Interactions Between Incentive Instruments: Contracts and Quality in Processing Tomatoes

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Contracting and other forms of vertical coordination are important parts of the supply chains for many agricultural products. Often the buyer cares about multiple product attributes affected by a grower's actions. Using data that are insulated from common methodological problems, we test whether or not price incentives for two processing tomato quality attributes exhibit complementarity in improving delivered quality. Price incentives for the two attributes are substitutes for the provision of one and complements for the other. This finding has consequences for the profit-maximizing choice of incentive instruments for processors, and contributes to the literature regarding tests for complementarities.

Key words: agricultural contracts, complementarity, incentives, processing tomatoes, quality, vertical coordination.

JEL Codes: D86, Q13.

Contracting and other forms of vertical coordination are important parts of the supply chains for many agricultural products. In many cases, the buyer cares about multiple product attributes that are influenced by a grower's actions. One natural way for the buyer to induce the grower to deliver output with a better set of attributes is to provide incentives for more than one attribute. If the buyer does so, he must consider interactions among the effects of these incentives on the grower's actions (Holmstrom and Milgrom 1991, 1994; Hart, Shleifer, and Vishny 1997). Our analysis tests whether or not price incentives for two specific quality attributes of processing tomatoes—material other than tomatoes (MOT) and limited use tomatoes (LU)—exhibit complementarity in improving delivered quality by reducing MOT, LU, and other negative quality attributes.

Previous research has established that tomato growers respond to price incentives for quality attributes (Hueth and Ligon 2004; Wu 2005; Alexander, Goodhue, and Rausser 2007). Our analysis goes beyond this literature to address a question that has long plagued the designers of multiple-incentive contracts; namely, given that growers respond to price incentives, do price incentives interact when incentives are offered for more than one quality attribute, and if so, are there unintended consequences? Because of the biological relationships governing tomato quality and production, we expect there to be interactions, but their nature will be influenced by growers' profit-maximizing behavior, which in turn is affected by the incentives offered by the processor.

Because we are interested in testing for complementarity, it is important to be able to control for unobserved heterogeneity. Unobserved heterogeneity can lead to correlation among decision variables, even in the absence of complementarities (Athey and Stern 1998). Other studies either do not address this issue or implement estimation strategies intended to mitigate any unobserved heterogeneity.[1]

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[1] Bai and Xu (2005) and Mohapatra, Goodhue, and Rozelle (2008) examine interactions among incentive instruments for managers of Chinese state-owned firms and township and village enterprises, respectively. Brickley (1999) examines franchising contracts. Outside of contracting, empirical studies testing for complementarities have focused primarily on determinants of productivity (Ichniowski, Shaw, and Prellushi 1997; Brynjolfsson and Hitt 2000;

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In our case the nature of our data eliminates most unobservable heterogeneity: we have a single processor who designs the contract each year, and every grower in a given year who contracts with the processor must use the same contract. Consequently we are able to test for an interaction between two incentive instruments using a relatively simple estimation strategy: seemingly unrelated regressions (SURs). Our data include a subset of growers who sell to the processor under a contract and without a contract each year, which allows us to re-estimate our empirical specifications with an additional control for any unobserved heterogeneity that influences an agent's decision to contract. Results are consistent between the full dataset and the subsample.

Because we observe grower performance for tomatoes sold under contract and on the spot market, concerns regarding growers' self-selection into contracting that apply to other econometric studies in the agricultural contracting literature are mitigated (e.g., Knoeber and Thurman 1994). At the delivery level, growers' ability to select individual loads of tomatoes for the spot market is greatly limited by institutional features of the processing tomato industry combined with the biology of processing tomatoes.

Institutional Context: California Processing Tomato Industry

California produces over 90% of U.S. processing tomatoes (National Agricultural Statistics Service 2009). Processing tomatoes were California's tenth most valuable agricultural commodity in 2007, with a value of production of $849 million. Approximately 300,000 acres were harvested in 2007, primarily in the Sacramento and San Joaquin Valleys (California Department of Food and Agriculture 2008). Planting occurs from January through May in order to create a continuous harvesting season from July until October (Hartz et al. 2008). The majority of the crop is made quickly into tomato paste, which is later reprocessed into ketchup, tomato sauce, and other products. Processing tomatoes are also canned, dried, and frozen.

Black and Lynch 2001; Caroli and Van Reenen 2001; Bresnahan, Brynjolfsson, and Hitt 2002; Miravete and Pernias 2006).

Prior to delivery to the processing plant, every load of processing tomatoes in California is legally required to be graded at a state inspection station. Each load is graded for seven quality attributes: a color score, the sugar content, and the percentage of each of five negative quality attributes: MOT, LU, mold, green tomatoes, and worms. Regardless of whether a load is sold under contract or on the spot market, it is subject to weight deductions for excessive levels of any of these five attributes.[2] The field identification tag, which includes the "contract number"[3] for a given load, must be provided to grading station personnel prior to the grading of the load, along with the name of the processor purchasing the load and the grower selling it (California Department of Food and Agriculture 1996). The contract number defines the conditions of sale, so it distinguishes between contract and spot sales. Generally the processor provides transportation from the grower's field to the grading station and on to the processing plant.

