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Fruit Quality Characteristics Influence Prices Received for Processing Apples

Jayson K. Harper[1]
Department of Agricultural Economics and Rural Sociology, 214-A Armsby Building, The Pennsylvania State University, University Park, PA 16802

George M. Greene II[2]
Department of Horticulture, The Pennsylvania State University, P.O. Box 309, Biglerville, PA 17307

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Abstract. **This study quantifies the discounts and premiums associated with various quality factors for processing apples *(Malus domestica* Borkh.). Discounts and premiums were estimated using a hedonic price model and quality data from a total of 137 samples representing three processing apple cultivars (45 'York Imperial', 43 'Rome Beauty', and 49 'Golden Delicious'). Price discounts in the sample were statistically significant for fruit size, bruising, bitter pit, decay, misshapen apples, and internal breakdown. Commonly cited defects, such as insect damage and apple scab, did not cause significant price discounts.**

The value of processing apples, as with most agricultural commodities, is influenced by the interaction of many factors. Unlike fresh-market apples, where color, crispness, and flavor are the dominant factors in consumer acceptance (Manalo, 1990), apple processors are more concerned with cultivar, fruit size, and quality characteristics that influence the amount of trim waste. Inspection procedures classify processing apples according to grade and size. Grade designations are U.S. #1 (up to 5% trim waste), U.S. #2 (up to 12% trim waste), eiders, and culls. The four sizes are ≥7.0 cm in diameter, 6.4 to <7.0 cm, 5.7 to <6.4 cm, and <5.7 cm. The inspection certificate received by the producer, however, does not give much feedback on the causes of downgrades. If producers had access to this type of information, orchard management practices could be adjusted to increase profits (Bahn and Morin, 1980; Gerling, 1984). Knowledge of the value of specific quality attributes is essential to producers in making economic management decisions and allocating limited resources. Dissatisfaction with the present grades for apples is evidenced by the pricing structures used by apple processors. New grading systems have been proposed by Russo and Rajotte (1983) for fresh-market apples and by Johnson et al. (1977) for processing apples. Baugher et al. (1989) and Greene (1982) have attempted to put revised versions of each system to a practical test. Baugher et al. (1989) found that after initial difficulties with the more detailed Russo-Rajotte system, the clearly defined ratings made quality evaluations of fresh-market apples easier. Greene (1982) found that the Johnson et al. (1977) system for processing apples was too slow, expensive, and inaccurate to be used commercially.

When a problem involves product heterogeneity, as with differentiating processing apples by cultivar, size, and grade, Ladd and Martin (1976) suggested that researchers take a product-characteristics approach to the analysis. This approach embodies the view first proposed by Lancaster (1971) of a product as a collection of characteristics. In this situation, products are valued for their utility-bearing characteristics, and prices depend on the amounts of each characteristic contained in the product (Lucas, 1975). One method of analyzing this type of problem is through the estimation of hedonic price functions, which are regressions of price received as a function of the product's quality attributes (Lucas, 1975). Recent examples of the estimation of hedonic price models for agricultural products include those for apples (Tronstad et al., 1992), livestock (Bailey et al., 1991; Mintert et al., 1990; Schroeder et al., 1988), rough rice *(Oryza sativa* L.) (Brorsen et al., 1984), wheat *[Triticum aestivum* (L.)] (Espinosa and Goodwin, 1991), and cotton *(Gossypium hirsutum* L.) (Ethridge and Davis, 1982). Tronstad et al. (1992) investigated marketing channel characteristics for fresh-market apples (i.e., location, time, cultivar, size, grade, and storage method) rather than production-related quality attributes, which are the focus of this study.

Study setting. Pennsylvania ranks fifth in the United States in apple production. In a typical year, between 227,000 and 272,000 t of apples are produced, with a farm gate value of around $50 million. About one-third of the apple crop is sold on the fresh market, with two-thirds going to the processing market. Apples are widely grown throughout Pennsylvania, but 61% of the commercial tree inventory is located in four south-central counties (Pennsylvania Agricultural Statistics Service, 1987).

The importance of the processing apple market is due in large part to the location of two major processors in the state—Knouse Foods Cooperative, one of the largest apple processing firms in the United States, and Cadbury Beverages, a U.S. leader in apple sauce production, which operates processing plants in Pennsylvania and New York. Three Virginia apple processors also provide an outlet for some Pennsylvania apples.

