A\left(p^{A*}, N^{A*}\right)\right] = \delta\int_Q^{N^c y_{max}} \left[Y - Q\right] dG \geq 0 .$$

Moreover, if the handling charge δ is strictly greater than zero, the processor's expected profits under the bushel contract are strictly greater than expected profits under the optimal acreage contract. Therefore, the proposed bushel contract Pareto dominates the optimal acreage contract. Finally, $E\left[\Pi^B\left(p^{B*}, N^{B*}, p^{u*}\right)\right] \geq E\left[\Pi^B\left(p^{A*}, N^{A*}, p^u = r\right)\right]$ by the definition of a maximum. This trivially proves that the proposed bushel contract may not be optimal.

The intuition behind Proposition 1 is that by offering an equivalent (as far as farmers are concerned) bushel contract, the processor is able to avoid handling excess specialty crop production in years with above average yield realizations. This result relies heavily on the assumptions that 1) farmers are indifferent between delivering bushels to the processor and selling them on the commodity market, and 2) the salvage value is equal to the commodity price *r*. Note that under the proposed bushel contract, the producer is guaranteed the premium *p* on each bushel contracted. For aggregate yield realizations below the contracted level the processor realizes higher procurement costs than those in the optimal acreage contract because he is paying the premium for the total contract size, but only being reimbursed *r* for each short bushel in the case of an aggregate yield shortage. This represents the "price" the processor must pay for the farmer to take on the risk of yield realizations below the bushel contract size.

A corollary to Proposition 1 is that producers will prefer the bushel contract proposed in Proposition 1 to the optimal acreage contract with $\delta \geq 0$. This can be formally stated as:

(20) $$\pi_i^B\left(p^{A*}, N^{A*}, p^u = r\right) \geq \pi_i^A\left(p^{A*}, N^{A*}; \delta \geq 0\right) \text{ for } \forall i$$

The proof of this claim is straightforward. Total differentiation of the first order conditions for the acreage contract with respect to δ yields the following comparative static results.

(21) $$\partial p^{A*} \big/ \partial\delta = \frac{\int_Q^{N^c y_{max}} \left(Y - Q\right) dG_p}{\partial^2 \Pi^A \big/ \partial p^2} \leq 0$$

(22) $$\partial N^{A*} \big/ \partial \delta = \frac{\int_{Q}^{N^c y_{max}} \left(Y - Q\right) dG_N}{\partial^2 \Pi^A \big/ \partial N^2} \leq 0$$

The denominators of (21) and (22) are negative by the second order conditions, while the numerators are both non-negative given increases in *p* and *N* induce shifts of first-order stochastic dominance in the distribution function *G*. Thus, both the premium and size of the contracting region are larger under acreage contracts when $\delta = 0$ implying farmer participation and expected producer profits are also greater when $\delta = 0$.

Noting that the proposed bushel contract is equivalent to the optimal acreage contract when $\delta = 0$, expected producer profits are greater under the proposed bushel contract than under the optimal acreage contract when $\delta > 0$, or

$$\pi_i^B\left(p^{A*}, N^{A*}, p^u = 1\right) = \pi_i^A\left(p^{A*}, N^{A*}; \delta = 0\right) \geq \pi_i^A\left(p^{A*}, N^{A*}; \delta \geq 0\right).$$

Finally, a claim can be made on the optimal bushel contract underage penalty. Except for very specific conditions, one of the constraints on the optimal underage penalty will bind.

Proposition 2: The optimal underage penalty equals r (R) if $\left[\frac{\int_0^{\overline{Y}} \left(\overline{Y} - Y\right) dG}{\left(\theta_1 - \theta_2\right) N^c \Delta y} - 1\right]$ *<(>) 0.*

Proof:

Suppose at the optimum that the constraints on the optimal underage penalty do not bind, $p^{u*} \in \left(r, R\right)$. Define a simultaneous change in the bushel contract premium and the underage penalty such that farmer acceptance is held constant (i.e. the marginal specialty crop production cost premium is held constant).

