Measuring Returns to an Innovation in an Imperfectly Competitive Market: Application to Mechanical Harvesting of Processing Tomatoes in Taiwan
Author(s): Shu-Yu Huang and Richard J. Sexton
Source: *American Journal of Agricultural Economics*, Vol. 78, No. 3 (Aug., 1996), pp. 558-571
Published by: Oxford University Press on behalf of the Agricultural & Applied Economics Association
Stable URL: http://www.jstor.org/stable/1243274
Accessed: 11/08/2011 09:11

Measuring Returns to an Innovation in an Imperfectly Competitive Market: Application to Mechanical Harvesting of Processing Tomatoes in Taiwan

Shu-Yu Huang and Richard J. Sexton

In this paper we develop and apply a general imperfect competition model to evaluate returns to a cost-reducing innovation. Most related work has applied models of perfect competition. Results demonstrate that welfare estimates derived from a model of perfect competition may be seriously distorted when the relevant market is imperfectly competitive. Application to mechanical harvesting of processing tomatoes in Taiwan reveals the potential for significant benefits to adoption of mechanical harvesting in Taiwan. However, farmers' incentives to adopt the harvester are attenuated because total benefits are reduced by oligopsony power in tomato procurement, and imperfectly competitive processors will capture a large share of the benefits that remain.

Key words: imperfect competition, oligopsony, processing tomatoes, Taiwan, tomato harvester, welfare analysis.

In this paper we analyze the welfare impacts of mechanical harvesting of processing tomatoes in Taiwan. A key distinguishing feature of the study relative to previous empirical work on returns to innovations is that it permits market power to be exhibited in both the markets for the raw agricultural product and the processed product outputs. Indeed, the empirical results find significant processor market power in Taiwan in both the procurement of raw tomatoes and the sale of processed products in the domestic market. The study demonstrates that welfare estimates derived from a model of perfect competition may be seriously distorted when in fact the relevant markets are imperfectly competitive.

The study represents an *ex ante* analysis of the benefits from mechanical harvesting because the harvester has yet to be adopted in Taiwan. Mechanical harvesting of processing tomatoes was introduced first in California in 1961, and by 1969 nearly all of the California crop was harvested by machine. Its adoption in Taiwan has been impeded by the small size of tomato fields; this has required the development of more mobile harvesting equipment. The results of this study indicate significant gross benefits to adoption of mechanical harvesting in Taiwan. However, they also show that, due to oligopsony power in tomato procurement, a substantial portion of the benefits accrue to processors, attenuating farmers' incentives to adopt the harvester.

The adoption of mechanical tomato harvesting in California was studied by Schmitz and Seckler, Chern and Just, Brandt and French, and Kim et al. This body of work illustrates the basis for concern about the role of market structure in evaluating returns to an innovation. The Schmitz and Seckler, and Brandt and French studies indicated the generation of substantial net benefits from mechanical harvest-

Shu-Yu Huang is an agricultural economist based in Saratoga, California. Richard J. Sexton is professor and chair in the Department of Agricultural and Resource Economics at the University of California, Davis, and a member of the Giannini Foundation of Agricultural Economics.

Financial support for this project was provided by the Council of Agriculture, Taiwan. The authors are grateful to the several Taiwanese government agencies and industry associations that contributed data for this study, and to Julian Alston, Garth Holloway, Alex McCalla, and the *AJAE* referees for helpful comments.

ing. However, these studies were based on competitive market models, and Chern and Just argued forcefully that the industry's response to mechanical harvesting indicated oligopsony behavior by processors.

Kim et al. subsequently tried to adapt the results from Brandt and French's econometric analysis to the oligopsony structure indicated by Chern and Just. Their study is apparently the first to adopt formally a model of imperfect competition in considering the welfare effects of an innovation. However, little further progress has been made on incorporating imperfect competition into analyses of returns to research, innovation, and technology adoption. Rather, emphasis has remained on the competitive model. Alston, Norton, and Pardey have carefully compiled and synthesized this work.

Recent attempts to incorporate imperfect competition into the analysis of returns to research include a study by Voon, who used simulations to compare results for monopoly versus perfect competition, and a study by Dryburgh and Doyle, who examined the impact of technology change in the British dairy industry under alternative scenarios of monopoly, monopsony, and perfect competition. These analyses indicate the importance of market structure both to the magnitude and distribution of research benefits. However, they do not evaluate the actual market behavior and conduct tests for alternative market outcomes. They rely instead on comparing alternative extreme forms of market structure such as monopoly and monopsony versus perfect competition. In contrast this study adopts a conjectural variations oligopoly-oligopsony model that admits monopoly/monopsony and perfect competition as special cases, tests empirically for the presence of market power, and applies the methodology in a real problem setting.[1]

The Model

This section formulates the supply and demand relationships for the Taiwanese processing tomato industry. Taiwanese tomato processors generally also produce other food products such as asparagus, bamboo shoots, mushrooms, and various fruits, so the analysis employs a multiproduct cost-function framework based upon the work of Wann and Sexton. The various nontomato products generally have similar processing methods and use common canning equipment. However, the major tomato products, tomato paste and puree, require distinct treatments for crushing, heating, juicing, filtering, and evaporating. We therefore considered two product composites: tomato products and other products.

Processors were assumed to employ a quasi fixed-proportions technology wherein substitution between the raw agricultural input and the processing inputs—labor, energy, and capital—is prohibited, but substitution among the processing inputs is possible.[2] In the cost function derived from this technology, raw product costs are separable from processing costs, and processor behavior can be represented in terms of marketing margins.

The model consists of the following components: (*i*) processors' cost function and associated demand functions for processing inputs, (*ii*) marketing margin equations which characterize processor behavior in the procurement of raw product and sale of processed products, (*iii*) farm supply of raw products, and (*iv*) domestic demand for processed products. Taiwanese processors are assumed to be perfect competitors in export sales.[3]

A representative tomato processor's profit function can be expressed as

$$(1) \quad \pi = \sum_{i=1}^{2} P_i^D(Q_i^D)q_i^D + \sum_{i=1}^{2} P_i^E q_i^E - \sum_{i=1}^{2} W_i(R_i)r_i - C(q_1, q_2, V_1, V_2, V_3)$$

where $P_i^D(Q_i^D)$ denotes the inverse domestic demand curve for tomato products ($i = 1$) and other processed foods ($i = 2$); Q_i^D denotes aggregate quantity supplied to the domestic market for product composite i; q_i^D is the representative processor's domestic market sales of product i; P_i^E is the parametric export price for the product composite i; q_i^E is the export sales of each product form for the representative processor; $W_i(R_i)$ denotes the inverse supply curve facing processors for raw product i; R_i denotes aggregate purchases of raw product i; r_i is the purchase level of raw product i by the represen-

[1] Dixit provides a discussion of the advantages and disadvantages of the conjectural variations framework.

[2] See Wann and Sexton for a discussion and justification of this modeling assumption.