Industry members estimate that roughly 97% of California processing tomatoes are delivered under contract. The remainder are spot market deliveries. Some of these tomatoes are from production in excess of that required to meet contractual obligations, and some are grown without a contract. Although the spot market's share of total deliveries is small, it is important, according to industry members. Processors use spot market purchases to cover any gaps in contracted deliveries in order to ensure that their plants can operate throughout the season. If a processing plant shuts down, it is very expensive to reopen because it must be resterilized.

All contracts are negotiated between individual processors and the California Tomato Growers Association (CTGA), a state-sanctioned collective bargaining agent. These negotiations establish a base price and any price incentives for quality. Although fewer than half of the state's growers belong to the CTGA, processors are prohibited from offering a lower-price contract to nonmembers. Thus, the contracts offered by processors are take-it-or-leave-it contracts from the

[2] See Starbird (1994) for additional information regarding the California processing tomato grading system.

[3] A contract number is assigned to every compensation agreement and denotes the terms of sale. It is not assigned to only contract sales. A processor may have one contract number denoting the terms under which contract tomatoes are produced, and multiple ones specifying prices at which spot tomatoes are purchased at different points in time.

perspective of an individual grower, meaning that contract terms are exogenous.[4] In addition to price incentives, contracts generally specify tonnage and fields and/or acreage to be devoted to producing tomatoes under that contract, as well as other provisions (Hartz *et al.* 2008). The contractual specification of fields and the language of the contract regarding the grower's obligations provide the processor with a legal claim on all tomatoes harvested from those fields until the grower's delivery commitment is satisfied (Hamilton 1995).

Price incentives represent a processor's efforts to achieve higher quality levels than those induced by the weight deduction system. The negotiations between the CTGA and a processor do not address the levels of incentives for individual attributes or which attributes have incentives. Rather, they address the expected contribution of the set of price incentives to the total payment per ton received by the grower. Hence, by understanding the interactions between incentive instruments for different attributes on the delivered shares of those attributes, a processor can maximize quality improvement through price incentives for any negotiated share of compensation for a load of average quality. In terms of incentive design, a processor must know the sign of the effect of each incentive on each quality attribute, whether pairs of incentives are independent or interact, and, if the latter, whether they are substitutes or complements for a given attribute.

The quality of a delivered load is a function of the grower's profit-maximizing harvest decisions and the load's preharvest quality. The grower chooses the harvest time and harvester speed that maximize expected profits. The harvesting process destroys the vines, so harvest is a onetime event. Tomato quality evolves over time, so the choice of the harvest date affects quality and expected returns. The harvest interval for peak quality is two to three days, depending on variety and harvest time weather. The harvest interval for acceptable quality is much longer, extending up to two weeks.

Processing tomatoes are harvested mechanically. All tomato harvesters sort for quality using two methods: a mechanical sorter and human sorters. Roughly speaking, the sorters' joint effectiveness can be defined as the reduction in the share of defects between a harvested and a delivered load. At lower speeds, both are more effective, so that lower harvester speeds increase the expected delivered quality of each load, but also increase the per-load cost of harvesting (Gould 1992). The mechanical sorter is better at identifying MOT than other quality defects, but its performance improves in both dimensions at slower speeds. No matter how slowly the harvester goes, sorting does not eliminate undesirables entirely due to human and mechanical error.

We focus on two tomato quality attributes—LU and MOT—that are unaffected by grower production decisions and exogenous factors outside the harvest window period (with the exception of the choice of variety affecting LU). Because these attributes are unaffected by decisions earlier in the growing season, whether spot sale tomatoes were grown originally in order to meet a contract obligation or without a contract should not alter the levels of LU and MOT. LU denotes tomatoes that are overripe, often split or squashed, and so soft that their processing use is limited. The percentage of LU in a load is a function of a number of factors, including tomato variety, the temperature at harvest and in the days immediately preceding it, and the speed of the mechanical tomato harvester. A grower chooses the tomato variety prior to planting, often in cooperation with the processor. High temperatures at harvest increase the share of LU. A grower can reduce the share of LU by harvesting at night. Because nighttime temperatures are lower, there will be a smaller share of LU in a delivered load. A grower can also reduce the share of LU by reducing the speed of the harvester. MOT describes all material other than tomatoes that arrives at the processing plant, such as vines, dirt, and insects. Unlike LU, MOT is almost completely under a grower's control. The slower the harvester, the more effective the sorters are at eliminating MOT. Preharvest grower decisions do not influence MOT. Weather near the time of harvest virtually never influences MOT.[5]

[4] While the CTGA's membership agreement provides conditions under which a grower can negotiate a contract containing a base price and premium individually with a processor (California Tomato Growers Association, n.d.), there were no instances of such a contract in our dataset.

[5] Conceivably rain could lead to more dirt and vines being harvested at any given speed. However, most of the harvest season is during California's dry season, which ends in September or October. Furthermore, the ground must be dry enough to operate the harvester. These considerations suggest that weather does not affect MOT substantially.