(23) $$d\hat{c}^{B*} = \left[\overline{y}\right] dp - \left[\left(\theta_1 - \theta_2\right) \Delta y\right] dp^u = 0 \quad \Rightarrow \quad dp = \frac{\left(\theta_1 - \theta_2\right) \Delta y}{\overline{y}} dp^u$$

Then the change in the processor's expected profits for the simultaneous change in the premium and underage penalty is given by $\left[\int_0^{\bar{Y}}\left(\bar{Y}-Y\right)dG-\left(\theta_1-\theta_2\right)N^c\Delta y\right]dp^u$. Thus, if

$\left[\frac{\int_0^{\bar{Y}}\left(\bar{Y}-Y\right)dG}{\left(\theta_1-\theta_2\right)N^c\Delta y}-1\right]$ > 0 and the underage penalty is less than *R*, the processor can increase expected profits by increasing the underage penalty to *R* while simultaneously increasing the premium according to (23), which violates an optimum for $p^{u*}\in\left(r,R\right)$. The same logic holds when $\left[\frac{\int_0^{\bar{Y}}\left(\bar{Y}-Y\right)dG}{\left(\theta_1-\theta_2\right)N^c\Delta y}-1\right]$ < 0, in that expected profits will increase if the underage penalty is reduced to *r* while the premium is simultaneously reduced according to (23), again a violation of the supposition of a maximum with $p^{u*}\in\left(r,R\right)$.

The intuition behind Proposition 2 lies in what the ratio $\frac{\int_0^{\bar{Y}}\left(\bar{Y}-Y\right)dG}{\left(\theta_1-\theta_2\right)N^c\Delta y}$ represents. The numerator reflects the marginal valuation of the underage penalty to the processor. Similarly, the denominator reflects the marginal cost of the underage penalty for the producers. If the marginal value to the processor is greater than the aggregate marginal cost to producers, the optimum is attained at the maximum underage penalty. An analogous argument holds when the marginal valuation of the underage penalty to the processor is less than the aggregate marginal cost to producers.

Numerical Example

Since an explicit analytical solution does not exist for the model, a numerical approach was used to solve the model given functional form assumptions for the farm level yield and specialty crop production cost premium distributions, and the monitoring cost function. Specialty crop production cost premiums were assumed to follow a uniform distribution, $\hat{c}_i \sim U\left[0, c^u\right]$. A simple quadratic form was assumed for the monitoring cost function.

$$(24) \qquad m(N) = \frac{\beta}{2} N^2$$

The three parameter beta distribution, described by (25), was chosen for the yield distribution because it can easily be parameterized to have finite bounds and to be either symmetric around the mean, left skewed, or right skewed. Moreover, the three parameter beta distribution has previously been used to approximate crop yield distributions (Babcock and Hennessy 1996). The beta distribution was calibrated so that farm level yields had a mean of 100 and a coefficient of variation of 20%. This level of yield volatility is consistent with federal crop insurance rates for corn and soybeans in many counties throughout the Midwest.

$$(25) \qquad f(y) = \frac{\Gamma\left[a+b\right]}{\Gamma\left[a\right]\Gamma\left[b\right]} \frac{(y)^{a-1}(y_{max} - y)^{b-1}}{y_{max}^{a+b-1}},\ 0 \leq \mathrm{y} \leq y_{max}$$

A baseline parameterization for an acreage contract with an optimal premium and contracting region size of 0.2 and 750, respectively, was achieved by solving the model with yields fixed at their means. The commodity price was set equal to one, the average yield level was set to 100, and the upper bound on the specialty crop production cost premium was set equal to 150. With fixed yields, the first order conditions (7) and (8) for the optimal acreage contract reduce to equations (26) and (27), which solve for the net processing return *R* and the diversification cost function parameter β in terms of the other model parameters and the desired optimal contract premium and region size. The plant capacity *Q* was then set equal to the optimal aggregate procurement level with yields fixed at their means. A summary of the calibrated parameters for the baseline case is given in table 1.

$$(26) \qquad R = 1 + 2p$$

(27) $$\beta = N \frac{c^u}{\left(p\bar{y}\right)^2}$$

The solution to the processor's profit maximization problem was then solved under yield uncertainty using numerical methods. Four different yield correlation structures were examined, ranging from independent to perfectly correlated yields[17]. A resorting method based on rank correlations was used to impose the desired level of correlation between individual farmer yield draws (Iman and Conover 1982). Additionally, model results were also calculated assuming the volatility of farm level yields was 40% to examine the effects of increasing yield volatility at the individual farm level.

Table 2 reports the optimal acreage contract terms for the baseline case. Compared to when yields are fixed at their mean (reported in the second column), the processor offers an acreage contract with a lower premium to fewer producers when yield uncertainty is introduced. The optimal premium decreases from \$0.197 to \$0.182 as yields become more correlated, while the number of contracted producers falls by more than 20% from nearly 96 to 76.