[3] Taiwan supplied on average only 5% of tomato paste and 2.5% of canned tomato exports during 1981–92.

tative processor; $C(\cdot)$ is the processing cost function, $q_1 = q_1^D + q_1^E$, $q_2 = q_2^D + q_2^E$; and V_1, V_2, and V_3, respectively, are the prices for processing inputs labor, capital, and energy.

Maximization of equation (1) is subject to the constraint of the quasi fixed-proportions technology which requires that $q_i = \alpha_i r_i$, where α_i denotes the fixed rate at which raw product form i is converted into processed product. Substituting these constraints into equation (1) enables the optimization problem to be expressed in terms of the volumes of raw product r_i^E and r_i^D, $i = 1, 2$, allocated to the export and domestic markets, respectively. The first-order conditions for maximization of equation (1) can be expressed in elasticity form as

$$(2) \qquad W_i = \alpha_i(P_i^E - C_i)/[1 + (\theta_i/\eta_i)], \qquad i = 1, 2$$

$$(3) \qquad P_i^D = (W_i[1 + (\theta_i/\eta)_i]/\{\alpha_i[1 + (\xi_i/\varepsilon_i)]\}) + \{C_i/[1 + (\xi_i/\varepsilon_i)]\}, \qquad i = 1, 2.$$

Substituting equation (2) into equation (3) obtains

$$(3') \qquad P_i^D = P_i^E/[1 + (\xi_i/\varepsilon_i)], \qquad i = 1, 2.$$

where

$C_i = \partial C/\partial q_i$ = marginal processing cost of processed product i,

$\theta_i = (\partial R_i/\partial r_i)\cdot(r_i/R_i)$,

$\eta_i = (\partial R_i/\partial W_i)\cdot(W_i/R_i)$ = market price elasticity of supply of raw product i,

$\xi_i = (\partial Q_i^D/\partial q_i^D)\cdot(q_i^D/Q_i^D)$,

$\varepsilon_i = (\partial Q_i^D/\partial P_i^D)\cdot(P_i^D/Q_i^D)$ = domestic market price elasticity of demand for product i.

The first-order conditions can also be expressed in terms of the Lerner index, i.e., the relative markdown in the raw product market and markup in the output market:

$$(2') \qquad [\alpha_i(P_i^E - C_i) - W_i]/W_i = \theta_i/\eta_i, \qquad i = 1, 2$$

$$(3'') \qquad (P_i^D - P_i^E)/P_i^D = -\xi_i/\varepsilon_i, \qquad i = 1, 2.$$

The key parameters for purposes of measuring and testing for market power are θ_i and ξ_i. These terms, sometimes known as "conjectural elasticities," range in the unit interval, with values of zero denoting perfectly competitive behavior (i.e., the firm perceives that its actions have no impact on the market) and values of 1.0 representing monopoly or monopsony behavior. The parameters θ_i and ξ_i thus represent convenient indices to measure behavior in the raw product and processed product markets, respectively.

Export sales in this model play the role of the competitive "benchmark" product in the Wann-Sexton methodology. Markups of domestic prices from export prices are used to measure departures from competition for domestic product sales. Similarly, markdowns of the raw-product price from the export price, after adjusting for processing costs, measure processors' oligopsony power in raw-product procurement.

Without further loss of generality, we choose units of measurement for raw and processed products so that $\alpha = 1.0$. One final re-expression of the first-order conditions will be useful in the subsequent comparison of welfare effects under perfect versus imperfect competition. Following Quirmbach, the market behavior parameter θ can be interpreted as a weight in expressing net export price, $P^E - C$, as a linear combination of average and marginal raw-product costs facing the industry. Similarly, ξ can be interpreted as a weight in expressing P^E as a linear combination of average and marginal revenues facing the industry in the domestic market:

$$(2'') \qquad P_i^E - C_i = (1 - \theta_i)W_i + \theta_i MC_i(R_i),\ i = 1, 2$$

$$(3''') \qquad P_i^E = (1 - \xi_i)P_i^D + \xi_i MR_i(Q_i^D),\ i = 1, 2$$

where $MC_i(R_i) = W_i + R_i(dW_i/dR_i)$ and $MR_i(Q_i^D) = P_i^D + Q_i^D(dP_i^D/dQ_i^D)$.

To develop an estimable model, functional specifications must be chosen for the processing cost function, raw-product supply functions, and processed-product demand functions. Studies of various flexible cost functions have indicated the generally superior performance of the generalized Leontief (GL) when substitution among inputs is limited (Guilkey, Lovell, and Sickles). This consideration supports adoption of the GL cost function in studies of food processing. A further advantage is that the GL more readily accommodates zero output levels and admits a more convenient expression of marginal costs than, for example, the translog.

The multiproduct GL cost function can be expressed as

$$(4)\quad C(q_1, q_2, V_1, V_2, V_3) = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{3}\sum_{l=1}^{3} a_{ijkl}(q_i q_j V_k V_l)^{0.5}.$$

To simplify equation (4) for estimation purposes, it is useful to impose the assumptions of symmetry of cross-product effects: $a_{ijkl} = a_{jikl}$ for all i, j and $a_{ijkl} = a_{ijlk}$ for all k, l and nonjointness of outputs: $a_{ijkl} = 0$ for all k, l, and $i \neq j$. Given these simplifications, equation (4) can be rewritten as

$$(4')\quad C(q_1, q_2, V_1, V_2, V_3) = \sum_{i=1}^{2}\sum_{k=1}^{3} a_{ik} q_i V_k + 2\sum_{i=1}^{2}\sum_{k=1}^{2}\sum_{l=2}^{3} a_{ikl} q_i (V_k V_l)^{0.5}, \quad k \neq 1.$$

This version of the GL satisfies homogeneity of degree one in both input prices and outputs by construction. The marginal processing cost functions, C_1 and C_2, indicated in equations (2) and (3), are obtained by differentiating (4′) with respect to q_1 and q_2. Demand functions for the processing inputs, X_1, X_2, and X_3, are also obtained readily from equation (4′) by Shephard's lemma. For example,

$$(5)\quad X_1 = \partial C/\partial V_1 = a_{11}q_1 + a_{21}q_2 + a_{112}q_1 (V_2/V_1)^{0.5} + a_{113}q_1(V_3/V_1)^{0.5} + a_{212}q_2(V_2/V_1)^{0.5} + a_{213}q_2(V_3/V_1)^{0.5}.$$

Farm supply of tomato hectarage was specified as a simple log linear function:

$$(6)\ \ln A = c_1 + \eta_1 \ln W_1 + c_2 \ln W_c + c_3 \ln V_1 + c_4 T.$$

Equation (6) expresses A, the planted area of processing tomatoes, as a function of W_1, the current period price of tomatoes received by farmers;[4] W_C, the price of carrots, a major competing crop; V_1, the factory labor wage; and a time trend, T.[5] The quantity V_1 represents the opportunity cost of family labor—the major input into tomato production.[6] The parameter η_1 is the price elasticity of supply of raw tomatoes as defined in equation (2). Monetary variables throughout the study are deflated by the Taiwanese CPI (1986 = 100).

