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c. Objectives of the Original Research

The goals of this research have been:

1. The estimation of the price response to qualitative characteristics of tomatoes.
2. Development and evaluation of appropriate pricing system for quality of the produce.
3. Estimation of the expected return from the investment in research and development process of new plant varieties.

d. Abstract

The research deals with optimal production of a quality differentiated agricultural product. We show that when the quality traits of a good are of binary form, the Binary Quality Price Function (BQPF) is convex. The convexity of the BQPF imply that if sorting is costless or inexpensive for the producer, or for the marketing board, selling two quality brands (or more) will be more profitable than marketing just one brand with average quality. The BQPF of the Israeli glasshouse export tomatoes in Germany are the subject of the empirical estimation carried out in this study. The hedonic price method is used to estimate a polynomial form of the BQPF. The results are found to be statistically significant, with $R^2 = .94$, and support our hypothesis of convexity.

Under deterministic market conditions, optimal quality premiums to growers that will induce optimal production decisions concerning quantity-quality tradeoffs, should be identical to the Hedonic price function. Under conditions of price uncertainty, the marketing board should absorb the risk, and present the growers with deterministic quality price function equal to the expected value of the Hedonic market price function. In estimating the rate of return to tomato breeding, we demonstrate that the hedonic prices for characteristics are helpful in determining the expected rate of return to one type of R&D activity - tomato breeding. This knowledge helps to determine how much should be invested in tomato breeding and provide conditions under which this investment should be increased or decreased.

(e) Body of the report

INTRODUCTION

This study deals with the internal policy of a governmental marketing board of an agricultural export product with which many growers are associated. The board is interested in maximizing the expected profits of the whole industry, and operates in a competitive foreign market with a randomly fluctuating hedonic price function. The analysis is, however, immediately applicable to any marketing agency operating on the basis of payments as percentage of profits. It is also applicable to the problem of a firm, facing a given hedonic price function subject to uncertainty, that works with profit maximizing subdivisions which respond to a management preset price function. The firm must determine the price-quality functions it is willing to pay for the intermediate products (inputs) it uses in the production process. Such a price-quality function is determined on the basis of the contribution of the input to the price of the final product (through its effect on the quality of the latter). Examples of this problem are abundant in sophisticated products composed of many components, such as cars, planes, electronics, fashion goods, wines and most foods, where processing and packaging affect the quality characteristics of the product, in much the same way as inputs in a production process.

The literature on quality-price relationship, started with Hotelling (1929), who developed a competitive equilibrium model dealing with consumers' distribution of preferences for quality. This model was recently investigated by Lancaster (1979). Our paper adopts Griliches' (1971) and Rosen's (1974) hedonic price method to identify the contribution of individual quality components to the price of a product. The method is applied to the problem of pricing tomatoes, whose quality

can be measured, like in many other goods, by a binary rule.

A quality trait is of binary nature, if each unit of the product either possesses, or does not possess, the quality trait in question. The quality trait is measured in this case by the probability of obtaining one unit of the product possessing the quality trait in question, in a random draw. When many units of the good are bought in a single transaction, a quality trait is measured by the percentage of units with that trait, and the over-all quality level is a vector of percentages, each for a given trait. It is shown below that when quality traits are binary, the competitive market price as a function of quality, must be a convex function, while this cannot be said of a hedonic price function in general.

The convexity of the price function has an important marketing policy implication: a marketing agency facing such a price function would increase its revenue by increasing product differentiation. e.g. the revenue from a given amount of 50% firm fruit would increase if the fruit was sorted into two transactions, one with 25%, and the other with 75% of firm fruit. Binary quality traits can be found in many products where the output is subject to quality control with a passing grade threshold; e.g. in electronics, cars, military equipment, and in agricultural products, one of which is the subject of this paper.

Rapid deterioration in the quality of Israeli export glass-house tomatoes, followed by price and profit decline, threatened the existence of this industry. A major reason for the decline in quality was considered to be the practice of paying a pooling price to all growers, independent of the quality of their fruit. The industry consists of many small growers, who market their tomatoes via a single marketing agency (Agrexco). The marketing agency sells the product in the European market

in a competitive environment, under a quantity independent price function, subject to random fluctuations. The only incentive for the growers to produce high quality has been quality control, that disqualified low quality fruit for export.