The introduction of yield uncertainty exposes the processor to the "risk" of above average yield realizations and having to handle grain in excess of his processing capacity. This effect increases as the individual yields become more positively correlated. This is due to the direct relationship between the volatility of total procurement and the spatial correlation of yields. When yields are independent, low yield realizations are balanced by above average yields on other farms. In short, the processor is able to pool the production risk. At the other extreme, when yields are perfectly correlated, the aggregate procurement of the processor is extremely volatile and the probability of the processor being obligated to purchase production in excess of plant capacity increases. In this extreme case, production risk is purely systemic and the processor is unable to pool any of the production risk across contracted farmers.

With acreage contracts the processor earns a negative profit margin, equal to the acreage contract premium plus the handling charge, on every bushel procured above capacity. To insure against these losses, the processor reduces the premium and size of the contracting region to reduce the chance of having to operate above capacity. This results in fewer farmers accepting the contract, implying a reduction in farmer profits when yield uncertainty is introduced. This effect is magnified as yield risk becomes increasingly systemic. The last row of table 2 illustrates this effect, showing that the additional profits earned by producers declines as the level of correlation between farm level yields increases.

Table 3 reports the optimal acreage contract parameters when the processor's handling fee δ for procurement above his plant capacity is equal to 0.10. The 10% handling charge implies even larger losses on every bushel procured above capacity compared to the situation in table 2. The resulting optimal acreage contract is characterized by a slightly lower premium, and is offered to fewer total farmers resulting in a lower level of farmer participation and a reduction in expected profits for both the processor and the producer for all levels of yield correlation. Again, the last row of table 3 illustrates the decline in additional profits earned by the producers through contracting as the poolability of yield risk declines.

The optimal bushel contract parameters, when farm level yields have a 20% coefficient of variation, are reported in table 4 over a range of yield correlation levels. Using the bushel contract structure, the processor is able to eliminate the risk of procuring a production level above his plant capacity. Moreover, the processor can set an underage penalty to recover profits when aggregate production is less than the total contracted. When aggregate production is greater than the total contracted, the processor can realize even greater profits by purchasing any excess (up to his capacity constraint) at the salvage value (commodity price) from contracted producers on the *ex post* spot market. This effectively shifts the majority of production risk on to the producers. However, producers are compensated for taking on a greater portion of the yield risk through higher contract premiums relative to the acreage contract structure for any given yield correlation structure. For example, when the correlation between farm yields is 0.8 and there is no handling charge, the acreage contract equilibrium results in 78.42 contracted farmers with a premium of 0.1844. The bushel contract equilibrium under the same conditions results in 85.22 farmers under contract at a premium of 0.2183.

When yields are independent so that production risk is poolable, the increase in the processor's expected profits from using bushel contracts is minimal. Expected profits under bushel contracts and independent yields was estimated to be $1027.70, an increase of only $30 compared to both acreage contract scenarios reported. However as the level of correlation between yields is increased, and production risk becomes increasingly systemic, the processor is able to extract even greater relative gains from using bushel contracts. In fact, the processor is able to earn greater expected profits using bushel contracts when yields are uncertain compared to when yields are fixed at the mean.

For example, expected processor profits for bushel contracts were estimated to be over $1,200 when yields are uncertain and positively correlated compared to only $1,000 in the case of certain yields. This is because of the *ex post* spot market that is created by bushel contracts. When aggregate production exceeds the total contracted, the processor is able to enter the spot market and purchase the excess at the commodity price, earning an even greater profit margin on each bushel in excess of the total contracted (up to his capacity constraint). These results imply that bushel contracts may be more prevalent when processors are unable to pool production risk across contracted producers. This may be the case for certain crops or geographic regions.

Comparing producer profits to the corresponding values in table 2 shows that the producers also earn greater profits, in expectation, under bushel contracts.

Table 4 also reports the prices on the specialty crop spot market expected by producers when farm-level yield is below or above the contracted amount (mean yield). In the case of an individual underage (overage), the producer's expectation for the spot price $p^{s.u}$ ($p^{s.o}$)ranges from 1.20 (1.20) when yields are independent to 1.34 (1.058) when the correlation between farm level yields is equal to 0.80. The last row of table 4 reports additional profits earned by the producers through contracting.