The domestic demand for tomato products was similarly expressed in log linear form as

$$(7)\quad \ln(Q_1^D/pop) = b_1 + \varepsilon_1 \ln P_1^D + b_2 \ln Y$$

where Q_1^D/pop is the annual per capita consumption of tomato products in Taiwan expressed as a function of the domestic price, P_1^D, and per capita income, Y. The parameter ε_1 in equation (7) is the price elasticity of domestic demand as defined in equation (3).

Application to the Taiwanese Processing Tomato Industry

The processing tomato industry in Taiwan has traditionally been export oriented, with major exports including paste, puree, ketchup, juice, and canned tomatoes. However, the domestic market has become increasingly important, and in 1992, for the first time, domestic sales measured in raw-product-equivalent volume exceeded 50% of export sales. The major tomato products consumed domestically in Taiwan are ketchup and tomato juice. Introduction of the mechanical harvester was considered as a means to revitalize the industry's declining export sales.

Several factors suggest the possible importance of market power in Taiwanese tomato processing. First, the number of Taiwanese firms processing tomato products has declined from twenty-seven to five from 1984 to 1993. The percentage of the tomato harvest purchased by the four largest firms rose throughout this period, with an average of 59%.

Second, processing tomato production in Taiwan takes place on small farms—the average size in 1990 was only 0.27 ha—and the contracting process does not appear favorable to farmers. Contracting is conducted exclusively through representatives selected by processors, and growers have no organized bargaining group to support them. Descriptions of the contracting process by industry analysts such as Lai and Hsu also suggest its possible use to facilitate the exercise of oligopsony power by processors. It is argued, for example, that assignment of tomatoes to various grades is used as a tool to manipulate price, and provisions limiting processors' purchase obligations are

---

[4] The tomato contract price is generally known before the planting season, so it is appropriate to model supply decisions based upon the contemporaneous contract price.

[5] Because a portion of the harvest is sometimes withdrawn from the market, farmers' decisions are most appropriately expressed in terms of hectarage committed to tomatoes rather than volumes actually sold.

[6] For the period 1979–90, 62% of processing tomato production costs were attributable to labor and 63% of the total labor force used in tomato production consisted of family labor, making family labor the key input cost in modeling tomato supply decisions.

used as instruments of supply control. Interviews conducted in the present study suggest that contract prices are set at a meeting of the largest processing firms, with other processors subsequently adopting that price schedule.[7]

Finally, tariffs are a major factor supporting processor oligopoly power in the domestic sales of processed tomato products. Tariffs were in the 50%–75% range in the early 1980s and have declined subsequently to the range of 17.5%–45% in 1992, depending upon product form. Comparisons of domestic versus export prices for comparable tomato products provide preliminary evidence of processor power in the domestic market.[8]

The complete model to be estimated consists of equations (2), (3′), (4′), (5), (6), and (7). In principle, the model may be estimated as a full system. In practice, however, the full system has proven difficult to estimate and, moreover, is very demanding of data resources. In the present study, as in related previous work (see Wann and Sexton for a discussion and references), both considerations led to simplifications for empirical purposes of the theoretical model. First, equations describing processing firms' buying and selling behavior with respect to the nontomato product composites were not estimated. These products were ancillary to the purpose of the study, and we lacked reliable data on both the raw product values and output prices.

Data limitations further required that the raw tomato supply function, processed tomato product demand function, and processor margin equation in domestic tomato product sales [equations (6), (7), and (3′), respectively] be estimated separately from the rest of the system. These functions were estimated from annual time-series data for 1980–90, while the processing cost function, input demand functions, and export marketing margin were estimated from pooled time-series, cross-section data for 1986–90.

Estimates of equations (6) and (7) were obtained by OLS. The quantity Q_1^D was measured in terms of standardized cases of tomato products (one standardized case equals 0.165 metric tons of raw tomatoes). A detailed discussion of the data used in the analysis and of variable construction is provided in Huang. The estimated functions are

$$(6') \quad \ln A = \underset{(3.36)}{26.41} + \underset{(3.81)}{3.90} \ln W_1 - \underset{(-2.34)}{0.95} \ln W_C - \underset{(-3.47)}{11.08} \ln V_1 + \underset{(3.14)}{0.85} T, \quad \bar{R}^2 = 0.85, \text{ D.W.} = 2.40$$

$$(7') \quad \ln (Q_1^D/pop) = \underset{(-5.80)}{-8.78} - \underset{(-4.43)}{0.50} \ln P_1^D + \underset{(5.55)}{0.52} \ln Y, \quad \bar{R}^2 = 0.97, \text{ D.W.} = 1.46$$

where t-statistics are indicated in parenthesis. All of the estimated coefficients have the signs expected from theory and all are statistically different from zero at levels of significance of 0.10 or less. Based on the Durbin-Watson statistics, the hypothesis of noncorrelated disturbance terms is not rejected.[9] Farmers in Taiwan are rather responsive to variations in the tomato contract price as indicated by $\eta = 3.9$. Taiwanese consumers are less responsive to changes in processed tomato product prices based on the estimated value of $\varepsilon = -0.505$.[10]

Use of equation (3′) to estimate oligopoly power in domestic tomato-product sales is appropriate only if the tomato-product mixes sold in the export and domestic markets are the same. This condition is not met in the present application because export sales focus on paste and puree, while most domestic sales are for ketchup and juice.[11] Because marginal processing costs for domestic versus export sales may not be equal, it is inappropriate to treat the composite export price as a benchmark to

[7] Antitrust laws did not exist in Taiwan until 1991, and it is not known whether this type of cooperative price-setting behavior will now be subject to challenge under these laws.

[8] Interviews with processors suggest that tomato products that are exported are of similar quality to those sold on the domestic market, eliminating quality differentials as an explanation for the price difference.

[9] Endogeneity of price variables is a possible concern when the raw-tomato supply function and processed-product demand function are estimated separately from the system of equations describing processor behavior. The tomato contracting process described previously provides a strong theoretical basis to treat W_1 as exogenous (see Chern, p. 212). To test for endogeneity of P_1^D, the demand equation was re-estimated using two-stage least squares. These estimates were very similar to the OLS results, and a Hausman test failed to reject the null hypothesis of exogeneity of P_1^D.

[10] Huang reports the results of Box-Cox tests on the functional form of the raw-product supply and processed-product demand equations. The tests support use of the log linear form relative to the linear form, although estimated elasticities are similar for the two models. Given that the data do not exclude use of the log linear forms, they are preferred for this type of analysis because they yield constant elasticities.

[11] Reformulating the theoretical model to express domestic versus export sales as different product composites is not useful in solving the empirical problem because processors do not separate production costs by either product form or market outlet (i.e., domestic versus export).

evaluate processor behavior in the domestic market. The approach undertaken to address this problem was to examine processor behavior in the output market for only ketchup and tomato juice, the two product forms with substantial sales in both the domestic and export markets.

