QUALITY MEASUREMENT AND CONTRACT DESIGN: LESSONS FROM THE NORTH AMERICAN SUGARBEET INDUSTRY

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Abstract. We examine contracts used in the North American sugarbeet industry. Though quite similar in many respects, the contracts we study vary across processing firms in the set of quality measures used to condition contract payments to growers. This is somewhat surprising given the homogeneous nature of the processors' finished product (refined sugar). It seems unlikely that processors differ significantly in how they value the various attributes of a sugarbeet, and such a difference is perhaps the most natural reason to expect variation in the structure of quality incentives across processors. Previous attempts to explain the observed variation in sugarbeet contracts have focused on differences in organizational form across firms. In this paper, we provide an alternative explanation that relies on variation across production regions in growers' ability to control the relevant measures of sugarbeet quality.

Introduction

Contract designs differ substantially across agricultural commodity sectors where growers and intermediaries coordinate their activities contractually. The design features that may or may not be observed in any given commodity include third party quality measurement, relative performance evaluation (e.g., tournaments), multi-year commitments, and direct intermediary involvement in farm-level decision making. It is perhaps natural to expect this kind of variation across commodity sectors. Differences in the nature of the final output, in the structure of the relevant production and processing technologies, and in institutional features of the relevant markets (e.g., farm policy), alter the coordination needs of contracting parties, and hence result in different contract designs. It is perhaps less natural to expect variation within commodity sectors, though even this is observed. One striking example occurs in North American sugarbeet markets. In these markets, contract payments to growers in one set of production regions depend only on measured sugarbeet *quantity*, while in another set of production regions payment depends on both measured sugarbeet quantity and *quality* (as represented by the degree of sugar "purity").

This sort of variation might be expected if processors had different end uses for sugarbeets, and hence valued quality differently.[1] But there is very little product differentiation in the production and marketing of refined sugar, so this explanation seems unlikely. An alternative explanation is based on the observation that many of the firms that condition payment on quality happen to be cooperatives (Balbach 1998, Sykuta and Cook 2001). It is argued that cooperative organizations are able to use such a contract, because grower and "firm" objectives are more closely aligned. However, this does not account for the observation that there are also *non*-cooperative firms that condition payment on quality, *and* cooperative firms that do not.

In this paper, we argue that the observed variation in contract structure can arise quite naturally from differences across production regions in the nature of the tradeoff between sugarbeet quantity and quality. Briefly, producing beets with a high degree of sugar purity (which is primarily achieved through reduced nitrogen use) comes at the cost of reduced beet yield. Because total refined sugar from an acre's production depends on sugar purity *and* yield, there is not an obviously "optimal" way to manage this tradeoff. For example, it may be efficient to produce relatively impure beets—an outcome that can be achieved by paying growers only on sugarbeet quantity—if increasing purity results in very large yield reductions.

To make this argument precise, we develop a model of contract design that captures the essential features of the sugarbeet contracting environment, and show how the value of measuring sugarbeet quality can be relatively low when the stochastic relationship between sugarbeet quantity and quality is such that growers have little control over quality. This corresponds to a situation where quality is not very "informative" in a sense we make clear below. Before presenting our model and results, we first describe sugarbeet contracts more fully, and document the type of variation in contract structure that is observed.

Sugarbeet Contracts: Description

Sugarbeets are grown by eleven processors across six major production regions in the United States and Canada (Lilleboe 1999/2000; U.S. Department of Agriculture

[1]See Wu (2001) for an analysis along these lines in the context of processing tomato contracts.

1999). These regions include the Red River Valley (North Dakota), Great Lakes (Michigan and Ohio), Great Plains (Colorado, Nebrask, Montana), Northwest (Idaho and Oregon), Southwest (mostly California), and Canada (mostly Alberta). All sugarbeet contracts between processors and growers use a measure of total estimated sugar quantity to adjust per-ton payments to growers.[2] Some processors also adjust payments to growers with a measure of sugarbeet quality. Although the total sugar content of a load of beets may be high, various impurities in sugarbeets can lead to low production of the final product (refined sugar), and "quality" is the estimated "extraction rate," or percentage of pure sugar, for a load of beets (Cooke and Scott 1993). Total refined sugar production in a load can thus be estimated by multiplying its weight by the percent measured sugar content and extraction rate.

Interestingly, most of the variation in contract structure that is observed occurs across, rather than within, regions (Balbach 1998). Contracts that condition grower payment only on sugar quantity are referred to by people in the sugarbeet industry as the "Western" contract, and, as its name suggests, is the predominate form in Western production regions (Great Plains, Northwest, and Southwest). In this contract, processors compute an average annual price for refined sugar sales that is net of various marketing and handling costs, and then adjust this price based on the measured sugar content of growers' beets. Growers and processors thus share in the aggregate price risk associated with refined sugar, and there is no sense in which payments are adjusted for sugarbeet purity.

There are two kinds of contracts that condition payment in some way on sugarbeet purity. The first of these, referred to in the sugarbeet industry as the "Eastern" contract (predominate in the Great Lakes region), does so indirectly by making the base payment to growers depend on the average annual price for the sale of *all* sugar products, including those derived from extracted impurities.[3] Since the price for the primary sugar product is high relative to secondary products associated with sugarbeet impurities, growers face some (though rather weak) incentive to deliver beets with a relatively high degree of sugarbeet purity. The base price is then adjusted

[2]Sugar "quantity" is measured as the total weight of beets delivered multiplied by the measured percent sugar content of the beets.

[3]The most important of these is molasses, which is essentially a by product of the sugar refining process, and is obtained directly from impurities.

for each load of beets according to measured sugar quantity in relation to the average measured sugar quantity across all loads delivered during the relevant crop year. The Eastern contract thus uses a form of relative performance evaluation that reduces aggregate production risk associated with producing beets with a high sugar content.