Given this quality production process, the effect of introducing a MOT premium on the share of MOT and other quality defects is clear. Because only harvest speed affects MOT, a MOT premium will lead to a lower speed and hence lower shares of all quality defects in a load, including LU.

While the LU premium will reduce LU in a delivered load, its effect on MOT is not obvious. If the grower responded to the premium only by slowing the harvester, MOT would decrease. However, the grower has other options to reduce LU. Harvesting at night will reduce the incremental gain of slowing the harvester; at any harvester speed, less LU will be delivered. The grower may even increase harvester speed in response to a LU premium, because nighttime harvesting reduces harvested LU, which in turn will reduce the benefit of slowing the harvester in order to eliminate more LU from the delivered load. If this were the case, we would expect a LU premium to increase MOT.

Such cross-effects are of great interest to tomato processors, who choose price incentives in order to encourage growers to produce tomatoes with desirable quality attributes. If a MOT premium reduces LU as well as MOT, as predicted above, then it may be better to implement a substantial MOT premium rather than dividing the negotiated premium amount into a MOT premium plus a LU premium. On the other hand, if a LU premium increases MOT, the processor may have to design an offsetting premium for MOT if it wishes to introduce a LU premium. If both premiums reduce one of the attributes, the two incentive instruments may be complements or substitutes. This relationship will affect the processor's returns from different menus of incentives.

Data

Our data include quality information on every load of tomatoes delivered to a processing plant in a four-year period, whether each load was under contract or purchased on the spot market, and the contract terms for each year. Our dataset contains roughly 147,000 observations. Approximately 1.8% of the tomatoes were purchased on the spot market, consistent with the share of spot market purchases in the farmgate processing tomato market as a whole. Regardless of year, spot market purchases did not receive any price incentives for quality. Our dataset includes deliveries from approximately 120 growers. Of these growers, about 80% made only contract deliveries, about 9% made only spot market deliveries, and about 12% made both contract and spot market deliveries. We estimate the effects of price incentives on tomato quality and test for the presence of complementarities using the entire dataset and using only the subset of growers who made both contract and spot market deliveries. The subset includes roughly 33,000 observations.

Contract Provisions

The contractual price incentives for LU and MOT across the four years of our sample combined with the presence of spot market loads allow us to test for complementarities between the two price incentives. In the first year, there was no MOT premium. In years 2, 3, and 4 there was a MOT premium for levels under 0.5%. There was a LU premium schedule in years 1, 3, and 4. Hence, our contracted loads provide us with quality observations associated with the presence of both a MOT and a LU premium schedule (*YY*), only a MOT premium (*YN*), and only a LU premium schedule (*NY*). Our spot market loads provide us with quality observations in the absence of both premiums (*NN*). For our full sample, 71,842 observations are in the *YY* category, 37,244 are in the *YN* category, 34,934 are in the *NY* category, and 2,582 are in the *NN* category. For our subsample (excluding growers who sold on only the spot market or sold only under contract), 7,824 observations are in the *YY* category, 17,977 are in the *YN* category, 6,037 are in the *NY* category, and 991 are in the *NN* category. The *NN* loads account for 1.8% of the loads in the full sample and 3% of the loads in the subsample. While these percentages are small, a two-sample Hotelling's T-Square test allowing for unequal variance-covariance matrices rejects at the 1% level the hypothesis that both mean LU and mean MOT are equal for contract and spot loads in the subsample. *t*-Tests for the equality of means across spot and contract deliveries for MOT and for LU individually rejected the null hypotheses for both the full sample and the subsample.

Quality

The average share of MOT did not vary much by year (table 1). There are greater annual variations in the share of delivered loads subject to weight deductions. Of delivered loads, 62.6% were not subject to weight deductions based

Table 1. Average Percentage MOT and LU by Year

	MOT (*SD*)	*LU* (*SD*)
Year 1	0.26 (0.37)	2.03 (1.86)
Year 2	0.24 (0.37)	1.63 (1.58)
Year 3	0.25 (0.38)	1.66 (1.90)
Year 4	0.21 (0.35)	1.83 (1.64)

on MOT. Annual shares ranged from 59.2% to 67.0%. By year, the cumulative percentage of loads with 0.99% MOT or less was virtually constant, ranging from 91.8% to 93.9%.

The average share of LU varied by about 20% to 25% over the four sample years, much more than did the average annual share of MOT. In contrast, annual differences in the share of loads subject to weight deductions for excessive LU were much smaller than those for MOT. For the sample as a whole, 95.3% of the loads had LU shares of less than 5.5% and thus were not subject to weight deductions. Annual shares ranged from 94.0% to 96.5%. Many loads had substantially lower shares of LU—79.6% had LU levels below 2.5%, of which 9.9% were in the 0.0% to 0.49% category; 20.5% were in the 0.5% to 0.99% category; 18.5% were between 1.0% and 1.49%; 13.9% were between 1.5% and 1.99%; and 9.8% were between 2.0% and 2.49%. Annual shares of loads with LU below 2.5% ranged from 67.3% to 76.4%.