Data. In Fall 1990, 137 35-liter samples of processing apples representing three of the major processing cultivars were taken from loads of apples delivered at harvest to processing facilities in south-central Pennsylvania. These included 49 samples of 'York Imperial', 43 of 'Rome Beauty', and 45 of 'Golden Delicious'. An inspector from the Federal State Inspection Service graded the apples and indicated the specific causes of downgrades. The inspector was not available during the fall, so the apple samples were held in cold storage for ≈4 months before they were graded. The apples in each grade and size category were weighed, and the weight of fruit with specific quality defects also was recorded. Apples were valued using Knouse Foods' price schedule (Table 1), which takes into account fruit size and U.S. Dept. of Agriculture (USDA) grade. Knouse pays according to a four-tier price scale in which large (≥7.0 cm) U.S. #1 apples

Table 1. Price schedule for 'York Imperial', 'Golden Delicious', and 'Rome Beauty' processing apples, 1990.[z]

Apple cultivar, grade, and size	U.S. $/t
Premium[y,x] York Imperial	
U.S. #1, ≥7.0 cm	264.48
U.S. #1, 6.4 to <7.0 cm	209.38
Others[w]	104.69
Regular York Imperial	
U.S. #1, ≥7.0 cm	242.44
U.S. #1, 6.4 to <7.0 cm	198.36
Others[w]	104.69
Premium[y,x] Golden Delicious	
U.S. #1, ≥7.0 cm	242.44
U.S. #1, 6.4 to <7.0 cm	192.85
Others[w]	104.69
Regular Golden Delicious	
U.S. #1, ≥7.0 cm	203.87
U.S. #1, 6.4 to <7.0 cm	159.79
Others[w]	104.69
Firm[x] Rome Beauty	
U.S. #1, ≥7.0 cm	209.38
U.S. #1, 6.4 to <7.0 cm	165.30
Others[w]	104.69

[z]Knouse Foods Cooperative, final 1990–91 apple prices (26 June 1991) were converted from dollars per hundredweight to dollars per tonne.
[y]To receive the Knouse premium price classification, the apples must adhere to U.S. #1 fresh-market apple standards (≤10% bruise) and be 90% U.S. #1, ≥5.7 cm.
[x]To receive the Knouse premium or Knouse firm classification, the apples must pressure test at ≥71 N. For the present analysis, a pressure test of ≥71 N was assumed for all the samples.
[w]Others include U.S. #1 (<5.7 cm), U.S. #2, and ciders. No payment is received for culls.

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[1]Assistant Professor.
[2]Associate Professor,

receive the highest price, medium (6.4 to <7.0 cm) U.S. #1 fruit receive a lower price, and all other usable apples (small U.S. #1, all U.S. #2, and cider apples) receive a much lower "juice" price (no payment is received for cull apples). 'York Imperial' and 'Golden Delicious' apples that are 90% U.S. #1 (≥5.7 cm) and have no more than 10% bruise by fresh-market apple standards are classified as "premium." Large and medium-sized apples receive a higher price under the premium classification, all others still receive the "juice" price. The overall price for a particular load of apples is a weighted price based on the proportion of apples falling into each price category.

Apple quality factors. In this study, apples were assessed for size and presence of various quality defects (Table 2). Nine types of quality defects were observed in the 137 samples, including trim bruise, misshapen fruit, bitter pit, decay, internal breakdown, scab, hail damage, insect damage, and York spot. Decay, internal breakdown, and certain types of insect damage resulted in the affected proportion of the apples being classified as culls, for which the producer received nothing. Other defects cause the relevant proportion of the apples to be downgraded to U.S. #2 or cider, which means they receive the juice price (Table 1). Seven of these defects were observed in the samples of 'York Imperial' and five in 'Rome Beauty' and 'Golden Delicious'.

Table 2. Descriptive statistics for processing apples.