Finally, the so called "extractable sugar contract," which is the predominant contract in the Red River Valley and in Canada, directly adjusts grower payment according to measured quantity and quality (extraction rate), and is thus considerably more "high powered" than the Eastern contract with respect to incentives for delivering beets with a high degree of sugarbeet purity. Given that total sugar production is the product of sugar content and the extraction rate, it is a bit surprising that this latter measure is not used by *all* processors. Intuitively, the extractable sugar contract seems more "efficient" in the sense that growers are given a more accurate signal concerning the relative value of alternative sugarbeet attributes.

For example, Balbach (1998) and Sykuta and Cook (2001) observe that the extractable sugar contract is used primarily by cooperative processors, and argue that these firms are able to use this more "efficient" contract because firm and grower objectives are more closely aligned, relative to private or investor-owned firms. However, as noted earlier, this observation is not universal.[4] Moreover, there are reasons to doubt that the organizational structure of a firm should affect efficient contract design. There would have to be a good reason to believe that the set of observable and contractible signals of performance differed across firm types. In the context of sugarbeet contracts, procedures used to measure the relevant quantity and quality signals are quite standard, and it is difficult to imagine reasons why a firm, regardless of its organizational structure, could not choose to contract on both measures, if doing so increased expected surplus.

In this paper, we argue that differences in contract structure can arise in response to variation in growing conditions across the various production regions. This argument is consistent with the observation that contract form varies consistently across

[4]In particular, the Michigan Sugar Beet Growers (a grower cooperative) use a version of the Eastern contract, and thus represents an instance of a cooperative firm that *does not* use the extractable sugar contract. Rogers Sugar, an investor owned firm in Alberta, Canada, uses a version of the extractable sugar contract, and thus represents an instance of a noncooperative firm that *does* use the extractable sugar contract. (source: Personal communication by the authors with representatives from each firm.)

regions, and not across firms within a given region. Of course, given the limited number of observations on the various contract types, it is impossible at this point to statistically reject either hypothesis, though later in the paper we suggest ways in which appropriate data might be collected to carry out such a test.

In what follows, we develop a simple model that demonstrates how the nature of the stochastic relationship between farm-level inputs, and quantity and quality outcomes, influences the value of including different performance measures in a contract. In the case of sugarbeet production, nitrogen is the key input that affects realizations of both quantity and quality measures (Cattanach, Dahnke, and Fanning 1993; Cooke and Scott 1993), and is apparently noncontractible.[5] As indicated earlier, nitrogen applications tend to increase total sugarbeet production, and reduce the degree of sugarbeet purity. Conditioning payment on sugarbeet purity is thus a means of addressing the perverse effect of nitrogen on total extractable sugar. The benefit of using quality incentives will therefore be largest in environments where this effect is most acute, and it is natural to expect the nature of this tradeoff to vary across production regions. Imagine for example, that nitrogen applications increase sugar quantity substantially in some region, but have little impact on sugar purity. Intuitively, the benefits from conditioning payment on quality in this region will tend to be low, because there is not much need to moderate nitrogen use.

In the following section, we develop a formal model of sugarbeet contract design where the stochastic relationship between quantity and quality is explicitly related to the value of including these measures in the contract. Our model is somewhat novel in that it considers multiple performance measures that can enter grower compensation in any arbitrary (possibly nonlinear) fashion, and does not rely on the so called "first-order approach" as in Sinclair-Desgagne (1994). This is important for the sugarbeet example, because actual contracts are multiplicative in the observed performance measures, and a standard linear contracts (e.g., Holmström and Milgrom (1994)) framework is thus both unsuitable and intractable.

[5] Interestingly, although no sugarbeet contract we have seen precisely specifies nitrogen application procedures (timing, method, and rate), each of the contracts do have provisions that prohibit certain practices. For example, in one Western contract, there is a provision that stipulates, "The grower will not apply nitrogen fertilizer, in any form, to the sugarbeet crop after July 15th without written permission of the company."

Sugarbeet Contracts: Theory

Model Setup

We model sugarbeet contracting between a processor and a single grower, and for simplicity assume the contract governs exchange of a single acre's production. Realized production from this acre is represented by its estimated sugar content $q \in Q \equiv \{q_1, \ldots, q_l\}$, and the estimated fraction of this sugar that is "recoverable", $r \in R \equiv \{r_1, \ldots, r_m\}$.[6] We let $s \equiv (r, q)$ denote the full vector of signals, and define $S \equiv \{(r, q) | r \in R, q \in Q\}$ to be the set of all possible realizations of s. The notation $s \geq s'$ has the usual componentwise meaning.

The grower conditions the joint distribution of s with the amount (measured in dollars per acre) of nitrogen $a \in A \equiv \{a_1, \ldots, a_n\}$ applied to his crops,[7] assumed noncontractible, and other production inputs that we suppress for notational simplicity. The set A is ordered with $a_i < a_j$ for $i < j$, and the probability of outcome s is denoted by $\pi(s|a) > 0$ with $\sum_S \pi(s|a) = 1$ for all $a \in A$.