Although differences across years in the shares of MOT and LU in delivered loads are fairly small, in each case the year with the highest share was the year in which contract growers were not offered a premium for the attribute in question. Table 2 provides another descriptive measure of the effect of incentives by comparing the annual means and standard deviations of MOT and LU for contract and spot market deliveries. Both MOT and LU varied by year. In three of the four years, the average share of MOT in contract deliveries was lower than the average share of MOT in spot market deliveries. A premium for MOT was offered in only two of those years.

The relationship in the no-MOT-premium year is consistent with either growers not responding to price premiums for MOT or growers responding to a LU premium, lowering the share of MOT. It is also consistent with growers responding to having a contract by improving tomato quality regardless of whether or not a MOT premium is offered, perhaps due to a desire to be offered a contract in the future. The year in which contract growers received a MOT premium but delivered tomatoes with higher MOT than spot market growers is consistent with growers not responding to a MOT premium.

The same pattern holds for differences in LU between annual contract and spot market deliveries. Contrary to theoretical predictions, the lowest average LU for contract deliveries was realized in the year in which there was no LU price premium. Because of the effects of harvest-time weather on LU, it is not surprising that a simple annual average does not conform to theoretical predictions, but the behavior of the share of MOT combined with the behavior of the share of LU suggests that there may be interaction effects between premiums for the two quality attributes.

Model

We specify a system of equations regarding tomato quality which we estimate using seemingly unrelated regressions (SUR) (Zellner 1962). The first equation is for MOT. Because MOT is determined by harvester speed, it is a function of the incentive regime. We include $K-1$ year-week dummies YW_k to capture the effects of weather, and $I-1$ grower dummies G_i to control for any differences in grower skill making these decisions and any other grower heterogeneity:

$$(1)\quad \text{MOT} = f\left(YY, YN, NY, \sum_{k=1}^{K-1} YW_k, \sum_{i=1}^{I-1} G_i\right).$$

The second equation regards the determination of LU, which we hypothesize is influenced by the incentive regime and biological factors. Because LU is affected by tomato variety, $J-1$ variety dummies V_j are included. Week dummies and grower dummies are included for the same reasons as in the MOT equation.

$$(2)\qquad LU = g\left(YY, YN, NY, \sum_{j=1}^{J-1} V_j, \times \sum_{k=1}^{K-1} YW_k, \sum_{i=1}^{I-1} G_i\right):$$

The third equation addresses a summary measure of other quality attributes, $DEDUCT$. It sums the weight deductions due to mold, worms, and green tomatoes. These deductions

Table 2. Average Percentage MOT and LU by Year and Contract Type

	MOT		*LU*	
	Contract (SD)	Spot (SD)	Contract (SD)	Spot (SD)
Year 1	0.25	0.55	1.96	4.13
Contract: LU premium only	(0.36)	(0.48)	(1.77)	(3.00)
Year 2	0.24	0.28	1.63	2.31
Contract: MOT premium only	(0.37)	(0.40)	(1.57)	(2.78)
Year 3	0.25	0.31	1.66	1.78
Contract: MOT and LU premiums	(0.38)	(0.45)	(1.90)	(1.74)
Year 4	0.21	0.14	1.84	1.66
Contract: MOT and LU premiums	(0.35)	(0.26)	(1.64)	(1.41)

are affected by grower ability, variety, and weather (especially rain, which leads to mold). We hypothesize that the contract regime may affect *DEDUCT* by altering the grower's harvester speed decision. Thus, the *DEDUCT* equation is

$$(3) \qquad \mathrm{DEDUCT} = h\left(YY, YN, NY, \sum_{k=1}^{K-1} \times YW_k, \sum_{i=1}^{I-1} G_i, \sum_{j=1}^{J-1} V_j\right).$$

One potentially confounding feature of our data is that the levels of the price incentives we analyze are not constant across years. Because we estimate the effect of the existence of a specific price incentive, rather than the effect of its specific premium schedule, the coefficients we use to test for the presence of complementarity may simply be reflecting the differences in incentive menus across years rather than true cross-effects. For MOT there is only a single premium, for less than 0.5% MOT. This premium is twice as high in the *NY* regime as in the two years of the *YY* regime, which suggests that differences in MOT premium levels may lead us to reject the hypothesis that complementarities are present when it is true. For LU, the quality-premium schedule varies, and there is no clear direction of bias. While the maximum premium is lower under the *YN* regime than either *YY* regime year, the premiums at the annual averages are roughly equal. Regarding the range of the premium schedules, one *YY* regime has the same range of qualities to which a premium is assigned as the *YN* regime, but the range of premiums is larger. The other *YY* regime has the same slope as the *YN* regime but extends over twice as many quality levels, ending only where weight deductions for excessive LU begin. It also includes negative premiums at the lower end of the range.