Equation (3′) was estimated for ketchup and tomato juice by nonlinear maximum likelihood. The analysis included estimation of the parameter ρ to correct for first-order autocorrelation. The estimation results, presented in table 1, reveal a modest but statistically significant departure from competitive pricing in domestic sales of both products. The estimates of $\xi_K = 0.252$ for ketchup and $\xi_J = 0.074$ for juice are consistent with the estimate of inelastic demand. Perfectly colluding oligopolists ($\xi = 1.0$) would restrict sales to operate in the elastic portion of demand. Dividing the estimates of ξ by -1.0 times the estimated composite demand elasticity, $\varepsilon = -0.505$, obtains estimates of the Lerner Index of 0.499 for ketchup and 0.147 for tomato juice. A relative markup of 0.5 indicates domestic prices twice the competitive benchmark, demonstrating that even modest departures from competition result in significant price markups in the presence of inelastic demand.[12]

The system based on equations (2), (4′), and (5) was estimated using pooled data for 1986–90. This period was chosen because it provided the most complete and reliable data.[13] Data were obtained for six tomato-processing firms. Among firms involved in tomato processing, these firms were chosen because their product mix consisted mainly of canned fruits and vegetables and because their sales were directed primarily to the export market. This choice of sample thus obviates the problems caused by product mixes differing between domestic and export sales and firms' failure to distinguish costs by product form.

The data for 1986 are from Taiwan's economic census, while the data for 1987–90 are from confidential factory surveys conducted by Taiwan's Ministry of Economic Affairs (MEA). Firms' processed outputs were assembled into tomato and other processed foods composites, with tomato products measured in standardized cases (farm weight equivalents). Other foods were measured in terms of actual cases sold.

Table 1. Estimation Results for the Domestic Marketing Margins

Tomato Product	Parameter	Estimated Value	t-ratio
Ketchup	ξ_K	0.252	20.62
	ρ_K	0.352	2.05
Tomato juice	ξ_J	0.074	6.78
	ρ_J	−0.092	−0.35

Tomato export prices were obtained by dividing the annual export value of paste and puree sales by the volume of exports in standardized cases. The estimated value of cans was then subtracted from this gross price because the MEA data on costs for cans and packaging material were unsatisfactory and, hence, not used.[14] The farm price for raw tomatoes was the first-grade price for each contract year plus estimated average hauling costs, which are paid by processors. The first-grade price was used because communications with farmer representatives indicated that upwards of 80% of the crop was assigned this grade.

Processing labor costs were measured by the same factory wage variable, V_1, used in estimating the tomato supply function. The quantity V_1 was divided into each firm's total labor expense to obtain annual labor hours. Energy costs, V_3, were represented by the fuel and electricity wholesale price index which was divided into energy expenses to obtain volumes of energy utilized. Capital assets were grouped into building, equipment, and vehicle categories. A unit of capital capacity was defined as that needed to produce one standardized case of tomato products per hour. A capital price and quantity series were obtained for each category and then merged together utilizing procedures similar to those outlined in Sexton, Wilson, and Wann.[15]

In conducting the system estimation, additive

[12] The result that ketchup sales have been less competitive than juice sales is consistent with the structure of the industry. The dominant processor has maintained a larger market share in ketchup sales than in juice. In 1991 six firms sold juice domestically, while only four sold ketchup.

[13] This period was also marked by relative stability in the industry. The four-firm concentration ratio trended slowly upward during the period but no major exogenous shocks were experienced.

[14] This step implicitly requires the assumption that can and packaging costs are separable from other processing costs, which, in turn, implies the rather reasonable assumption that other processing inputs (labor, energy, and capital) cannot substitute for cans and packaging material in the production process. This same procedure was used to handle "miscellaneous expenses" contained in the MEA factory data.

[15] See Huang for detailed discussion of data sources and variable construction, including appendix tables of the actual data except for those firm-level data obtained in confidence. Summary statistics of the confidential data are provided in table 5.9 of Huang.

error terms were appended to each equation in (2), (4′), and (5). The system was treated as a set of seemingly unrelated equations in that error terms between equations were assumed to be uncorrelated across observations but not within observations. Each of the five equations also included a parameter, ρ_i, to correct for first-order autocorrelation. The system was estimated by nonlinear full information maximum likelihood. Estimation results are provided in table 2. Eleven of the thirteen estimated parameters are statistically different from zero at significance levels of 0.10 or less. The estimates are robust to alternative starting values for the estimation process.[16]

Among the cost-function properties, the GL satisfies homogeneity of degree one in input prices by construction. Monotonicity in input prices was satisfied by the estimated function at all data points. However, concavity in input prices was not satisfied at all data points. This outcome may be a consequence of limited substitution among inputs in the food-processing technology. For example, a pure Leontief technology is affine in input prices and, as such, not strictly concave. In any event, failure to meet the concavity restriction is a limitation of the estimated model, as is the relatively limited sample size used in the estimation.[17] These factors need to be considered along with the positive aspects, such as high proportion of significant coefficients, use of micro versus aggregate data, and stability of results with respect to starting values, in evaluating conclusions based on the model.

The key parameter from the system estimation is θ. Its estimated value of 0.98 is rather close to the theoretical monopsony value of 1.0. The hypothesis of monopsony, $\theta = 1.0$, is not rejected, but the hypothesis of competition, $\theta = 0$, is soundly rejected. This result indicates highly collusive conduct among processors in procuring tomatoes and is quite consistent with the information presented earlier on the contracting process.

From equation (2′), the estimation results can be used to decompose the export value of tomato products into farm value, marketing cost, and processor markup components. The average net export price for paste per standardized case for 1986–90 was 474 New Taiwan dollars (NT\$). (NT\$ is the monetary unit used throughout the application, where 27NT\$ ≈ 1U.S.\$ based on the 1993 year-end exchange rate.) The estimates indicate this amount consisted of NT\$274 in farm value, NT\$138 in processing and transportation cost, and NT\$62 in processor markup. Thus, 13% of the export value of processing tomatoes was estimated to be due to processor monopsony power. Interesting to note is that, although processors' relative market power in raw-product procurement is considerably greater than their power in domestic processed-product sales, the consequence of that power is less in the input market than in the output market. The reason for this is the greater elasticity of supply of the raw product relative to the elasticity of demand for the processed product, which prevents even perfectly colluding oligopsonists from driving price too much below the competitive level.

Table 2. Estimation Results for the System of Equations

Parameter	Estimate	t-ratio
θ	0.978	4.681
a_{11}	−2.816	−3.435
a_{12}	−0.001	−1.740
a_{13}	−1.063	−3.543
a_{112}	0.061	3.557
a_{113}	2.089	4.698
a_{123}	−0.032	−3.182
a_{21}	1.377	1.863
a_{22}	0.001	2.706
a_{23}	1.196	3.052
a_{212}	0.009	0.552
a_{213}	−0.886	−1.823
a_{223}	−0.011	−0.918
ρ_1	0.402	2.063
ρ_2	0.832	14.904
ρ_3	0.826	15.208
ρ_4	0.761	10.745
ρ_5	0.894	13.583

Analysis of Returns to Mechanical Tomato Harvesting

We develop a partial equilibrium framework to evaluate the impacts of a cost-reducing innovation. In our application, events in the Taiwanese

[16] The competition parameter θ was initiated in the interval [0, 1] at increments of 0.1. Each starting value of θ was combined with three alternative sets of starting values for the other parameters. In all instances the estimates converged to the values contained in table 2.