For nitrogen level a and compensation w, grower utility is given by some von Neumann-Morgenstern utility function $H(w, a)$ satisfying:

Assumption 1. *Grower utility $H(w, a)$ can be written as $G(a) + K(a)U(w)$ with*

(i) *U real-valued, continuous, strictly increasing, and concave on some open interval $W = (\underline{w}, \infty)$;*

(ii) $\lim_{w \to \underline{w}} U(w) = -\infty$;

(iii) *G and K real-valued and continuous on A with K strictly positive;*

(iv) *for all $i < j$ and $w, \widehat{w} \in W$, if $G(a_i) + K(a_i)U(w) \geq G(a_j) + K(a_j)U(w)$ then $G(a_i) + K(a_i)U(\widehat{w}) \geq G(a_j) + K(a_j)(\widehat{w})$.*

[6] As alluded to in the previous section, there are actually three signals used in sugarbeet contracts: the quantity of beets delivered, their estimated percent sugar content, and the estimated "extraction rate" (i.e., sugarbeet purity). Thus, in our model, q represents the estimated quantity of sugar delivered (the per-acre yield for a single acre's production times estimated percent sugar content), and r represents the estimated extraction rate, or the estimated amount of delivered sugar that can be recovered in processing. Explicitly modeling all three signals unnecessarily complicates presentation, without adding any additional insight.

[7] We might also think of a representing any arbitrary set of noncontractible "actions" that influence the joint distribution of quantity and quality, though for this setting we often refer to a as "nitrogen" which is the primary input affecting the joint distribution of r and q.

This set of assumptions is intended to allow for the greatest possible degree of generality in grower preferences, while preserving analytic tractability of the model (Grossman and Hart 1983). In particular, as we describe in more detail below, preferences that take this form allow the processor's contract design problem to be solved in two stages, with the first stage being a simple linear program.[8] Special cases of $H(w, a)$ commonly employed in the principal-agent literature include additively separable disutility of effort and utility from compensation (e.g., $K(a) \equiv 1$, $G(a) < 0$, decreasing in a and convex, and $U(w) > 0$ increasing and concave), and exponential utility with multiplicative separability (e.g., $G(a) \equiv 0$, $K(a) = e^{\rho a}$, and $U(w) = -e^{-\rho w}$, where ρ is interpreted as the grower's degree of constant absolute risk aversion).

Because we interpret a as the dollar cost of nitrogen use, it is also natural to assume that for given w, utility is lower for higher a:

Assumption 2. *For all w, $G(a_i) + K(a_i)U(w) \geq G(a_j) + K(a_j)U(w)$ for $i < j$.*

The processor is assumed risk neutral, with the value of an acre's production given by $V(r, q)$, assumed increasing in both arguments. The processor prefers high quantity and quality, but we do not make any explicit assumptions about the *relative* value of these measures. In keeping with our objective to evaluate the influence of variation in the structure of $\pi(s|a)$ on the value of quality measurement, we will take $V(r, q)$ to be a given, but will allow $\pi(s|a)$ to take on a variety of forms that are intended to capture possible technological differences across the various sugarbeet production regions.

Reservation utility for the grower is denoted by $\underline{H}$. To induce participation by the grower, the processor must ensure that its contract offers an expected utility at least as large as $\underline{H}$. Under full information, the processor can observe and verify the level of nitrogen applied by the grower. Let $C_{FB}(a) \equiv U^{-1}\left(\frac{\underline{H}-G(a)}{K(a)}\right)$ represent the first-best cost of getting the grower to choose action a. When action a is contractible, the processor can pay the grower $C_{FB}(a)$ if the grower chooses a, and otherwise impose a large penalty. From Assumption 2, it follows that $C_{FB}(a_i) \leq C_{FB}(a_j)$ for $i < j$.

[8]The restrictions embodied in Assumption 1, which restrict the way a and w interact, rule out lotteries in the optimal contract. Compensation lotteries are ruled out because the grower's preferences over income lotteries are independent of his action. Similarly, action lotteries are never optimal because, from part (iv) of Assumption 1, the grower's ranking over *perfectly certain* actions is independent of income.

When a is noncontractible, the processor pays the grower conditional on the realization of s. Denote compensation given a particular outcome s by $w(s)$, and let $u(s) = U(w(s))$. Grossman and Hart (1983) show that the processor's contract design problem can be solved in two stages. In the first stage, the processor chooses $u(s)$ to minimize the cost of implementing a given action (subject to individual rationality and incentive compatibility constraints), and in the second stage chooses the action that yields the highest expected net benefit. The optimal compensation schedule is then computed as $w(s) = U^{-1}(u(s))$. Let $C(a)$ denote the minimum cost of implementing action a. If for some a, there is no feasible solution, then we set $C(a) = \infty$; such an a is not implementable. The optimal level of nitrogen use is the one that solves

$$V_s \equiv \max_a \sum_S \pi(s|a)V(r,q) - C(a).$$

Now suppose there is some strictly positive cost m that must be incurred to measure r. The benefit associated with this measurement is given by the expected increase in profits to the principal from conditioning w on s, relative to a contract that is conditioned only on q. Define V_q as the maximum net benefit to the principal from a contract conditioned only on q. Then it is optimal to condition compensation on s when $\Delta \equiv V_s - m - V_q > 0$.

Based on the discussion in our introduction, we would like to evaluate how a change in the structure of $\pi(s|a)$ affects the (expected) value of measuring r, given by Δ. To do this, we impose a structure on $\pi(s|a)$ that is intended to capture the essential features of the tradeoff between quantity and quality inherent in sugarbeet production.

Sugarbeet Technology

We consider the simplest possible environment where there is a meaningful tradeoff between quantity and quality, and where choosing a "moderate" level of nitrogen use may be efficient. There are two possible outcomes for each signal, and the grower selects from three possible levels of nitrogen use. Let q_L and q_H, with $q_L < q_H$, and r_L and r_H, with $r_L < r_H$ denote the possible values of quantity and recoverable sugar, respectively. Then, the full vector of signals $s \equiv (r, q)$ has four possible realizations, $S \equiv \{(r_L, q_L), (r_L, q_H), (r_H, q_L), (r_H, q_H)\}$. Let $s_1 \equiv (r_L, q_L)$, $s_2 \equiv (r_L, q_H)$,

$s_3 \equiv (r_H, q_L)$ and $s_4 \equiv (r_H, q_H)$, $v_i = V(s_i)$, and $u_i = u(s_i)$, for $i = 1, \ldots, 4$. The processor's payoff is an increasing function of yield and recoverable sugar, so we have $v_1 \leq \min\{v_2, v_3\}$ and $v_4 \geq \max\{v_2, v_3\}$. For simplicity, we further assume that $v_i \neq v_j$ for $i \neq j$. Then, since the processor's payoffs are distinct under all four realizations of the signal s, the ability of the two parties to contract on s is equivalent to contracting on the realization of v.