When yields are perfectly correlated, the expected spot price in the case of a farm-level underage equals the underage penalty of 1.4, and is equal to the commodity price of one in the case of an above average yield realization at the farm level. Farmers expectations of the *ex post* spot price depend only on their own yield distribution, which is the aggregate distribution when yields are perfectly correlated. The farmer's expectations do not dampen the underage penalty. The processor then chooses a lower underage penalty compared to the cases of positively, but not perfectly correlated, yields and expected profits fall.

Tables 5-7 report the numerical results when farm yield volatility is doubled to 40%. Increasing volatility at the farm level increases the volatility of aggregate contracted production for all levels of yield correlation. The processor offers acreage contracts with a lower premium to an even smaller group of producers when the farm level yield volatility is increased. Similar to the baseline volatility case, when a positive handling fee is imposed the processor further reduces the premium and contracting region size to contract with a smaller group of producers to reduce the magnitude an probability of losses when yields are above average, although the effects are relatively small. Additionally, increased farm-level yield volatility increases the expected costs of an underage to the producer, requiring either a higher premium or lower underage penalty to keep participation constant.

However, increased farm level yield volatility actually increases expected profits, relative to the baseline case, when the processor uses bushel contracts. Table 7 shows that expected profits increase over $100 relative to the 20% yield volatility solution. Again, this is illustrating the benefit of the *ex post* specialty crop spot market to the processor. When yields are more volatile at the farm level, aggregate contracted production will also be more volatile. The processor optimally contracts with fewer farmers by reducing the premium and size of the contracting region, and is able to take advantage of above average aggregate production by purchasing the specialty crop on the spot market at the commodity price up to his capacity constraint.

When yields are perfectly correlated, farmers expect *ex post* spot prices to be equal to the underage penalty or the salvage value depending on aggregate yields, which are equal to farm level yields. There is no dampening effect on the spot price expectations of farmers so the processor must lower the underage penalty and realizes smaller expected profits compared to the cases of positively, but not perfectly, correlated yields. Again, comparing the last row in tables 5-7 shows that producers also prefer the bushel contract structure because they earn greater expected profits compared to either acreage contract scenario.

Conclusions

The fact that vertical coordination through contractual relationships in agriculture is becoming increasingly important is well documented. The rise of vertical coordination in agriculture has been more apparent in livestock markets, which is reflected in the academic literature. Many authors have explored the effects of varying contract structures using theoretical, empirical, and experimental approaches. Special consideration has been given to the effect of compensation structures on the efficiency of contract market equilibriums and the co-existence of contract and spot markets for the same commodity. However, previous studies have focused more heavily on contracting in livestock markets, while production contracts in crop production have been given much less attention.

This paper makes a contribution in this area by presenting a comparison of contract structures within a theoretical model of a contracting relationship between a risk-neutral monopsonistic processor and risk-neutral producers. The main analytical result is that there exists a bushel contract structure which Pareto dominates the optimal acreage contract. However, this bushel contract may not be optimal. This result departs from the conventional thinking in the contract literature that acreage contracts will be the preferred choice of contract structure.

Furthermore, it is shown that the magnitude of the optimal underage penalty for bushel contracts depends on the relative marginal valuations of low yield realizations for the processor and producers, which are themselves functions of the spatial correlation of yields, or the poolability of production risk. Moreover, the (expected) magnitude of the underage penalty is dampened at the farmer level because of the producers' expectations of *ex post* spot market prices for the specialty crop under bushel contracts, which are conditional on the aggregate production of the specialty crop.

A calibrated numerical example shows that acreage contract premiums, farmer participation, and expected profits for both the processor and producers decline as the correlation between farm level yields across space increases. Increasing the level of yield volatility at the farm level results in the same type of effect. Numerical solutions for the optimal bushel contract under different assumptions for the spatial correlation of yields and farm level yield volatility illustrate the analytic result that the processor will prefer bushel contracts (greater expected profits) and that they may Pareto dominate acreage contracts.

The bushel contract structure allows the processor to contract with a greater number of producers at higher premium rate, increasing farmer profits relative to the acreage contract equilibrium. As production risk becomes more systemic (larger correlation between yields), the processor benefits relatively more from using bushel contracts. When risk is largely poolable, the two contract structures are nearly equivalent with respect to expected profits and farmer participation in the resulting equilibriums. These results imply that bushel contracts may be more prevalent for crops and regions where the nature of production risk is highly systemic. When production risk can be pooled, the choice of contract structure may be less important.