[17] Judge et al. note that, due to the wide variety of nonlinear model specifications, it is almost impossible to state definitive results on their small sample properties.

processing-tomato industry are unlikely to have significant spillover effects on other industries that would necessitate a general equilibrium approach.[18] The stakeholders in the industry are assumed to be consumers, farmers, and processors. Farm input suppliers are not considered as an independent group of stakeholders in this application because the major input in tomato production, labor, is supplied primarily by the farm families.[19]

Welfare Analysis Methodology

The key component to welfare analysis of a cost-reducing innovation is estimation of the supply curve shift associated with the cost reductions. In an *ex post* analysis, the supply curve shift may be estimated econometrically. In this *ex ante* analysis it was imputed from the results of government field trials. Given the estimated market behavior and the supply curve shift, new equilibrium values for prices and output can be derived. Per conventional practice, consumer and producer welfare effects were measured via changes in economic surplus. Processor welfare was measured as the change in profits induced by mechanical harvesting.

Considerable discussion has evolved over how to model the supply curve shift, with divergent, parallel, and convergent shifts having been considered (Lindner and Jarrett). The nature of the supply curve shift is important, in general, for the measurement of producer surplus. But in models of imperfect competition it takes on added significance due to the implications for producers' elasticity of supply, which plays a key role in determining markdowns due to monopsony power. Alston, Norton, and Pardey argue that neither economic theory nor econometric estimation is likely to be very informative on the resolution of this issue, and they recommend, in the absence of strong contrary evidence, the use of a parallel shift.[20]

In the previous work on adoption of the tomato harvester in California, Brandt and French estimated a parallel supply curve shift which was also adopted in the subsequent work of Kim et al. Schmitz and Seckler did not estimate a supply curve, but a parallel shift is implicit in their analysis. Chern and Just, however, argued for a convergent supply curve shift because mechanical harvesting replaced a variable cost (harvest labor) with a fixed cost (the harvester). The Chern and Just argument for a convergent shift is less relevant in Taiwan because mechanical harvesting would be performed on a custom basis due to small farm sizes and would represent a variable rather than a fixed cost to farmers. We proceed, therefore, to develop the analysis with a parallel shift in the raw-tomato supply curve.[21]

We use the interpretation of the market behavior parameters given in equations (2″) and (3‴) to provide a graphical depiction in figure 1 of the benefits to a cost-reducing innovation under imperfect competition and to compare the relative change in benefits under market power versus perfect competition. The market is depicted at the farm level.[22] Henceforth, to ease the notational burden, subscripts 1 and 2 denoting tomato versus other processed products are omitted, and all prices and outputs are understood to refer to tomatoes. For graphical convenience, we use linear approximations of the derived demand and farm supply curves and set $\theta = \xi = 0.5$. Hence, the curve defined by (2″) lies midway between the inverse supply curve $W^o(R)$ and the associated marginal cost curve $MC^o(R)$, and the curve defined by (3‴) lies midway between the inverse demand curve $P(R)$ and the associated marginal revenue curve $MR(R)$.[23]

The initial competitive equilibrium is given by ($P_o^c = W_o^c$, R_o^c) and the initial oligopoly-oligopsony equilibrium is given by (P_o^m, W_o^m, R_o^m). The cost-reducing innovation is assumed to shift farm supply to $W^1(R)$. Production increases to R_1^c and price decreases to $W_1^c = P_1^c$ under perfect competition. The expansion in raw product input and processed product output

---

[18] See Alston, Norton, and Pardey for further discussion of partial versus general equilibrium approaches to welfare analysis.

[19] This situation contrasts with adoption of the mechanical harvester in California, where the impact on farm workers' welfare has been debated extensively. See Schmitz and Seckler; Brandt and French; and Alston, Pardey, and Carter.

[20] A practical advantage of parallel supply curve shifts is that choice of functional form of the supply curve then becomes rather unimportant to the measurement of producer welfare.

[21] Both parallel and convergent supply curve shifts imply that the post-innovation supply is less elastic at all positive quantity levels, so the qualitative implications of either shift are similar. An intuitive rationale for less elastic supply with mechanical harvesting is the adaptation of fields and roads needed to accommodate the harvester. Land would become specialized to tomato production and not readily transferrable among alternative crops.

[22] Given the assumptions of quasi-fixed proportions and constant returns to scale in the processing technology, the wholesale supply and demand curves are obtained simply by adding per unit processing costs to the farm supply and derived demand curves in figure 1.

[23] The expression $\theta = \xi = 0.5$ would, for example, depict an equilibrium between equal-sized Cournot duopsonists/duopolists.

is $\Delta R^c = R_1^c - R_o^c$. Production increases as well under oligopoly-oligopsony, but by a smaller amount, $\Delta R^m = R_1^m - R_o^m < \Delta R^c$, than under perfect competition. As a consequence, the raw-product price generally falls more and the processed-product price falls less than under perfect competition. This important result is true in general whenever either θ or ξ are positive. In these cases, the conduct of the processing sector involves firms taking into account the effect of their input and output expansion on either the raw product price ($\theta > 0$), the processed product price ($\xi > 0$), or both (θ, $\xi > 0$), and expanding inputs and output less than under competition as a consequence. The magnitude of output expansion, ΔR, is decreasing in both θ and ξ over their entire theoretical range $\theta, \xi \in [0, 1]$.

In static market models, the social loss or reduction in total economic surplus from monopoly/monopsony power is the deadweight loss (DWL) caused by the restriction in inputs purchased and/or output supplied relative to perfect competition. The difference in benefits from a cost-reducing innovation under imperfect versus perfect competition is, therefore, exactly the change in the deadweight loss as a consequence of the innovation.[24] DWL is a monotonic increasing function of the output difference $R^c - R^m$ under perfect versus imperfect competition. Thus, since $\Delta R^m < \Delta R^c$, the benefit of a cost-reducing innovation is necessarily less under imperfect competition than under competition.

For the linear model depicted in figure 1, the increase in consumer surplus from the innovation is $P_o^m D_o D_1 P_1^m$ under imperfect competition versus $W_o^c B_o B_1 W_1^c$ under perfect competition. Because $\Delta R^c > \Delta R^m$, price decreases more and consumers benefit more under perfect competition. The change in producer surplus under perfect competition is $W_1^c B_1 A_1 - W_o^c B_o A_o$ versus $W_1^m E_1 A_1 - W_o^m E_o A_o$ under imperfect competition. Except when demand is perfectly inelastic, farmers benefit from the innovation under either market structure, but the benefit is less under imperfect competition. Processors receive no benefit from the innovation under perfect competition, but under imperfect competition, their benefit is $\pi_1 - \pi_o = (P_1^m - W_1^m) R_1^m - (P_o^m - W_o^m) R_o^m > 0$. Thus, the collective consumer and producer welfare benefit from a cost-reducing innovation is diminished under imperfect competition both because the total benefit is reduced by the increase in the deadweight loss and because processors capture part of the benefit that does exist.