The grower has a choice over three levels of nitrogen, $A \equiv \{a_1, a_2, a_3\}$, where $a_1 < a_2 < a_3$. The probability distribution over the v_i's induced by action a_i is given in Table 1. We assume that a_1 is some arbitrarily "bad" action that induces a high probability of q_L and r_L, relative to actions a_2 and a_3. We include this action to ensure that the optimal contract is never a fixed payment. We also assume $l_i > 0$ and $\sum_i l_i = 1$, and similarly for p_i. We noted earlier that increasing nitrogen tends *on average* to decrease purity r and increase quantity q. In the context of our model, we take this to mean that expected r and q decrease and increase, respectively, in moving from action a_2 to action a_3. Thus, we assume $\delta_1 + \delta_2 < 0$ (expected r falls) and $\delta_1 + \delta_3 > 0$ (expected q increases). To ensure that $\pi(v_i|a_3)$ is a probability measure, we further suppose that $0 < p_i - \delta_i < 1$, for all i. All of the analytical results we derive in what follows rely solely on this set of restrictions. In particular, there are no restrictions placed on the probabilities of individual pairs of outcomes. When we specify our model for computational purposes later in the paper, we choose a specification where moving from a_2 to a_3 increases the probability of (r_L, q_H) ($\delta_2 < 0$) and decreases the probability of (r_H, q_L) ($\delta_3 > 0$). Although this last pair of restrictions seem intuitively plausible given the influence of nitrogen on sugarbeet quantity and quality, they are not necessary for the analytical results derived in this section.

	$\pi(v_i \vert a_1)$	$\pi(v_i \vert a_2)$	$\pi(v_i \vert a_3)$
v_1	l_1	p_1	$p_1 - \delta_1$
v_2	l_2	p_2	$p_2 - \delta_2$
v_3	l_3	p_3	$p_3 - \delta_3$
v_4	l_4	p_4	$p_4 + \sum_i \delta_i$

TABLE 1. Probability of v_i given a_i

Let $B(a_i) = \sum_j \pi(v_j|a_i)v_j$ denote the expected benefit to the processor if the grower picks action a_i. When $\delta_1 + \delta_3$ is relatively large, and the absolute value of $\delta_1 + \delta_2$

is relatively small, choosing action a_3 instead of action a_2 (increasing nitrogen use), raises expected output substantially, without significantly reducing expected quality. This will tend to make a_3 a preferred action, relative to a_2. Intuitively, the value of using two signals is largest when action a_2 is preferred (i.e., when it is important to provide incentive for moderating nitrogen use). Thus, we expect that the value of measuring quality will be relatively low for a technology with large $\delta_1 + \delta_3$ and small absolute value of $\delta_1 + \delta_2$. To evaluate this intuition more carefully, we need to consider the effect of measuring r on expected net benefits. We do this in the next section.

Contract Design

$s-$contract. We start by supposing the two parties contract on both signals of the grower's action. The processor faces three constraints for implementing action a_2. First, the grower must be offered a contract that generates an expected utility at least as large as his reservation utility $\underline{H}$:

$$G(a_2) + K(a_2) \sum_{j=1}^{4} p_j u_j \geq \underline{H}. \tag{1}$$

Next, given the contract offered by the processor, choosing action a_2 must yield the grower at least as much expected utility as choosing action a_1, and similarly for action a_2 with respect to action a_3:

$$G(a_2) + K(a_2) \sum_{j=1}^{4} p_j u_j \quad \geq \quad G(a_1) + K(a_1) \sum_{j=1}^{4} l_j u_j, \tag{2}$$

$$G(a_2) + K(a_2) \sum_{j=1}^{4} p_j u_j \quad \geq \quad G(a_3) + K(a_3) E[u|a_3], \tag{3}$$

where $E[u|a_3] = (p_1 - \delta_1)u_1 + (p_2 - \delta_2)u_2 + (p_3 - \delta_3)u_3 + (p_4 + \delta_1 + \delta_2 + \delta_3)u_4$. The cost of implementing action a_2 is then given by

$$C_s(a_2) = \min_{u_1,\ldots,u_4} \{\sum_j p_j h(u_j) \mid (1), (2), (3)\},$$

where $h \equiv U^{-1}$.

Similarly, to implement action a_3 the processor faces the constraints

$$G(a_3) + K(a_3)E[u|a_3] \geq \underline{H}, \tag{4}$$

$$G(a_3) + K(a_3)E[u|a_3] \geq G(a_1) + K(a_1)\sum_{j=1}^{4} l_j u_j \tag{5}$$

$$G(a_3) + K(a_3)E[u|a_3] \geq G(a_2) + K(a_2)\sum_{j=1}^{4} p_j u_j, \tag{6}$$

and the cost of implementing a_3 is given by

$$C_s(a_3) = \min_{u_1,\ldots,u_4} \{E[h(u)|a_3] \mid (4),(5),(6)\},$$

where $E[h(u)|a_3] = (p_1 - \delta_1)h(u_1) + (p_2 - \delta_2)h(u_2) + (p_3 - \delta_3)h(u_3) + (p_4 + \delta_1 + \delta_2 + \delta_3)h(u_4)$. We assume that both actions are implementable ($C_s(a_2) < \infty$ and $C_s(a_3) < \infty$), and that for both cost minimization problems, the equilibrium u_i satisfy $u_4 \geq \max\{u_1, u_2, u_3\}$. This (relatively weak) form of monotonicity allows us to analytically derive a number of useful comparative static results.