	Cultivar				
	All		York Imperial	Rome Beauty	Golden Delicious
Variable[z]	Mean	SD	Mean	Mean	Mean
	U.S. $/t				
Price	194.77	23.61	218.79	190.56	181.83
	Samples with >10% fresh-market bruise (%)				
Freshbruz	3.65	18.82	2.22	0.00	8.16
	Apples by weight (%)				
Very small	0.38	0.99	0.59	0.18	0.36
Small	9.46	8.68	10.86	3.72	13.20
Medium	38.97	17.13	39.30	24.01	51.79
Large	51.20	23.58	49.25	72.09	34.65
	Apples downgraded by weight (%)				
Trimbruz	1.13	2.41	1.53	0.00	1.74
Misshapen	0.57	1.31	0.02	0.40	1.23
Bitter pit	0.52	1.69	0.38	1.26	0.00
Decay	0.14	0.72	0.09	0.16	0.16
Breakdown	0.16	0.69	0.00	0.50	0.00
Scab	0.17	0.83	0.05	0.00	0.43
Hail	0.10	0.56	0.00	0.24	0.60
Insect	0.03	0.23	0.09	0.00	0.00
York spot	0.01	0.11	0.03	0.00	0.00

[z]Freshbruz, proportion of samples with >10% bruising by fresh-market standards; very small, apples <5.7 cm in diameter; small, apples 5.7 to <6.4 cm in diameter; medium, apples 6.4 to <7.0 cm in diameter; large, apples ≥7.0 cm in diameter; trimbruz, trim bruise; misshapen, misshapen fruit; bitter pit, bitter pit evident; decay, decay evident; breakdown, internal breakdown; scab, fruit scab evident; hail, hail damage; insect, insect damage; York spot, York spot evident.

Fruit size was determined by running the sample over standard sizing chains. Size is important in processing apples because large apples have a higher percentage of usable flesh following peeling and coring than smaller apples. Overall, 51% of the apples, by weight, fell into the size class ≥7.0 cm, 39% were in the 6.4 to <7.0 cm range, 9% fell in the 5.7 to <6.4 cm class, and <1% were <5.7 cm in diameter. Size varied greatly between the three cultivars, with >72% of 'Rome Beauty' being ≥7.0 cm compared to only 49% for 'York Imperial' and <35% for 'Golden Delicious'.

Trim bruise is a defect that is scored based on waste. For U.S. #1 apples, up to 5% trim waste is acceptable. From a pricing standpoint, only the U.S. #1 standard is important, because trim waste >5% causes that proportion of the apples to be downgraded to U.S. #2 and paid the juice price (Table 1). Apples with >5% trim bruise averaged 1.1% by weight across all the samples. There were no downgrades for trim bruise in 'Rome Beauty', but an average of >1.5% of apples by weight were discounted for 'York Imperial' and 'Golden Delicious'.

Misshapen apples are those that cannot be cored or peeled properly by machine and are caused most often by nonsymmetrical seed distribution, the result of poor pollination. In the study, 0.6% of the fruit by weight was downgraded because of shape. This defect was most common in 'Golden Delicious' and least common in 'York Imperial'.

Bitter pit is a disorder of apples in which brown corky areas form beneath the skin in the flesh of the apple deficient in Ca. It usually develops during storage, but can be present at harvest. Bitter pit led to downgrading 0.5% of the apples by weight, with 'Rome Beauty' having the most at 1.3% and 'Golden Delicious' none.

Decay and internal breakdown are important economically because they are exclusionary defects. The presence of these defects automatically classifies affected apples as culls, regardless of other attributes. Decay averaged O. 14% of the apples by weight, with 'York Imperial' having the least decay at 0.09% and 'Golden Delicious' having the most at 0.16%. Internal breakdown is associated with fruit senescence at the end of storage, but can occur earlier if water core is present. Freezing and certain growing, handling, or storage practices, especially low fruit Ca levels, can cause internal breakdown. Internal breakdown was present only in some lots of 'Rome Beauty'.

Apple scab is Pennsylvania's most prominent apple disease. In the study, <0.2% of the apples by weight were downgraded due to scab. No scab was observed in 'Rome Beauty', while 'York Imperial' averaged 0.05% scab by weight and 'Golden Delicious' 0.43%.