These results must be interpreted with care. The model includes a set of restrictive assumptions including producer risk-neutrality, an exogenous commodity market with no price uncertainty, and the ability to dump the specialty crop on the commodity market at the commodity price. Thus, the model can be thought of as a starting point, providing for a multitude of possible extensions for future research. Obviously, producer risk aversion and commodity market price uncertainty are two potential areas for further analysis. Risk averse producers will, in general, require more compensation for taking on a larger share of production risk, potentially eroding away the gains from bushel contracts. The addition of price uncertainty may also greatly affect the results, especially if the commodity price is assumed to be correlated with aggregate or farm-level yields. Furthermore, extending the model to an oligopsony setting where multiple processors compete in production contracts would reduce the ability of the processor to increase profits using the *ex post* spot market when bushel contracts are offered.

While the limitations of the current model are well recognized, the results of this analysis do provide circumstances where bushel contracts are strictly preferred by all agents. Empirical testing of the validity of these assumptions in real-world contract markets is another area for further research.

Endnotes

[1] The phrase "production contract" is used as a general term encompassing the more specific acreage and bushel contract types.

[2] The model abstracts from the specifics of the contract regarding management requirements. These could include specific input requirements as well as guidelines for the timing of field operations.

[3] Note that this assumption is not critical under acreage contracts because the monopsonist would never offer a price above the salvage value for any spot market production in years when the aggregate production on contracted acres is below his operating capacity. This implies no producer would ever choose to produce the specialty crop without a contract. However, under bushel contracts there exists a positive probability that a spot market for the specialty crop will exist *ex post*, and that the price on that spot market may be higher than the premium offered by the processor in the contract because of excess demand. The assumption that the processor will only purchase specialty crop production from "verified" acres is critical to the results of the paper, as it prevents any producer from choosing to speculatively produce the specialty crop for the spot market (referred to in the industry as "wildcatting").

[4] The problem outlined in this paper can be thought of as a short-term optimization problem for the processor. A long-term optimization problem would include the choice of the optimal plant capacity. Discussions with industry representatives in Iowa justified the assumption of an exogenous capacity constraint in a given period.

[5] Note that this assumption may not hold for certain specialty varieties. As an example, waxy corn cannot be sold on the #2 yellow corn market.

[6] Net processing returns R are assumed to be net of the handling charge δ for processed bushels below the capacity constraint.

[7] N could also be loosely interpreted as the number of counties in which the processor offers the contract. In reality, N may be a discrete variable, but for modeling purposes its assumed to be continuous.

[8] Alternatively, r could be interpreted as the expected commodity price at harvest and that specialty crop yields within the contract region are uncorrelated with the commodity market price. This interpretation would not affect the results given the risk-neutrality assumptions for both the processor and producers.

[9] These costs are the producer analogue of the processor's handling charge δ.

[10] The term spatial here is used loosely. The only spatial aspect in the model is the spatial correlation of yields across farmers. Transportation costs are assumed equal across producers.

[11] While not explicitly motivating the model as a principal-agent problem, the processor's consideration of producer's actions is analogous to rationality constraints within a principal-agent framework.

[12] If yields at the farm level were assumed independent, normality could be assumed as an approximation for the distribution of total procurement using the Central Limit Theorem.

However, it is widely accepted that crop yields exhibit positive spatial correlation. Therefore, no assumptions are made on the functional form of *g*, or the distribution of yields at the farm level *f*. The cost of this generality, as usual, is the inability to derive explicit analytic solutions for the contract equilibriums in either the acreage or bushel contract cases.

[13] Note that if the aggregate yield realization is such that only one farmer would not be able to fulfill his contract obligation with purchases on the spot market the prevailing spot market price would not be p^u. There is no solution in this specific case where there are a limited number of buyers bidding for a fixed supply. This is the same problem faced by Carriquiry and Babcock (2004). For simplicity, it is assumed that farmers expect the price on the specialty crop spot market to be bid up to p^u for all excess demand scenarios.

[14] This is assuming $p^u \geq r$ in equilibrium, which is shown to hold, and that yields are positively correlated across space.

[15] Again, from a principal-agent perspective, the constraints on the underage penalty would be analogous to incentive compatibility constraints.