Without further parameterizing our model, we cannot determine which action maximizes the net benefit to the principal. However, we can determine how changes in the parameters δ_1, δ_2, and δ_3 affect the second-best action. Similar to the two-stage algorithm used for characterizing the optimal contract, we perform comparative statics by separately considering the effect of parameters on the expected payoff to the principal $B(a)$ and the cost $C(a)$ of implementing a given action. For example, if changing a parameter increases the net payoff $B(a) - C(a)$ for action a, while the net payoffs for other actions decrease or remain unchanged, then we can say that such a change may make a second-best, when previously it was not

Consider first an increase in parameter δ_1, which corresponds to a reduction in the probability of simultaneously observing both low r and low q, and a corresponding increase in the probability of simultaneously observing both high r and high q. The benefit $B(a_2)$ is unaffected by such an increase, while $C_s(a_2)$ is nondecreasing. This is easily verified by observing that an increase in δ_1 results in a smaller constraint set for the processor's cost minimization problem with respect to action a_2 (the right-hand-side of the inequality in (3) increases). Thus, the net payoff $B(a_2) - C_s(a_2)$ decreases as a result of an increase in δ_1. Analogously, it is straightforward to verify that an increase in δ_1 leads to an increase in the net payoff $B(a_3) - C_s(a_3)$. Thus, as δ_1 increases, the expected net benefit from action a_3 relative to action a_2 also increases (the difference between $B(a_3) - C_s(a_3)$ and $B(a_2) - C_s(a_2)$ increases). For δ_1 sufficiently large, a_3 will be the efficient action. Similar reasoning can be employed to show that increases in δ_2 and δ_3 also increase the expected net benefit of action a_3 relative to action a_2.

Intuitively, an increase in each δ_i (which recall for δ_2 may mean a reduction in its absolute value) raises the expected benefit of choosing a_3 over a_2 because the probability of the best possible outcome (r_H, q_H) increases. The cost of implementing action a_2 also goes up: the grower receives the highest possible payment when (r_H, q_H) is realized, and because choosing action a_3 increases this probability by a larger amount when δ_i increases, it becomes more difficult to implement action a_2.

$q-$contract. Now we consider the scenario where the two parties contract only on q. There are two possible outcome states, q_L and q_H, on which compensation can be conditioned. We denote compensation when q_L (resp. q_H) is realized by u_L (resp. u_H), and note that $\Pr[q_L|a_3] = p_1 + p_3 - \delta_1 - \delta_3$, and $\Pr[q_H|a_3] = p_2 + p_4 + \delta_1 + \delta_3$. To implement action a_2, the following participation and incentive compatibility constraints must be satisfied:

$$(7) \qquad G(a_2) + K(a_2)[(p_1 + p_3)u_L + (p_2 + p_4)u_H] \geq \underline{H},$$

$$(8) \qquad G(a_2) + K(a_2)[(p_1 + p_3)u_L + (p_2 + p_4)u_H] \geq G(a_1) + K(a_1)[(l_1 + l_3)u_L + (l_2 + l_4)u_H],$$

and

$$(9) \qquad G(a_2) + K(a_2)[(p_1 + p_3)u_L + (p_2 + p_4)u_H] \geq G(a_3) + K(a_3)[\Pr[q_L|a_3]u_L + \Pr[q_H|a_3]u_H].$$

The minimum cost of implementing action a_2 with a contract conditioned only on q is then given by

$$C_q(a_2) = \min_{u_L, u_H} \{(p_1 + p_3)h(u_L) + (p_2 + p_4)h(u_H) \mid (7), (8), (9)\}.$$

Similarly, to implement action a_3, the processor must satisfy

$$G(a_3) + K(a_3)(\Pr[q_L|a_3]u_L + \Pr[q_H|a_3]u_H) \geq \underline{H}, \tag{10}$$

$$G(a_3) + K(a_3)(\Pr[q_L|a_3]u_L + \Pr[q_H|a_3]u_H) \geq \tag{11}$$
$$G(a_1) + K(a_1)[(l_1 + l_3)u_L + (l_2 + l_4)u_H],$$

and

$$G(a_3) + K(a_3)[\Pr[q_L|a_3]u_L + \Pr[q_H|a_3]u_H] \geq \tag{12}$$
$$G(a_2) + K(a_2)[(p_1 + p_3)u_L + (p_2 + p_4)u_H],$$

and the minimum cost of implementing action a_3 with a contract conditioned only on q is

$$C_q(a_3) = \min_{u_L, u_H} \{\Pr[q_L|a_3]h(u_L) + \Pr[q_H|a_3]h(u_H) \mid (10), (11), (12)\}.$$

As in the previous subsection, we consider how parameters δ_i affect the optimal second-best action. Since δ_2 does not enter any constraint, it only affects the processor's objective function. An increase in δ_2 therefore increases the expected net benefit of action a_3, relative to a_2. Intuitively, δ_2 does not affect the probability of high q under action a_3, but does make the outcome (r_H, q_H) more likely, relative to (r_L, q_H). Thus, for a given contract, the grower's incentive to choose a_3 over a_2 remains unchanged, while expected benefits to the principal go up. It is also not difficult to show that an increase in either δ_1 or δ_3 leads to an increase in the difference between $B(a_3) - C_q(a_3)$ and $B(a_2) - C_q(a_2)$. An increase in either of these parameters lowers the cost of implementing action a_3 relative to action a_2, and increases the expected net benefit under action a_3.