Application of the Methodology to Taiwanese Tomato Processing

Taiwan undertook field trials of mechanical tomato harvesting beginning in 1989–90. The trials included introduction of new tomato cultivars from California that produced fruit amenable to mechanical harvesting. Data for this analysis were derived from the eleven participating farmers in 1990–91, the second year of field trials. The average yield attainable from the new cultivars was 70 metric tons (MT) per ha, about the same as that attained from conventional cultivars.

Production costs were disaggregated into preharvest and harvest periods. Three harvest regimes were considered: total hand harvest, total machine harvest, and a combination of hand and machine harvest. A disadvantage to pure machine harvesting is that yields may be reduced relative to multiple hand-harvests because tomatoes are not uniformly ripe at the time of the single mechanical harvest.[25] The Taiwanese trials all involved a hand harvest conducted two to three weeks before the mechanical harvest. In the 1990–91 trials 37% of the crop was harvested by hand, with the remaining 63% machine harvested.

The combination of hand and machine harvesting reduced both preharvest and harvest costs relative to pure hand-harvesting. Preharvest cost savings were primarily due to mechanical direct seeding and reduced fertilizer use. Machine harvest costs are primarily a function of the hectarage harvested, and the key factor in achieving harvest cost savings under a switch to machine harvesting is the yield relative to pure hand-harvesting.

Table 3 reports preharvest and harvest cost results based on the field trials. Strategy S_1, a combination hand-machine harvesting, reduced production costs 28% relative to the baseline strategy, S_0, of pure hand-harvest. Strategies S_2 and S_3 refer to pure machine-harvesting. Strat-

[24] This proposition is consistent with the principle articulated by Alston, Edwards, and Freebairn that the benefits from research in the presence of a trade distortion are equal to the benefits in the absence of the distortion minus the increase in the costs of the distortion due to the supply curve shift.

[25] The California cultivars did not ripen as uniformly in Taiwan as they did in California, thus exacerbating the crop loss from a single mechanical harvest.

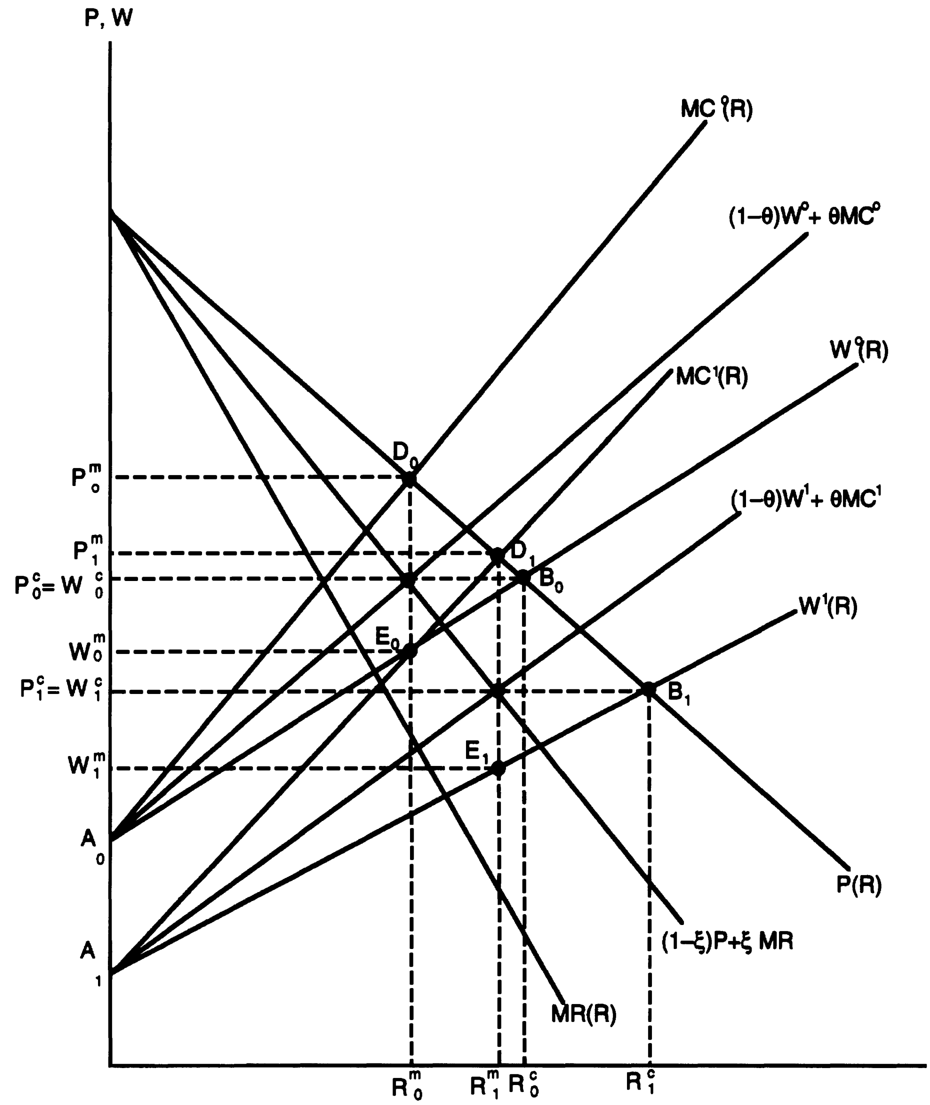

Figure 1. Returns to a cost-reducing innovation under perfect versus imperfect competition

egy S_2 assumes that the full 70 MT/ha harvest can also be attained under pure machine-harvesting. Strategy S_2 was estimated to reduce production costs 45% relative to S_0. Strategy S_3 assumes that the 37% of the crop hand harvested in the field trials would be lost under a pure machine-harvest. The per unit production cost savings relative to S_0 under this scenario were estimated to be only 12%.

To measure the potential supply curve shift from mechanical harvesting, the hectarage supply function (6′) was first converted to a quantity basis by multiplying both sides by a constant yield term. The supply curve under hand harvesting was then expressed as

$$(8) \quad R = \beta(W)^{\eta}$$

where R denotes volume of tomatoes supplied in standardized cases, the constant term β is found by valuing all variables in equation (6′) other than W at their 1993 values and aggregating. Producer surplus (PS_o) based on equation (8) for the hand-harvest technology is computed as

$$(9) \quad PS_o = \beta(1 + \eta)^{-1}(W_o)^{1+\eta},$$

where W_o is the equilibrium farm price under hand harvesting.