[16] Note that this result would also hold for risk-averse producers, at least in a mean-variance framework. By definition, expected producer profits are equal under the proposed bushel and optimal acreage contracts, while the variance of expected profits under the proposed bushel contract are actually smaller than the optimal acreage contract $\left(\left(\left(r + p^{A*}\right)\sigma_y\right)^2 \geq \left(r\sigma_y\right)^2 \text{ for } p^{A*} \geq 0\right)$.

[17] A (possibly) more realistic assumption would be that the correlation structure was a function of the size of contracting region *N* and the distance between farming operations. However, this would have required estimation (and possible misspecification) of a relationship between distance and correlation of yields as well as significantly increased the computing time needed for solution convergence. The simpler approach was adopted because of a lack of farm-level data for specialty crop yields.

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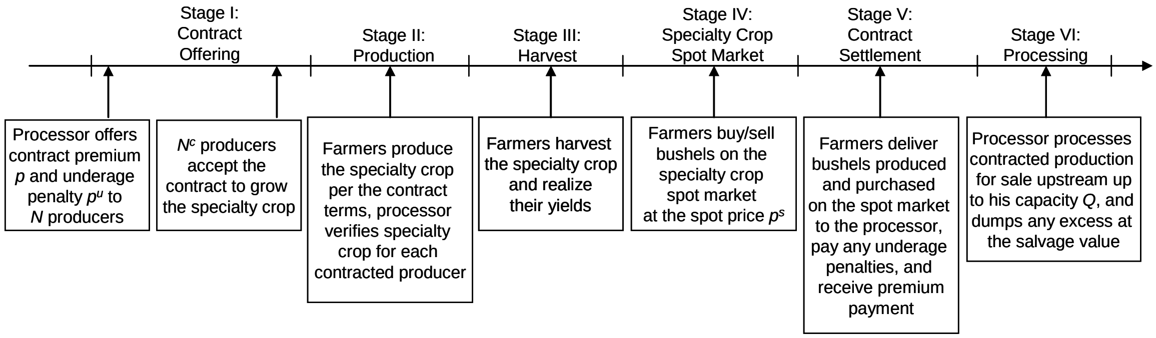

Figure 1: Timeline of the contract process

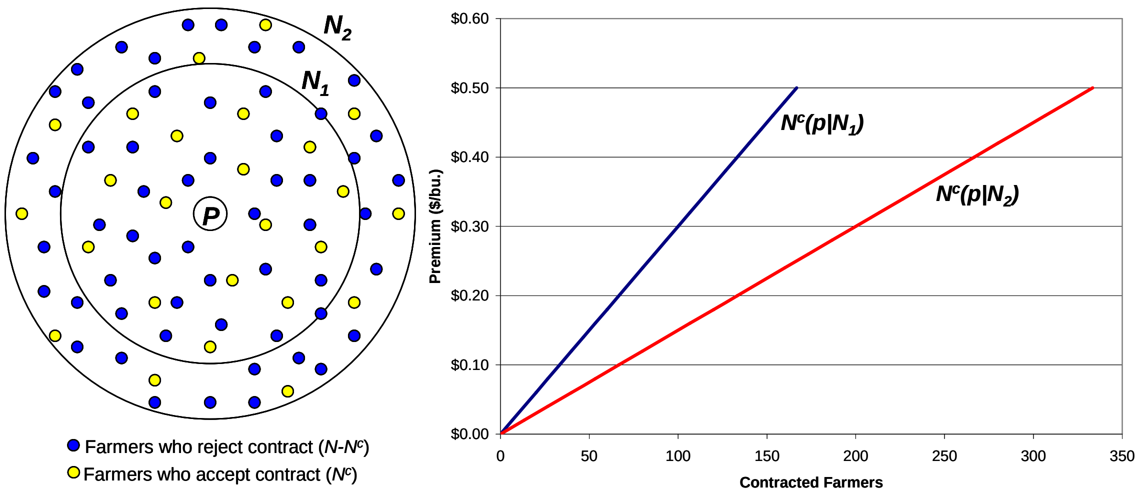

Figure 2. Effects of the premium and contract region size on the processor's contract supply curve.