Comparative Static Results

The comparative static results from the previous two subsections are summarized in Table 2.

In all cases, net benefits weakly go up (resp. down) under action a_3 (resp. a_2) when δ_i increases. Ultimately, however, we are not interested in these comparative

	$B(a_2) - C_s(a_2)$	$B(a_2) - C_q(a_2)$	$B(a_3) - C_s(a_3)$	$B(a_3) - C_q(a_3)$
δ_1	$-$	$-$	$+$	$+$
δ_2	$-$	0	$+$	$+$
δ_3	$-$	$-$	$+$	$+$

TABLE 2. Comparative static results.

statics *per se*, but rather in the effect of each parameter on Δ, which is the *difference* between expected net benefits under the two different information regimes. Such a comparison can only be made after identifying the second-best action under each regime. In what follows, we consider all possible scenarios (of which there are only two). In the first scenario, the second-best action is the same under each regime; either a_2 is the equilibrium action under both types of contracts, or the equilibrium action is a_3. In the second scenario, a_2 is second-best when contracting on s, but a_3 is second-best when contracting only on q.[9]

Suppose first that the second-best action is the same under each information regime. In this case, changes in Δ are due entirely to differences in implementation costs. From Table 2, increases in δ_1 and δ_3 change net benefits in the same direction under both information regimes, and thus have an ambiguous effect on Δ. When δ_2 increases, the net benefit of implementing action a_2 decreases under the two-signal contract, and remains unchanged under the one-signal contract. When a_3 is second best, increasing δ_2 raises net benefits under both information regimes, but by a smaller amount for the two signal contract.[10] Thus, when a_2 (resp. a_3) is second-best, increasing δ_2 unambiguously reduces (resp. increases) Δ. We summarize the comparative static effects of δ_2 (which is the only parameter that yields unambiguous results for this scenario) on the expected value of quality measurement Δ in the following result:

Result 1. *If action a_2 (resp. a_3) is second-best under both information regimes, then increasing δ_2 reduces (resp. increases) the expected benefit from quality measurement.*

Heuristically, when the equilibrium action is a_2, the benefit from quality measurement comes from the processor's ability to distinguish between (r_L, q_H) and (r_H, q_H).

[9]It is not difficult to verify that if a_3 is optimal when contracting on s, then it is also optimal when contracting only on q. Thus, there is no need to consider the converse of the second scenario above.
[10]Expected benefits go up by the same amount under both types of contracts. The cost implementing action a_3 goes down when contracting on s, and remains constant when contracting only on q.

This distinction is particularly important if (r_L, q_H) is more likely under a_3 than under a_2 (which holds under the intuitively plausible assumption that $\delta_2 < 0$). Associating a relatively low payment with this outcome therefore provides incentive to *not* choose a_3. The power of this incentive is weakened as δ_2 increases (becomes less negative), making the distinction between (r_L, q_H) and (r_H, q_H) less valuable. When a_3 is the equilibrium action, an increase in δ_2 has no effect on implementation costs under the one-signal contract (because the probabilities of observing q_L or q_H remain unchanged), while implementation costs fall under the two-signal contract. This increases the benefit from quality measurement.

We consider the scenario where equilibrium actions are the same under each information regime for completeness, though later we argue that the empirically relevant case is the one where second-best actions are different under the two regimes. For this case, inspection of Table 2 yields the following result:

Result 2. *If action a_2 is second-best when contracting on s, and action a_3 is second-best when contracting only on q, then increasing δ_1, δ_2, or δ_3 decreases the expected value of quality measurement.*

Increases in δ_i make a_3 a "better" action through two channels. First, expected benefits increase under a_3 because expected quantity goes up and expected reductions in quality go down. Second, the cost of implementing action a_3 relative to action a_2 goes down: the grower has greater incentive to choose a_3, because doing so increases the probability of receiving the highest possible payment. Because the primary benefit from quality measurement comes from being able to implement a_2 at lower cost, the expected value of quality measurement falls.

Thus, there are two different scenarios to consider when trying to answer the question, how do changes in the nature of the stochastic relationship between quantity and quality outcomes affect the expected benefits of quality measurement? The scenarios are defined by which set of actions are second-best under each regime. When the actions implemented under the two information regimes are the same, it is generally difficult to determine how changes in the δ_i influence the expected value of quality measurement. However, increasing the probability of r_H, while holding the total probability of q_H constant (i.e., increasing δ_2) has an unambiguous affect, which differs depending which of the two actions is second best.

When the actions implemented under the two information regimes are different (action a_2 implemented when contracting on s, and action a_3 implemented when contracting only on q), improvements in the productivity of action a_3 (increasing the δ_i's) unambiguously reduce the value of quality measurement. Taken together, Results 1 and 2 are consistent with the intuition outlined in our introduction that the benefit of measuring and contracting on quality is relatively large when doing so moderates nitrogen use, relative to a contract where quality is not measured. This is because the additional signal r provides a means of rewarding high purity, even as q may fall, and this is the outcome that is achieved with moderate nitrogen use.

As noted in our introduction, processors are universally concerned with growers' fertility practices, and in particular with avoiding excessive nitrogen applications. Contract incentives are used to moderate applications, and encourage relatively high-purity outcomes. Result 2 thus seems like the empirically relevant scenario. However, regardless of which result is the empirically relevant one, we have demonstrated that the value of quality measurement can differ across production regions if there is variation in the nature of the tradeoff between quantity and quality. In the next section we evaluate our comparative statics computationally. In addition to confirming the analytic comparative static results discussed in this section, computation allows to get some sense for the potential *magnitude* of the benefit from quality measurement.