Of the two types of hail damage, only one causes fruit to be downgraded. Superficial hail marks easily removed by peeling do not affect grade, but old hail marks with healed, broken skin and dry, corky tissue downgrade the fruit to eiders. In the study, 0.1 % of the apples by weight were downgraded because of hail damage. Hail damage varied from none in 'York Imperial' to 0.6% in 'Golden Delicious'.

The most serious insect pest of fresh-market apples in Pennsylvania is the tufted apple bud moth. Generally, bud moth injury does not reduce the grade of processing apples, but storability can be affected because of decay. In the sample, <0.03% of the apples by weight were downgraded, with insect damage only evident in samples of 'York Imperial'. The absence of insect damage in 'Rome Beauty' and 'Golden Delicious' may indicate a more aggressive spray program to satisfy fresh-market demands.

York spot or corking are dead areas in apple flesh that start to develop early in the season and are related to low levels of Ca. A low incidence was found in 'York Imperial'.

Procedures. Hedonic price functions are regressions of the following form (Lucas, 1975): $P_i = f(V_{i1},..., V_{ij}; u_i)$, where P_i is a function of the observed price of commodity i, V_{ij} is the amount of quality factor j per unit of commodity i, and u_i is the disturbance term. This type of model could be derived from a mathematical programming model by assuming that apple processors choose apples that maximize profit, subject to their production technology and a cost constraint. For commodities that vary continuously with respect to quality characteristics, this interpretation implies a linear model for the hedonic function (Ladd and Martin, 1976). Because the data set used in this study contains only 1 year of data, no adjustments for price differences overtime are required. The estimated processing apple hedonic price equation is a linear function of: P_{Apples} = f(cultivar, size, fresh-market bruise, defects; u_i), where the effect of the three cultivars, four size classes, presence of more than 10% bruise (fresh-market bruise standard for the premium price class), and nine quality defects are considered. These variables are defined in the footnotes in Tables 2 and 3.

Results. The estimated coefficients for the processing apple hedonic price model (Table 3) represent the premiums or discounts (in dollars per unit of quality factor per tonne) associated with each quality factor. Of the 15

Table 3. Estimated processing apple hedonic price model (standard error).

Independent variable[z]	Estimate[y]	Level of significance
Intercept[x]	218.725 (5.378)	**
Rome	–47.122 (2.380)	**
Gold	–25.787 (2.402)	**
Freshbruz	–18.337 (4.452)	**
Very small	–2.887 (0.882)	**
Small	–0.838 (0.176)	**
Large	0.309 (0.066)	**
Trimbruz	–1.917 (0.353)	**
Misshapen	–2.689 (0.705)	**
Bitter pit	–1.256 (0.485)	**
Decay	–3.615 (1.102)	**
Breakdown	–2.402 (1.168)	*
Scab	–1.851 (1.190)	NS
Hail	–0.661 (1.411)	NS
Insect	–1.366 (3.394)	NS
York spot	2.711 (7.405)	NS
R^2 = 0.873	R^2 = 0.857	F = 55.39

[z]Rome, 1 if 'Rome Beauty', 0 otherwise; gold, 1 if 'Golden Delicious', 0 otherwise. All other variables, which are based on percent by weight, are defined in Table 2.

[y]Coefficient values in U.S. \$/unit.

[x]The intercept value is based on 'York Imperial', medium size class (6.4 to <7.0 cm).

NS,*,**Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

quality factors considered in the model, 11 have estimated coefficients significantly different from zero at $P \leq 0.05$, and 14 are of the expected sign. Although the estimated coefficient for York spot did not have the expected sign, it was not significantly different from zero. The high R^2 of 0.857 and significant F value of 55.39 indicate that a large proportion of the observed variation in price is explained by the model. To avoid a singular matrix, no dummy variable was used for 'York Imperial', and the variable for the 6.4- to <7.0-cm size class was dropped from the model. This step allowed determination of the premium associated with large apples (27.0 cm) and the discounts associated with small apples (<6.4 cm).