Mechanical harvesting shifts the inverse sup-

Table 3. Estimated Taiwanese Processing-Tomato Production Costs in 1991 under Alternative Harvest Regimes

Harvesting Strategy	Yield MT/ha	Preharvest Cost NT$/MT	Harvest Cost NT$/MT	Total Cost Savings	
				NT$/MT	% Baseline
S_0 hand harvest only	70	772	637	—	—
S_1 hand & machine harvest	70	658	357	394	28.0
S_2 machine harvest, ideal yield	70	658	122	630	44.7
S_3 machine harvest, 63% of ideal yield	44	1,046	193	170	12.1

ply curve downward by the amount of the per unit reduction in costs $z > 0$: $W = \beta^{-1/\eta}(R)^{1/\eta} - z$, or

$$(10)\quad R = \beta(W + z)^{\eta}.$$

The elasticity of the new supply curve is $\eta' = \eta[W/(W + z)] < \eta$. Producer surplus ($PS_1$) under machine harvesting is computed from equation (10) as follows:

$$(11)\quad PS_1 = \beta(1 + \eta)^{-1}(W_1 + z)^{1+\eta},$$

where W_1 is the equilibrium farm price with adoption of the harvester.

The decrease in the farm price $\Delta W = W_o - W_1$ due to mechanical harvesting can be derived using (2′): the equilibrium condition prior to adoption of the harvester is $P^E - C - W_o = W_o\theta/\eta$. The comparable post-harvester condition is $P^E - C - W_1 = W_1\theta/\eta'$. Setting $W_1 = W_o - \Delta W$, using the pre-harvester equilibrium condition to substitute for $P^E - C$ in the post-harvester equilibrium condition, and solving for ΔW obtains

$$(12)\quad \Delta W = z\frac{\theta}{\theta + \eta}.$$

From equation (12), the farm price decrease caused by adoption of mechanical harvesting is greater the larger is the cost reduction, z, the more collusive is processor behavior as measured by θ, and the more inelastic is the supply. Under perfect competition in the procurement of processing tomatoes, the farm price would not decline as a consequence of adopting the tomato harvester, given the perfectly elastic export demand.

Using equation (12) to substitute for W_1 in equation (11), and defining $k = z/W_o$ as the relative per unit cost reduction, the relative increase in producer surplus from mechanical harvesting can be expressed as

$$(13)\quad PS_1/PS_0 = \left(1 + k\frac{\eta}{\theta + \eta}\right)^{1+\eta}.$$

From equation (13) the relative gain in producer surplus is increasing in k and η and decreasing in θ.

The major adaptation distinguishing the Taiwan application from the general welfare evaluation methodology described previously is the presence of the elastic export demand, which results in the domestic price for processed tomato products, P^D, being unchanged despite adoption of the harvester. Processor behavior in selling tomato products involves equating perceived marginal revenue from domestic market sales with the exogenous export price P^E. Any additional sales in the domestic market causes perceived marginal revenue to fall below P^E, meaning that the entire output expansion, ΔR, under either perfect or imperfect competition will be exported and benefit to domestic consumers from adoption of the harvester will be zero. This result does not, however, hold generally as figure 1 indicates. Rather, consumers benefit from cost-reducing innovations whenever demand slopes downward in all market outlets for the finished product(s).[26]

Given that the domestic sales and tomato-product prices facing Taiwanese processors do not change as a consequence of mechanical harvesting, the change in processor profits from innovation in the supply of R can be expressed

[26] The conceptual framework summarized in figure 1 adapts readily to the open economy context. See Huang, chap. 4, for the details.

Table 4. Returns to Mechanical Harvesting of Taiwanese Processing Tomatoes

Harvesting Strategy	Cost Reduction (z) NT$/std.case	Reduction in W NT$/std.case	Producer Surplus (000 NT$)	Processor Profit (000 NT$)
S_1	65	13.04	75,000	92,000
S_2	104	20.86	143,000	176,000
S_3	28	5.62	27,000	33,000

in terms of the change in markdown of the raw-product price from the competitive level $W^c = P^E - C$:

$$(14)\quad \Delta\pi = \pi_1 - \pi_o = (W^c - W_1)R_1 - (W^c - W_o)R_o.$$

Equation (14) can be re-expressed using the first-order condition (2) to substitute for W^c, the pre- and post-harvester supply curves, equations (8) and (10), respectively, to substitute for R_o and R_1, and $W_1 = W_o - \Delta W$ and equation (12) to eliminate W_1. The resulting expression is

$$(15)\quad \Delta\pi = \frac{\beta\theta}{\eta}\left[W_o^{1+\eta}\left(1 + k\frac{\eta}{\theta + \eta}\right)^{1+\eta} - W_o^{1+\eta}\right].$$

From equation (15) processors derive benefits from the innovation whenever $k, \theta > 0$ and $\eta < \infty$.

Table 4 presents the welfare analysis for mechanical harvesting of processing tomatoes in Taiwan under strategies S_1, S_2, and S_3. The deflated values of W_o and β for the 1992–93 crop year and the estimated values of $\eta = 3.90$ and $\theta = 0.978$ are used for the welfare evaluation. All values are measured in NT$ relative to the baseline scenario, S_0, of pure hand-harvesting. Under each of the mechanical harvesting scenarios, processors' collective benefit exceeds the benefit accruing to farmers. The total annual benefit to adopting a combination hand-machine harvest was estimated to be NT$167 million (approximately U.S.$6.17 million). Given projected post-harvester hectarage of 4,414 and 70 MT yield, the benefit is roughly U.S.$20 per MT, with processors capturing 55.1% of that amount. In evaluating the efficacy of adopting the harvester in Taiwan, this annual stream of benefits must be discounted and compared to the fixed costs of adapting fields and roads to accommodate mechanical harvesting. No comprehensive study of these costs has been made, but they are unlikely to surpass the estimated benefit flow, suggesting that mechanical tomato harvesting is indeed beneficial for Taiwan and represents a possible avenue to enhance the international competitiveness of the industry.[27]

Table 5 compares the benefits to mechanical harvesting based on the model of imperfect competition with benefits calculated assuming that the industry is perfectly competitive. Estimation of the supply and demand equations, (6′) and (7′), is unaffected by the market structure because those relationships were estimated at the primary levels where behavior is unequivocally competitive.[28] Thus, estimated benefits from mechanical harvesting under perfect competition within the present model can be obtained simply by setting $\theta = \xi = 0$. The result is $\Delta W = 0$ from equation (12) and, hence $\Delta\pi = 0$ from equation (14). Benefits under perfect competition accrue solely to farmers and are estimated using equations (9) and (11) to compute the change in producer surplus, given $\Delta W = 0$.

Table 5 indicates that about 25% of the benefits from mechanical harvesting are lost due to imperfect competition under any of the harvest strategies. The loss to producers is much more dramatic—equaling about two-thirds of the benefits attainable under perfect competition in procurement of raw tomatoes. From a welfare perspective, these estimates illustrate the proportion of benefits from a cost-reducing innovation that can be lost due to imperfect competition. From a behavioral perspective, they illustrate the magnitude of error in benefit estimation that may accrue from incorrectly assuming perfect competition in an industry that is in fact oligopsonistic. Consumer benefits to the innovation disappear in our model due to

[27] Indirect benefits to mechanical harvesting may include freeing an aging farm labor force from some of the present hand-harvesting requirements and possible reduction in government subsidies to corn production if increased returns to tomato production move hectarage from corn into tomato production.