Computations

We suppose that the processor values the quality/quantity attributes (r, q) according to $V(r, q) = rq - c(r)$, where for simplicity we set the price of refined sugar equal to 1, and

$$c(r) = \begin{cases} \bar{c} & \text{if } r = r_L \\ 0 & \text{if } r = r_H \end{cases}$$

where $\bar{c}$ is the cost of processing beets with low recoverable sugar. The grower is assumed constant absolute risk averse with $G(a) = 0$, $U(w) = -e^{-\rho w}$, and $K(a) = e^{\rho a}$, where ρ is the grower's measure of constant absolute risk aversion. We let $r_L = .15$,

$r_H = .17$, $q_L = 24$, $q_H = 26$, and $\bar{c} = 0.05$ (roughly 1 percent of expected revenue). Nitrogen use can be either .2, .3, or .4 (these numbers are in units of 100 dollars per acre). Finally, we let $l = (.5, .3, .15, .05)$ and $p = (.2, .3, .3, .2)$, where $l \equiv \pi(s|a_1) \equiv (l_1, l_2, l_3, l_4)$ denotes the vector of outcome probabilities conditioned on action a_1, and p the outcomes probabilities conditioned on a_2.

Table 3 summarizes comparative static results for the parameters δ_i, holding ρ constant. The column labeled "Relative Efficiency" contains the value of $\Delta/C_{FB}(a_2)$ for each set of parameters, representing the expected benefit from quality measurement as a percentage of first-best compensation at action a_2. We use this normalization because we do not have good information about processing costs, and it is therefore difficult to evaluate the magnitude of Δ by itself. The "Action" and "Compensation" columns, contain second-best actions and compensation schedules, respectively, when only q ("$q-$contract") is contractible and when s is contractible ("$s-$contract").

	$\delta_1 = .1$		$\delta_3 = .1$	$\rho = .8$	
	Action		Compensation Schedule		
δ_2	$q-$contract	s-contract	q-contract	$s-$contract	Relative Efficiency
-.15	.4	.3	.31,.88	.35,.59,.66,.69	.151
-.175	.4	.3	.31,.88	.35,.59,.66,.69	.175
-.20	.2	.3	.48,.48	.35,.59,.66,.69	.179
	$\delta_1 = .14$		$\delta_3 = .2$	$\rho = .8$	
	Action		Compensation Schedule		
δ_2	$q-$contract	s-contract	q-contract	$s-$contract	Relative Efficiency
-.15	.4	.4	.35,.75	.32,.72,.54,.74	.006
-.175	.4	.3	.35,.75	.35,.59,.66,.70	.019
-.20	.4	.3	.35,.75	.35,.59,.66,.70	.040

TABLE 3. Computed comparative static results for δ_i. "Relative Efficiency" measures the surplus gain from contracting on s relative to q, computed as the increase in expected surplus, Δ, relative to first best compensation, $C_{FB}(a_2)$ at action a_2.

The first three rows of Table 3 correspond to changes in δ_2 for relatively low values of δ_1 and δ_3. Because $a = .4$ is efficient when contracting on q and $a = .3$ is efficient when contracting on s, the expected benefit from quality measurement increases with decreases in δ_2 from roughly 15 percent of first-best compensation when $\delta_2 = -.15$ to 18 percent of first-best compensation when $\delta_2 = -.20$. When contracting only on q, action $a = .2$ is efficient for δ_2 sufficiently small, even when action $a = .3$ is first best.

This is because implementing a moderate level of a is very costly when contracting only on q, and because a_3 becomes a less productive action when δ_2 falls (expected r falls, while expected q remains constant). Also, note that for given actions, the structure of the optimal contract is invariant with respect to changes in δ_2. When contracting only on q this occurs because an increase in δ_2 does not affect the relative probabilities of low and high q. When contracting on s, this occurs because the only binding incentive constraint turns out to be the one for action a_2 with respect to action a_1. When the incentive constraint for action a_2 with respect to action a_3 is not binding, the parameter δ_2 does not affect implementation costs under action a_2.

The second three rows of Table 3 correspond to changes in δ_2 for relatively high values of δ_1 and δ_3. Note that the value of quality measurement (relative to first-best compensation) is substantially lower for this set of parameter values, ranging between .6 percent and 4 percent of first-best compensation. When a_3 is a relatively productive action, there is little benefit from quality measurement. Also, note that action $a = .4$ is efficient for δ_2 sufficiently low, even when contracting on s. This occurs because for this set of parameter values, action $a = .4$ becomes first best.

Though we did not consider the effect of risk aversion in our analytic comparative statics, intuitively one might expect increased risk aversion to make quality measurement more valuable. When there are more signals of the grower's action, the processor can achieve similar incentives with less risk in the compensation schedule. Table 4 confirms this intuition. The value of quality measurement is relatively low when the grower is not very risk averse. Because we do observe quality measurement in some instances, this result provides some degree of support for the hypothesis that sugarbeet growers are risk averse. However, this support is weak since quality measurement can be valuable even when contracting with a risk-neutral grower. None of the comparative statics in Table 2 relied in any way on the growers' degree of risk aversion.