As expected from knowledge of the price structure detailed in Table 1, significant price discounts existed when marketing either 'Rome Beauty' (\$47.12/t) or 'Golden Delicious' (\$25.79/t) apples for processing (Table 3). If 'York Imperial' remains the benchmark on which other processing cultivars are judged, the discounts associated with other cultivars will continue. This premium may influence producers to maintain present 'York Imperial' acreage in the short run or to replant with 'York Imperial' in the long run. However, replanting decisions also must consider yield potential, fruit size, and marketing alternatives. Cultivars such as 'Rome Beauty' and 'Golden Delicious' are dual-purpose cultivars, while 'York Imperial' is almost exclusively a processing apple. In addition, the widespread use of 'Golden Delicious' as a pollinizer and its early harvest season will see its continued use as a processing cultivar despite its lower relative price. In contrast, 'Rome Beauty' is "grower friendly," producing large crops of large fruit.

The binary variable for fresh-market bruise (freshbruz = 1 if fresh-market bruise is >10%, 0 if otherwise), in conjunction with the size variables, attempts to quantify the discount that would change the sample of either 'York Imperial' or 'Golden Delicious' from the premium price class to the regular price class (see Table 1). The discount of \$18.34/t may be a significant incentive to try and keep fresh-market bruise within the 10% tolerance. In the data set, only 4% of the samples exceeded this tolerance.

Discounts were significant for five of the nine defects observed, varying from a low of \$1.26 for each 1% change in bitter pit to a high of \$3.62 for decay. Other defects with significant discounts were misshapen apples (\$2.69), trim bruise (\$1.92), and internal breakdown (\$2.40). Because decay and internal breakdown are associated with storage, producers who deliver their crop to the processor at harvest would be less concerned about these quality factors. Those who store apples for later sale should balance the higher prices of later delivery against the storage cost and the possible discounts associated with these defects and weight loss due to shrinkage. At harvest, only three defects are of interest: misshapen apples, bitter pit, and trim bruise. No significant discounts were found for apple scab and insect damage, and additional efforts to control these factors would not have improved the price received. Whether the present management level for insects and scab is warranted cannot be answered with these data, but they indicate that additional expenditures to better control these defects would not improve net returns. Defects associated with hail and York spot had no significant discounts and were limited in the sample.

The most important factor in the processing apple hedonic price equation was size. As is readily apparent from the three-step price classification, medium and large U.S. #1 apples obtain higher processing prices, while small apples, regardless of grade, receive juice prices. For each 1% increase in the weight of apples from 5.7 to <6.4 cm in diameter, price fell by \$0.84/t (Table 3). A discount of \$2.89/t applies for each 1% of weight increase in apples <5.7 cm in diameter. Conversely, a premium of \$0.31/t was found to apply for each 1 % weight increase in apples ≥7.0 cm in diameter.

The mean value of the quality factors (Table 4) was calculated by using the mean values from Table 2 along with the estimated coefficients for the hedonic price model (Table 3) to arrive at the value per tonne. These data show that the premiums and discounts associated with fruit size for all cultivars dwarf other quality factors, none of whose discounts amount to more than \$2.16/t for each 1% change. Because most management practices address an orchard block rather than a tonne of apples, the mean values of the quality factors are also calculated on a hectare basis (Table 5). As would be expected, the value of the discounts per hectare increases as yields increase. Although we did not estimate the costs of managing the individual quality factors, the magnitude of losses due to certain quality factors indicates the potential for increasing net returns by reducing their occurrence.

Study limitations. We report on the value of processing quality characteristics based on only 1 year's data. If additional years of data were added, binary variables would be needed to account for annual variations in price because of supply-and-demand factors. In general, prices for processing apples have been very stable in south-central Pennsylvania in past years. Because the price received for a particular lot of apples is a weighted price, coefficient values for quality factors likely would not change dramatically. The incidence of defects will change from year to year, but the basic discount likely would be fairly stable. Additional years of data may indicate statistically significant discounts for scab, hail, insect damage, and York spot. Because these defects were not observed in 1990, no discounts could be established.

The delay between sampling and grading led to more storage-related defects (internal breakdown, bitter pit, and decay) than would normally be observed at harvest. Because the apples were not valued until the grading took place, these types of defects did not bias the results and helped establish the value of discounts if these defects were found at harvest.