Another potentially confounding factor is the presence of price incentives for two additional quality attributes, sugar content and mold. Fortunately, the scope of the possible influence of such incentives is limited in our data. While premiums for sugar content were offered all four years, the primary way to increase sugar content is to reduce yield. Because the base price is per ton delivered, the relatively small sugar premiums do not justify reducing yield, according to growers. Supporting growers' statements, previous studies have shown that premiums do not have a statistically significant effect on sugar content (Alexander, Goodhue, and Rausser 2007) or have an effect that is very dependent on the precise econometric specification (Wu 2005). A mold premium was offered in one of the two *YY* regime years. The maximum achievable mold premium was exactly equal to the difference between the associated *YY* MOT premium and the higher *YN* MOT premium. Because rain is the primary reason there would be a large share of mold in a load, a grower can only respond to a mold premium by either harvesting early if rain is predicted (and risk weight deductions for a high share of green tomatoes) or slowing the harvester. The limited scope for grower decision making and the magnitude of the price incentive suggest that at most the mold premium will partially offset any bias due to the difference in MOT premium levels across the *YN* and *YY* regimes.

A third potentially problematic factor is our use of dummy variables to indicate contract regimes. These dummies do not estimate marginal incentives to improve quality at a given quality outcome, which are dependent upon the precise position of that point in the multivariate quality distribution. To the extent that the use of dummy variables groups points on the quality distribution where incentives to improve quality are nonpositive with ones where the incentives are positive, the null hypothesis that contractual incentives do not improve delivered quality is less likely to be rejected.

A final consideration is that we do not control for selection bias. The institutional characteristics of the processing tomato market and biological characteristics of processing tomatoes limit substantially the ability of growers to select which tomatoes are spot sales. Because the terms of sale and the buyer must be furnished to the grading station prior to grading, the grower cannot use the results as a basis for selection. Because the processor provides transportation from the field to the grading station and on to the plant, a grower cannot assign tomatoes on a load-by-load basis without being observed by the processor's agents. If a grower is selling contract tomatoes to one processor and spot sale tomatoes to another, he will not be able to assign tomatoes on a load-by-load basis because the processor's employees (or contracted service providers) will be able to observe if trucks from a competing processor are being loaded from the same field. If a grower intends to sell both types of tomatoes to a single processor, then the processor will be able to observe the selection decision and either prohibit it directly or inform the grower that future contracts are at risk due to this behavior. Because contracts specify the field(s) from which tomatoes must be delivered, the processor has a legal claim on the tomatoes until the grower's contractual delivery obligation is met. Within our subsample, consistent with this legal structure, growers who delivered both contract and spot tomatoes of a given variety in a given year always delivered contract tomatoes before spot tomatoes. Of course, this observation is also consistent with contractual incentives inducing growers to provide contract loads first due to the effect of weather on LU.

If the sequencing of loads is due to weather effects on LU, then labeling this response selection implies that at the time harvest is initiated, there is a known or expected change in LU. If there is any known difference in LU within a field or across fields included in a single contract, a grower can choose the highest-quality location to begin harvesting and first deliver contract tomatoes. Any such selection is unlikely to be important in our analysis. Variations in LU within a field or across nearby fields are likely to be small for a given variety harvested at a given time for reasons observable at the beginning of harvest, because realized and expected weather are common factors prior to harvest. Any observed differences in LU are driven by additional heat absorbed by the tomatoes between the beginning and the end of the harvest period, plus two decisions made by the grower: the speed of the harvester and whether or not to harvest at night. The grower can predict that tomatoes will absorb additional heat during harvest. However, the effect of this additional heat on tomato quality can be either positive or negative, and is most likely small due to the limited time frame over which harvesting occurs.

Beyond these considerations, there is one critical biological constraint that places an absolute limit on a grower's scope for selection: the perishability of processing tomatoes. Tomatoes have a limited harvest period before they rot, so selection is possible for only a short period. This fact allowed us to check our subsample to see the extent to which selection bias could be a problem for our analysis. We identified the grower-variety-year triples for which both contract and spot tomatoes were delivered within a 4-day window that encompasses the window for maximum quality at harvest. We also identified the grower-variety-year triples for which both contract and spot tomatoes were delivered within a 15-day window that encompasses the window for acceptable quality at harvest. Because every grower in such a triple was observed to have delivered contract and spot loads within a quality window, he could potentially select loads for the spot market. Of the 310 grower-variety-year triples in our subsample, 15 exhibited the potential for selection into the spot market by the grower within the 4-day window, and 16 exhibited that potential within the 15-day window. While this analysis is necessarily incomplete because we do not know if a grower delivered tomatoes to another processor, the institutional and biological factors limiting the scope for selection into the spot market by the grower would still apply.