[28] This situation contrasts to the Chern and Just, and Brandt and French analyses, where attempts to estimate processors' derived demand for raw tomatoes result under oligopsony in estimating the "perceived demand" curve defined implicitly in equation (3‴) and illustrated in figure 1.

Table 5. Benefits to Mechanical Tomato Harvesting in Taiwan under Perfect Versus Imperfect Competition

Harvest Strategy	Total Benefit to Harvester (NT$ 000)		% Loss from Imperfect Competition	
	Imperfect Comp.	Perfect Comp.	Farmers	Total
S_1	167,000	224,000	66.5	25.4
S_2	319,000	429,000	66.7	25.6
S_3	60,000	81,000	66.7	25.9

Taiwan's relationship to the export market for tomato products. However, such benefits will exist in many applications and also be diminished by imperfect competition, as figure 1 illustrates.

Conclusions

In this paper we have developed and applied a conceptual framework to evaluate the impacts of a cost-reducing innovation in an imperfectly competitive market for an agricultural product. The methodology applies generally to oligopolistic and/or oligopsonistic markets and includes perfect competition and monopoly/monopsony as special cases. Previous work on returns to research and product innovations has generally assumed perfect competition. This study demonstrates that serious errors in the estimation of the magnitude and distribution of benefits are possible when an imperfectly competitive market is erroneously modeled as perfectly competitive.

In general, the benefits of a cost-reducing innovation are less under imperfect competition than perfect competition because the output expansion is relatively muted by the conduct of imperfectly competitive firms. In addition, marketing firms as a class of agents derive benefits from the innovation as imperfect competitors that they would not obtain as perfect competitors under a constant returns marketing/processing technology.

Application of the model to mechanical tomato harvesting in Taiwan revealed first that the industry is imperfectly competitive both in raw-product procurement and domestic product sales. Field trials indicated the potential of mechanical harvesting to reduce processing tomato per unit production costs from 12% to 45%, depending upon the machine harvest yield. Consumers in Taiwan were shown not to benefit from mechanical harvesting because additional production will flow into the export market where Taiwan is a perfect competitor. Further, the benefit will be shared by farmers and processors, with the latter receiving about 55% of the total, based upon the study results. Conversely, under perfect competition, benefits from the innovation would accrue to farmers only. The loss to farmers from oligopsony in tomato procurement was estimated to be about two-thirds of the benefits attainable under perfect competition, with the overall loss due to imperfect competition estimated to be 25% of the benefits attainable under perfect competition.

Aside from its importance in obtaining accurate estimates of research/innovation benefits, estimating and working with the appropriate market model can have considerable policy relevance, as the present application illustrates. With the processing sector poised to obtain 55% of the benefits from mechanical harvesting, the sector collectively has incentive to facilitate farmers' adoption of mechanical harvesting. An obvious avenue for processor assistance would be sharing in the costs of modifying fields and roads to accommodate mechanical harvesters. However, free-riding may well prevent such assistance from emerging in the absence of government policies to address and internalize the spillover effects. This market failure may explain in part why mechanical harvesting has not been adopted in Taiwan despite the apparent benefits it would generate.

[Received August 1995; final revision received April 1996.]

References

Alston, J.M., G.W. Edwards, and J.W. Freebairn. "Market Distortions and Benefits From Research." *Amer. J. Agr. Econ.* 70(May 1988):281–88.

Alston, J.M., G.W. Norton, and P.G. Pardey. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority*

Setting. Ithaca NY: Cornell University Press, 1995.

Alston, J.M., P.G. Pardey, and H.O. Carter. "Valuing UC Agricultural Research and Extension." Agricultural Issues Center Publication No. VR-1, University of California, DANR, March 1994.

Brandt, J.A., and B.C. French. "Mechanical Harvesting and the California Tomato Industry: A Simulation Analysis." *Amer. J. Agr. Econ.* 65(May 1983):265–72.

Chern, W.S. "Acreage Response and Demand for Processing Tomatoes in California." *Amer. J. Agr. Econ.* 58(May 1976):209–16.

Chern, W.S., and R.E. Just. "Econometric Analysis of Supply Response and Demand for Processing Tomatoes in California." Giannini Foundation Monograph No. 37, University of California, Division of Agricultural Sciences, September 1978.

Christensen, L.R., and D.W. Jorgenson. "The Measurement of U.S. Real Capital Input, 1929–1967." *Rev. Income and Wealth* 15(1969):293–320.

Dixit, A. "Comparative Statics for Oligopoly." *Int. Econ. Rev.* 27(1986):107–22.

Dryburgh, C.R., and C.J. Doyle. "Distribution of Research Gains under Different Market Structures: The Impact of Technological Change Within the UK Dairy Industry." *J. Agr. Econ.* 46(January 1995):80–96.

Guilkey, D.K., C.A.K. Lovell, and R.C. Sickles. "A Comparison of the Performance of Three Flexible Functional Forms." *Int. Econ. Rev.* 24(October 1983):591–616.

Hsu, C.I. "A Study on the Taiwan Processing Tomato Industry and a Forecast on the Supply and Demand for Processing Tomatoes (in Chinese)." *J. Agr. Econ.* 32(1978):47–55.

Huang, S.Y. "Research Benefits under Imperfect Competition with Application to Mechanical Tomato Harvesting in Taiwan." PhD dissertation, University of California, Davis, June 1994.

Judge, G.G., R.C. Hill, W.E. Griffiths, H. Lutkepohl, and T.C. Lee. *Introduction to the Theory and Practice of Econometrics.* New York: John Wiley, 1982.

Kim, C.S., G. Schaible, J. Hamilton, and K. Barney. "Economic Impacts on Consumers, Growers, and Processors Resulting from Mechanical Tomato Harvesting in California—Revisited." *J. Agr. Econ. Res.* 39(Spring 1987):39–45.

Lai, S.H. "The Production of Processing Tomatoes in Taiwan (in Chinese)." *J. Chinese Soc. for Hort. Sci.* 21(March 1975):64–71.

Lindner, R.K., and F.G. Jarrett. "Supply Shifts and the Size of Research Benefits." *Amer. J. Agr. Econ.* 60(February 1978):48–58.

Quirmbach, H.C. "Comparative Statics for Oligopoly: Demand Shift Effects." *Int. Econ. Rev.* 29(August 1988):451–58.

Schmitz, A., and D. Seckler. "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester." *Amer. J. Agr. Econ.* 52(November 1970):569–77.

Sexton, R.J., B.M. Wilson, and J.J. Wann. "Some Tests of the Economic Theory of Cooperatives: Methodology and Application to Cotton Ginning." *W. J. Agr. Econ.* 14(July 1989):55–66.

Voon, T.J. "Measuring Research Benefits in an Imperfect Market." *Agr. Econ.* 10(January 1994):89–93.

Wann, J.J., and R.J. Sexton. "Imperfect Competition in Multiproduct Food Industries with Application to Pear Processing." *Amer. J. Agr. Econ.* 74(November 1992):980–90.