Table 4. Mean value of apple processing quality characteristics (\$/t).[z]

	Cultivar			
Variable[y]	All	York Imperial	Rome Beauty	Golden Delicious
Freshbruz	–0.70	–0.40	0.00	–1.50
Very small	–1.10	–1.71	–0.52	–1.03
Small	–7.92	–9.10	–3.12	–11.06
Large	15.80	15.20	22.24	10.69
Trimbruz	–2.16	–2.94	0.00	–3.33
Misshapen	–1.54	–0.06	–1.08	–3.32
Bitter pit	–0.65	–0.48	–1.59	0.00
Decay	–0.50	–0.33	–0.58	–0.59
Breakdown	–0.38	0.00	–1.21	0.00
Scab[x]	–0.31	–0.09	0.00	–0.79
Hail[x]	–0.06	0.00	–0.16	–0.04
Insect[x]	–0.04	–0.12	0.00	0.00
York spot[x]	0.02	0.08	0.00	0.00
Price (estimated)	195.16	218.77	185.60	181.97

[z]Values calculated using the means from Table 2 and the model coefficients in Table 3.

[y]For a description of the variables, see Table 2.

[x]Variable not statistically different from zero at $P \leq 0.05$.

Table 5. Mean value of apple processing quality factors (U.S. $/ha) at representative yields (t•ha^{-1}).[z]

Variable[y]	Yield (t•ha^{-1}) 10	20	30	40	50
Freshbruz	–6.97	–13.94	–20.90	–27.87	–34.84
Very small	–10.97	–21.94	–32.91	–43.89	–54.86
Small	–79.21	–158.43	–237.64	–316.85	–396.06
Large	157.97	315.93	473.90	631.87	789.84
Trimbruz	–21.59	–43.18	–64.77	–86.36	–107.95
Misshapen	–15.43	–30.87	–46.30	–61.74	–77.17
Bitter pit	–6.55	–13.09	–19.64	–26.18	–32.73
Decay	–5.02	–10.05	–15.07	–20.10	–25.12
Breakdown	–3.80	–7.59	–11.39	–15.18	–18.98
Scab[x]	–3.13	–6.26	–9.39	–12.52	–15.64
Hail[x]	–0.63	–1.27	–1.90	–2.54	–3.17
Insect[x]	–0.38	–0.77	–1.15	–1.53	–1.91
York spot[x]	0.24	0.49	0.73	0.98	1.22

[z]Per hectare figures calculated using the discounts/premiums associated with all apple varieties in Table 4.
[y]For a description of the variables, see Table 2.
[x]Variable not statistically different from zero at $P \leq 0.05$.

The drawback is that average values for these defects are probably much higher than would be normally observed at harvest, and their presence possibly may have affected the levels of other defects observed. If the grading had been done at harvest, significant discounts for internal breakdown, bitter pit, and decay might not have been observed.

The sampling approach may have influenced the incidence of the defects. Fruit samples were taken during a relatively short period at harvest, and more variability in defects probably would have been observed if samples had been taken randomly over a longer period. Labor limitations and storage constraints did not permit this in 1990.

Summary and implications. This study's purpose was to quantify, by means of a hedonic price model, the discounts and premiums associated with various quality factors for processing apples. This type of information should help apple producers prioritize management practices and allocate limited resources. Statistically significant price discounts for apple size, bruise, bitter pit, decay, misshapen apples, and internal breakdown were found. Commonly cited defects, such as insect damage and apple scab, did not cause significant price discounts. These results indicate that cultural factors, including pruning, fertility, thinning, and pollination, which have an impact on fruit size and yield, may merit more consideration in producing quality processing apples than additional efforts to control insects or disease. As evidenced by discounts for decay and internal breakdown, improved postharvest handling and storage management techniques for growers or processors who store fruit may also be of value. Attention to improving quality not only will improve the prices received by the producer for the raw product, but also will improve processing efficiency.

By linking quality discounts and premiums with the costs of managing specific quality factors, the grower can allocate management practices and resources more efficiently. Economic decisions regarding management practices that affect quality attributes should be evaluated on the basis of their cost per marginal unit of control relative to the associated marginal returns (Grant et al., 1986). A marginal approach is necessary, because absolute control of the causes of poor quality is generally recognized as infeasible due to the diminishing marginal productivity of additional levels of inputs, which at some point will cause the cost associated with an additional unit of management to exceed its benefit. The next step in this research will be to identify the potential causes of processing apple defects and identify alternative management practices and their implementation costs.

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