Table 1. Baseline Parameter Values

Parameter	Value	Parameter	Value
$\bar{y}$	100	R	1.4
c^u	150	r	1
β	0.00355	a	12
Q	10000	b	12
δ	0.00	y_{max}	200

Table 2. Optimal Acreage Contracts, $\sigma_y = 20$, $\delta = 0$

	$y_i = \bar{y}$	$y_i \sim f(y) = Beta(a,b,y_{max})$			
$\rho_{i,j}$	-	0.00	0.50	0.80	1
$p^A{*}$	0.2	0.1971	0.1866	0.1844	0.1828
$N^A{*}$	750	728.43	652.91	637.91	626.62
N^c	100	95.72	81.22	78.42	76.36
$E[\Pi]$	1000	998.38	966.59	953.80	945.74
$E\left[\sum_i \left(\pi_i^A - \pi_i^C\right)\right]$	1000	943.32	757.78	723.03	697.93

Table 3. Optimal Acreage Contracts, $\sigma_y = 20$, $\delta = 0.10$

	$y_i = \bar{y}$	$y_i \sim f(y) = Beta(a,b,y_{max})$			
$\rho_{i,j}$	-	0.00	0.50	0.80	1
$p^A{*}$	0.2	0.1970	0.1861	0.1837	0.1820
$N^A{*}$	750	727.74	649.15	632.91	621.02
N^c	100	95.58	80.54	77.51	75.35
$E[\Pi]$	1000	998.30	964.60	950.73	942.45
$E\left[\sum_i \left(\pi_i^A - \pi_i^C\right)\right]$	1000	941.46	749.42	711.93	685.69

Table 4. Optimal Bushel Contracts, $\sigma_y = 20$

	$y_i = \bar{y}$	$y_i \sim f(y) = Beta(a,b,y_{max})$			
$\rho_{i,j}$	-	0.00	0.50	0.8	1
$p^B{*}$	0.20	0.1956	0.2183	0.2183	0.2139
$N^B{*}$	750	753.53	654.12	654.12	694.24
N^c	100	97.16	88.03	85.22	84.87
$E[\Pi]$	1000	1027.70	1208.40	1240.23	1202.46
$p^u{*}$	-	1.400	1.400	1.400	1.299
$p^{s.u}$	-	1.200	1.303	1.342	1.299
$p^{s,o}$	-	1.200	1.099	1.058	1.000
$E\left[\sum_i \left(\pi_i^B - \pi_i^C\right)\right]$	1000	944.27	888.55	832.74	833.82

Table 5. Optimal Acreage Contracts, $\sigma_y = 40$, $\delta = 0$

	$y_i = \bar{y}$	$y_i \sim f(y) = Beta(a, b, y_{max})$			
$\rho_{i,j}$	-	0.00	0.50	0.80	1
p^A*	0.2	0.1947	0.1779	0.1742	0.1719
N^A*	750	710.77	593.73	568.98	554.07
N^c	100	92.26	70.42	66.08	63.50
$E[\Pi]$	1000	994.63	916.95	891.83	876.44
$E\left[\sum_i\left(\pi_i^A - \pi_i^C\right)\right]$	1000	898.15	626.39	575.56	545.78

Table 6. Optimal Acreage Contracts, $\sigma_y = 40$, $\delta = 0.10$

	$y_i = \bar{y}$	$y_i \sim f(y) = Beta(a, b, y_{max})$			
$\rho_{i,j}$	-	0.00	0.50	0.80	1
p^A*	0.2	0.1946	0.1768	0.1732	0.1707
N^A*	750	709.84	586.28	562.72	546.29
N^c	100	92.09	69.10	64.98	62.17
$E[\Pi]$	1000	994.32	912.61	886.37	870.83
$E\left[\sum_i\left(\pi_i^A - \pi_i^C\right)\right]$	1000	896.04	610.84	562.73	530.62

Table 7. Optimal Bushel Contracts, $\sigma_y = 40$

	$y_i = \bar{y}$	$y_i \sim f(y) = Beta(a, b, y_{max})$			
$\rho_{i,j}$	-	0.00	0.50	0.8	1
p^B*	0.20	0.1987	0.1987	0.1986	0.1984
N^B*	750	735.50	735.50	735.44	644.25
N^c	100	95.39	80.81	74.25	67.55
$E[\Pi]$	1000	1065.83	1352.32	1363.11	1310.83
p^u*	-	1.400	1.400	1.400	1.169
$p^{s,u}$	-	1.20	1.303	1.343	1.169
$p^{s,o}$	-	1.20	1.099	1.058	1.000
$E\left[\sum_i\left(\pi_i^B - \pi_i^C\right)\right]$	1000	927.51	666.15	612.07	623.16