Results

Selected coefficients are reported in table 3. Year-week, grower, and variety dummies, over 200 in all for the full sample, are

Table 3. Determinants of Tomato Quality, Selected Coefficients

	Subsample			Full Sample		
	MOT (*SE*)	*LU* (*SE*)	*DEDUCT* (*SE*)	*MOT* (*SE*)	*LU* (*SE*)	*DEDUCT* (*SE*)
YY	−0.027	−2.272	−172.961	−0.039	−3.076	−203.463
	(0.019)	(0.062)*	(38.999)*	(0.015)*	(0.054)*	(31.021)*
YN	−0.029	0.498	−120.715	−0.039	−0.285	−159.952
	(0.018)	(0.058)*	(36.841)*	(0.015)*	(0.053)*	(30.148)*
NY	−0.069	−2.666	−57.916	−0.057	−2.551	−79.972
	(0.010)*	(0.034)*	(21.626)*	(0.004)*	(0.015)*	(8.587)*
Constant	0.319	3.287	−402.816	0.219	9.206	−1,002.650
	(0.061)*	(0.862)*	(607.975)	(0.136)	(0.874)*	(512.363)
Observations	32829	32829	32829	146874	146874	146874
R^2	0.11	0.46	0.24	0.09	0.45	0.21

Note: A single asterisk (*) denotes significance at the 5% level.

omitted to conserve space.[6] Because the variance-covariance matrix can be poorly estimated using SUR, we also estimated our model using iterated SUR, which yields fully efficient maximum likelihood estimates. The changes in the standard errors yielded by the iterative procedure were very small and did not alter our coefficients of interest in a substantial way in either sample. We report only the SUR results here. The iterated SUR results are available from the authors upon request.

Subsample Results

As reported in table 3, price incentives had a statistically significant negative effect on *LU* under the *YY* and *NY* regimes, and a statistically significant positive effect under the *YN* regime. (Statistical significance is at the 5% level.) All three contract regimes had a statistically significant negative effect on *DEDUCT*. Their negative effects on *MOT* were not statistically significant. This may be due to relatively little variability in MOT in the subsample, compared with the other two quality measures.

Relative to the sample averages, the magnitudes of the coefficients on the contract regime variables indicate that the effects of the price incentives are substantial, suggesting that the potential for incentives to increase processor profits exists. In addition, the significant reductions in *DEDUCT* due to price incentives for LU and MOT indicate that restricting the estimation of the effects of price incentives to *LU* and *MOT* would understate the value of these incentives to the processor. Of course, whether or not the incentives have an economically significant effect depends on the value of the resulting improvement in tomato quality compared with the cost of the incentive.

The latter result is particularly interesting because one of the more important (by volume) components of *DEDUCT* is green tomatoes, which are on the opposite end of the ripeness spectrum from LU tomatoes. The sign and statistical significance of the coefficient are consistent with price incentives inducing growers to slow the speed of the harvester. Thus, this result also provides support for our hypothesis that the lack of a statistically significant effect on *MOT* of price incentives may be due to the relatively low variability of realized MOT in the subsample.

Although we do not report estimated dummy variable coefficients, the pattern of their significance by type and dependent variable provides information regarding how well the econometric results match our predictions based on institutional and biological factors. Substantially more grower dummies had significant coefficients than predicted: roughly two-thirds for the *MOT* equation, half for the *LU* equation, and 90% for the *DEDUCT* equation. This suggests that grower heterogeneity exists and affects their delivery of tomato quality attributes. The results regarding the significance of the coefficients of the year-week variables are very consistent with the hypothesized role of weather. While only about a fifth of the coefficients are significant for the *MOT* equation, about two-thirds are significant for *DEDUCT* and virtually all are significant for *LU*. All but one of the variety dummy variables have statistically significant coefficients for *LU*, but only one is significant for *DEDUCT*. These findings support the

[6] Complete results are available from the authors upon request.

biological fact that temperatures near harvest and variety are critical determinants of *LU*.

Full Sample Results

In our estimations using the full sample, all of the contract regime coefficients reduced *MOT* and *LU* and were statistically significant. Interestingly, the *NY* regime reduced *MOT* more than did either the *YY* or the *YN* regime. As was the case for the subsample, the magnitudes of the coefficients for the contract regimes relative to the sample means for the quality variables indicate that price incentives have the potential to increase processor profits. Again, the statistically significant reductions in the *DEDUCT* variable demonstrate that the benefit of a price incentive for a specific quality attribute must be evaluated in terms of its effect on all quality attributes.

The pattern of significance for coefficients on the grower and year-week dummy variables differed from that in the subsample. Less than a tenth of the grower dummies in the full sample had statistically significant coefficients in the *MOT* equation, and less than a third did in the *LU* equation. Both of these shares are much lower than those observed for the subsample. The share of significant coefficients on the grower dummies in the *DEDUCT* equation for the full sample was similar to that for the subsample: roughly 90%. For the coefficients on the year-week dummies, a higher share were significant in the *MOT* equation (half) and the *DEDUCT* equation (roughly 90%) than in the subsample. This is consistent with growers slowing the harvester when the weather is particularly hot in order to reduce LU. On the other hand, the share that was significant in the *LU* equation fell slightly, to about 90%. The pattern of significance for the coefficients on the variety dummy variables was consistent with the subsample results. All but one had statistically significant coefficients in the *LU* equation, and only two had statistically significant coefficients in the *DEDUCT* equation.