Discussion

We have presented a model and formal analysis to demonstrate why one might expect to observe different sets of performance measures used in grower/processor contracts

$\delta_1 = .1$		$\delta_2 = -.15$		$\delta_3 = .1$	
	Action		Compensation Schedule		
δ_2	$q-$contract	s-contract	q-contract	$s-$contract	Relative Efficiency
.50	.4	.3	.46,1.04	.51,.75,.82,.86	.104
.70	.4	.3	.34,.92	.39,.63,.70,.74	.136
.90	.4	.3	.28,.85	.32,.56,.63,.67	.165

TABLE 4. Computed comparative static results for grower risk aversion, ρ.

across the various sugarbeet production regions. In short, the expected benefits from quality measurement may be low in areas where sugarbeet purity is not a very "informative" signal of unobserved grower actions (Holmström 1979). Intuitively, this will be the case when sugarbeet purity does not respond much to grower actions, or in other words when growers do not exercise much control over sugarbeet purity. There are a variety of factors that can generate this kind of environment. For example, suppose some other input, say irrigation, is complementary with nitrogen in the sense that it increases the expected marginal purity of nitrogen applications.[11] In comparing two regions, one irrigated and one nonirrigated, one would then observe that sugarbeet purity is less "responsive" to nitrogen applications on irrigated ground (purity falls by less when nitrogen applications increase). A reasonable test of our hypothesis could then be constructed with observations on the performance measures used in contracts across irrigated and nonirrigated production regions.

Of course, observed production inputs other than irrigation, and region-specific growing conditions, also influence the distribution of quantity and quality outcomes conditional on unobserved grower actions. Nevertheless, in principle one could collect agronomic data across the various production regions to quantify the degree of potential "control" over sugarbeet purity. One relevant metric for this purpose would be the variance of the likelihood ratio for the joint distribution of quantity and quality associated with different levels of nitrogen application (Kim 1995). One could then see if such a measure added some explanatory power in a regression of contract choice (the set of performance measures included in a contract) on various exogenous

[11]Winter (1990) provides evidence that such a complementarity indeed exists.

regressors (location, firm type, firm size, etc.). Unfortunately there is no readily available secondary data from which such a measure might be constructed, and carrying out the necessary experimentation (across each of the relevant production regions) to generate primary data would be quite costly. Nevertheless, empirical work along these lines represents a potentially productive avenue for future research.

Although we have talked at considerable length about the relative value of quality measurement in sugarbeet contracts, we have said very little about the *cost* of quality measurement. Since it will normally be the case that sugarbeet purity provides *some* additional information, relative to total sugar content, the expected benefits of quality measurement will generally be positive. Thus, in order for our argument to have merit, it is important to identify costs associated with conditioning grower payment on quality that may outweigh expected benefits. We can think of at least two sorts of costs. First, quality must be measured, and this takes additional time and resources that can be avoided when quality is not measured. However, anecdotal evidence and conversations with industry participants suggests that in the case of measuring sugarbeet purity these kinds of measurement costs are actually quite low. Second, introducing a second performance measure into grower contracts substantially increases the complexity of the contracts, both in terms of their design and implementation. Contract design requires assessing the distribution of outcomes (conditional on a variety of potential grower actions), which in the case of two signals is of course multivariate. If there are m possible outcomes for sugar content and n possible outcomes for sugarbeet purity, the number of contingent payments that need to be specified increases by a factor of $n(m-1)$ when comparing a contract conditioned only on q, with a contract conditioned on s. It seems reasonable to expect that processors (and growers) would want to avoid these contract design costs if the expected benefits from improved design were small.

Conclusion

We use principal-agent theory to explain variation in the structure of contracts used in the North American sugarbeet industry. This particular industry is interesting to study because we observe clearly identifiable variation in the set of performance measures used to condition contract payments to growers. Processors in one set of regions use a contract that conditions grower payment on both total sugar production and sugarbeet purity, while in the remaining regions contract payments depend only on total sugar production. We develop a simple model that shows how the observed variation can occur in response to regional differences in the stochastic relationship that governs quantity and quality outcomes conditional on grower actions.

Briefly, growers' use of nitrogen to fertilize their crops is a key input affecting quantity and quality outcomes. More nitrogen tends to increase the total amount of sugar produced on a given plot of land, but also to reduce sugarbeet purity. The efficient use of nitrogen therefore requires managing a tradeoff between total sugar content and sugarbeet purity. When a contract is conditioned only on total sugar production, growers have an incentive to apply large amounts of nitrogen. When payment also depends on sugarbeet purity, some incentive is provided to reduce the amount of nitrogen applied. Thus, intuitively, the benefit from quality (purity) measurement will be low when nitrogen applications do not have a large influence on sugarbeet purity, or in the language of agency theory, when sugarbeet purity is not an informative signal with respect to unobserved grower actions. Thus, if measuring quality is costly (so that it is only carried out when the benefits of doing so are sufficiently high), we would expect to see variation in the use of quality measurement across production regions, if differences in growing conditions alter the informativeness of sugarbeet purity as a signal of performance.

Although we are unable to provide much direct agronomic evidence that such variation indeed exists, our explanation is at least consistent with the observation that the set of performance measures used in contracts varies consistently across production regions, rather than across firms within regions. We also offer suggestions for how one might go about collecting the data needed to test our hypothesis. It is unclear at this point how one could go about testing our hypothesis against the (potentially) competing hypothesis mentioned in our introduction that the observed differences in contract structure can be explained by differences in the organizational structure of processing firms. These two explanations are in no way nested. Nevertheless, attempts to empirically validate either or both explanations represent potential avenues for future research.

Finally, although we have focused on how variation in the grower's sugar production technology can influence contract design, variation in the *processing* technology can have a similar effect. To see this, note that even though the end product of sugarbeet processing (refined sugar) is homogeneous, processors may differ in how they value purity if they possess different technologies for processing sugarbeets. For example, if processors with more advanced sugar extraction technologies face a lower cost of extracting impurities, then the value of contracting on purity may be lower. Consideration of both contrat and technology choice thus represents an interesting possible extension of our analysis. The model in this paper is well suited to such an examination. Choice of technology could be modeled as selection of a valuation function $V(r, q)$ by the processor. An extended model would consist of an *ex ante* choice of technology followed by the strategic interaction considered in this paper.

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