Tests for Complementarity

Because higher quality requires lower MOT and LU, tests for complementarity in our analysis parallel those used elsewhere for cost functions. Complementarity is associated with the supermodularity of $-f(x)$ and $-g(x)$, the negatives of the *MOT* and *LU* equations, and hence the submodularity of $f(x)$ and $g(x)$ (Topkis 1978, 1998). Accordingly, we test the following three inequalities, where α_i is the coefficient on incentive regime i in the *MOT* equation, β_i is the coefficient on i in the *LU* equation, and γ_i is the coefficient on i in the *DEDUCT* equation:

$$\alpha_{YY} \leq \alpha_{YN} + \alpha_{NY} \tag{4}$$

$$\beta_{YY} \leq \beta_{YN} + \beta_{NY} \tag{5}$$

$$\gamma_{YY} \leq \gamma_{YN} + \gamma_{NY} \tag{6}$$

Results are consistent across samples. The two incentive instruments were substitutes for decreasing *MOT* and complements for decreasing *LU*. All tests were significant at the 5% level. Table 4 reports test results. The results are consistent with a grower having one instrument to reduce MOT, i.e., slowing the speed of the harvester, and two instruments to reduce LU, i.e., slowing the harvester and altering the time of harvest, including harvesting at night. Slowing the harvester reduces both MOT and LU, so an incentive for MOT reduces LU. On the other hand, because the grower can allocate his LU reduction effort across two instruments, an incentive for LU will not be reflected fully as a reduction in harvester speed and, hence, a reduction in MOT.

Table 4. Tests for Complementarity Between Incentives for MOT and LU on *MOT*, *LU*, and *DEDUCT*

Subsample
Substitutes in *MOT*
$\alpha_{YY} - (\alpha_{YN} + \alpha_{NY}) = 0.07$
χ^2 test statistic = 26.14*
Complements in *LU*
$\beta_{YY} - (\beta_{YN} + \beta_{NY}) = -0.10$
χ^2 test statistic = 5.31*
Substitutes in *DEDUCT*
$\gamma_{YY} - (\gamma_{YN} + \gamma_{NY}) = 5.67$
χ^2 test statistic = 0.04
Observations: 32,829
Full Sample
Substitutes in *MOT*
$\alpha_{YY} - (\alpha_{YN} + \alpha_{NY}) = 0.057$
χ^2 test statistic = 85.25*
Complements in *LU*
$\beta_{YY} - (\beta_{YN} + \beta_{NY}) = -0.24$
χ^2 test statistic = 117.50*
Substitutes in *DEDUCT*
$\gamma_{YY} - (\gamma_{YN} + \gamma_{NY}) = 36.4$
χ^2 test statistic = 8.27*
Observations: 146,874

Note: A single asterisk (*) denotes significance at the 5% level.

We also tested whether or not incentives for MOT and LU displayed complementarity in their effects on *DEDUCT*. All three contract regimes reduced *DEDUCT* significantly. The two price incentives were substitutes in terms of reducing *DEDUCT*, although the relationship was only statistically significant for the full sample. These results are consistent with the earlier finding that the two price incentives are substitutes in *MOT*. Like *MOT*, *DEDUCT* is affected by harvester speed and would not be expected to increase with very hot weather at harvest.

Effects of Substituting Year Dummy Variables for Contract or Year-Week Dummy Variables

In order to examine the effects of using contract provision dummy variables and year-week dummy variables as explanatory variables rather than using year dummies, we estimated two additional models.[7] The base model presented here had the highest explanatory power for both the subsample and the full sample. For the subsample, the significance and sign of the contract variables are not affected by whether year or year-week dummies are used, although the magnitudes of the coefficients mostly change. In the full sample, however, the substitution of year dummy variables for year-week variables eliminates the significance of the *YY* and *YN* regimes for *MOT* and the *YN* regime for *LU*. Overall, the estimation and comparison of these related models support our arguments that contract term and year variables are not identical and that year-week dummy variables represent the effects of weather more accurately than year dummy variables, although the support from the full sample estimates is weaker than the support from the subsample estimates. This difference is likely due at least in part to the greater control of the effects of grower heterogeneity in the subsample. Our conclusions regarding complementarity and substitutability are unchanged by the substitution of year dummy variables for year-week dummy variables.

Conclusion

Our analysis illustrates that when an agent has multiple means of responding to an incentive instrument, the effects on other quality attributes will depend on their physical relationships with the incentivized attribute. On the other hand, the physical relationships alone cannot be used as a predictor of the cross-attribute effect; it will also depend on the agent's profit-maximizing decisions. The dataset we use is not subject to common methodological problems seen elsewhere in the literature. Consequently, the tests for the nature of the relationship between the two incentive instruments on the desired attributes are particularly clean.

We find that incentives for one tomato quality attribute affect the delivered share of the other attribute. A price incentive for LU can substitute for a price incentive for MOT in lowering delivered MOT shares. Similarly, the two price incentives are substitutes in reducing the delivered share of an aggregated measure of other undesirable quality attributes. In contrast, a price incentive for MOT complements a price incentive for LU in lowering delivered LU shares. Moreover, while a LU price incentive lowers the delivered share of MOT by a substantial amount, a MOT price incentive leads to a relatively small reduction in the delivered share of LU.

These results have implications for the profit-maximizing choice of incentive instruments and incentive levels. Given that a processor must bargain over the share of price incentives in the total price received for a ton of average quality tomatoes, our results suggest that allocating a relatively large share of that negotiated incentive payment to rewarding low LU may increase delivered quality relative to allocating a relatively large share to rewarding low MOT.

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References

Alexander, C., R. E. Goodhue, and G. C. Rausser. 2007. Do Incentives for Quality Matter? *Journal of Agricultural and Applied Economics* 39(1): 1–15.

Athey, S., and S. Stern. 1998. An Empirical Framework for Testing Theories About Complementarity in Organizational

[7] Results for these additional models are available from the authors upon request.

Design. Working Paper 6600, National Bureau of Economic Research.
Bai, C., and L. C. Xu. 2005. Incentives for CEOs with Multitasks: Evidence from Chinese State-Owned Enterprises. *Journal of Comparative Economics* 33: 517–539.
Black, S. E., and L. M. Lynch. 2001. How to Compete: The Impact of Workplace Practices and Information Technology on Productivity. *Review of Economics and Statistics* 83: 434–445.
Bresnahan, T. F., E. Brynjolfsson, and L. M. Hitt. 2002. Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence. *Quarterly Journal of Economics* 117: 339–376.
Brickley, J. A. 1999. Incentive Conflicts and Contractual Constraints: Evidence from Franchising. *Journal of Law and Economics* 42: 745–774.
Brynjolfsson, E., and L. M. Hitt. 2000. Beyond Computation: Information Technology, Organizational Transformation, and Business Performance. *Journal of Economic Perspectives* 14(4): 23–48.
California Department of Food and Agriculture. 2008. *California Agricultural Resources Directory: 2008–2009*. Sacramento.
California Department of Food and Agriculture. 1996. *California Processing Tomato Inspection Program.* Sacramento.
California Tomato Growers Association. n.d. Membership Agreement of California Tomato Growers Association, Inc. http://www.ctga.org/images/stories/pdf/grower%202009%20membership%20docs.pdf (accessed June 17, 2010).
Caroli, E., and J. Van Reenen. 2001. Skill-Based Organizational Change? Evidence from a Panel of British and French Establishments. *Quarterly Journal of Economics* 116: 1449–1492.
Gould, W. A. 1992. *Tomato Production, Processing and Technology,* 3rd ed. Timonium, MD: CTI Publications, Inc.
Hamilton, N. D. 1995. *A Farmer's Legal Guide to Production Contracts*. Philadelphia: Farm Journal, Inc.
Hart, O., A. Shleifer, and R. W. Vishny. 1997. The Proper Scope of Government: Theory and an Application to Prisons. *Quarterly Journal of Economics* 112: 1127–1161.
Hartz, T., G. Miyao, J. Mickler, M. Lestrange, S. Stoddard, J. Nunez, and B. Aegerter. 2008. *Processing Tomato Production in California.* Publication 7228, University of California Division of Agriculture and Natural Resources.
Holmstrom, B., and P. Milgrom. 1991. Multitask Principal-Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design. *Journal of Law, Economics, and Organization* 7: 24–52.
Holmstrom, B., and P. Milgrom. 1994. The Firm as an Incentive System. *American Economic Review* 84: 972–991.
Hueth, B., and E. Ligon. 2004. On the Efficacy of Contractual Provisions for Processing Tomatoes. Working paper, Iowa State University Dept. of Economics.
Ichniowski, C., K. Shaw, and G. Prellushi. 1997. The Effects of Human Resource Management Practices on Productivity. *American Economic Review* 87: 291– 313.
Knoeber, C. R., and W. N. Thurman. 1994. Testing the Theory of Tournaments: An Empirical Analysis of Broiler Production. *Journal of Labor Economics* 12: 155–179.
Miravete, E. J., and J. C. Pernias. 2006. Innovation Complementarity and Scale of Production. *Journal of Industrial Economics* 56: 1–29.
Mohapatra, S., R. E. Goodhue, and S. Rozelle. 2006. Incentive Complementarity: Investment-bonding, Profit-sharing and the Performance of Firms in Rural China. *Review of Industrial Organisation* 33: 63–79.
National Agricultural Statistics Service. 2009. Quick Stats. http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats (accessed June 17, 2010).
Starbird, S. A. 1994. The Effect of Quality Assurance Policies for Processing Tomatoes on the Demand for Pesticides. *Journal of Agricultural and Resource Economics* 19: 78–88.
Topkis, D. M. 1978. Minimizing a Submodular Function on a Lattice. *Operations Research* 26: 305–321.
Topkis, D. M. 1998. *Supermodularity and Complementarity.* Princeton, NJ: Princeton University Press.
Wu, S. 2005. Identifying "Incentive Effects" Using Agricultural Contracting Data. The Ohio State University AED Economics Working Paper.
Zellner, A. 1962. An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests of Aggregation Bias. *Journal of the American Statistical Association* 57: 348–368.