There exists a short term (let alone a long term) tradeoff in production between quality and quantity; for example, increasing irrigation and nitrogen fertilization raises the yield while reducing quality. As a result of the pooling price system, together with low bounds on quality, the growers have been led to produce the lowest export qualified quality, thereby reducing the overall profits of the industry. The problem of the marketing board is to find a solution that will pass on the correct incentives to the individual growers, without diverting from the marketing board practices of selling one or two brands only, where individual growers are unidentified in the market.

The major issues investigated in this study are:

- a) Measurement of the quality traits and estimation of the market hedonic price function of the Israeli tomatoes.
- b) A pricing policy that will induce optimal production decisions concerning quantity-quality tradeoffs in the production process, given a deterministic market hedonic price function.
- c) Problems of uncertainty in the market price function and the appropriate signals that should be passed on to the individual growers by the marketing board.
- d) Optimal quality control by the packing house

Correspondingly, our main results are:

(a) We demonstrate that the market price is sensitive to quality variations. We have estimated a hedonic tomato price function with significant coefficient of quality variables and high coefficient of

determination ($R^2=0.94$). Problems of autocorrelation with missing information were resolved by using an appropriate econometric procedure (Appendix 1). As predicted by the model, the estimated hedonic price function turned out to be convex in the quality traits. The average daily price of the Canary Island tomatoes, which was taken as a proxy to the random fluctuation of the market prices, proved to be highly significant.

(b) It is shown that the optimal policy of the marketing board (in a deterministic price situation) is to expose the growers to the market price, or devise a quality premium system, which rewards the growers for quality of their produce in the same way that the market does.

Increasing returns to specialization in quality in the production process, will cause the growers to specialize at a single quality level. If all growers are assumed to be identical, they will thereby produce fruits of homogeneous quality. Indeed, in practice, after several years of implementation of the quality premium method, we observe that the product produced by the growers is much more homogenous than before this method was implemented.

(c) It is shown that under conditions of price uncertainty, the marketing board should absorb the risk, and present the growers with a deterministic quality price function equal to the expected value of the market price function. The behavior of the growers will then match the decision rules implied by the maximization of the expected profits, this being the goal of the marketing board.

(d) Last but not least, we establish the growers' schedule of payments to the packing house, which will induce the latter to act efficiently on the growers' behalf. Namely, the growers should pay all variable costs of sorting and packing, plus a percentage of the net revenue (total revenue minus the variable cost). The latter should be

sufficient to cover the fixed cost and normal profits of the packing house. The optimal behavior of the packing house obtained in this way involves the establishment of a quality threshold of fruit to be admitted into the packing house. We also show that sorting does not change the quality ranking of fruits among growers, i.e. higher quality fruit entering the packing house will also leave it being of higher quality.

Table 1. illustrates the improvement of our over-all tomato quality since the initiation of our study, as reflected by the average price ratio of Israeli to Canary Island tomatoes (the most prevalent quality tomatoes on the market).

Table 1. Comparison of Israeli and Canary Island tomato prices
(German Marks/kg) ⁽¹⁾

Year	1979	1980	1981	1982	1983	1984
(1) Israel	2.85	3.42	4.63	3.76	4.38	3.38
(2) Canary	2.45	3.16	3.11	2.88	2.87	2.60
(1)/(2)	1.16	1.08	1.49	1.31	1.52	1.30

⁽¹⁾ Source: ZMP 1984

It should be noted that during this period (1979-1984), the varieties of Israeli tomatoes marketed changed several times, which contributed to the improved price ratio. The new varieties were developed by a genetic research group especially for the glasshouse tomatoes. However, the incentive to the growers to grow quality tomatoes was induced mainly by

the price mechanism suggested and worked out by this study.

The first section of the paper characterizes the price-quality relationship for binary quality. The second section develops the theoretical basis for internal pricing policy by a marketing board, and the third section presents the empirical application, data, estimation method, and analysis of the results.

1. CHARACTERIZATION OF THE BINARY QUALITY PRICE FUNCTION (BQPF)

Consider a product, many units of which are bought and sold in a single transaction, and whose quality traits are of binary type, that is, each unit either attains or does not attain a given level for that trait. Consequently, a quality trait of that good can be measured, for any given transaction, by the percentage of units having the desired quality level. The same applies to a vector of quality traits for each of its components. Examples include many food products, clothing items, matches, screws, bricks, etc. Clearly, tomatoes are included in this class.

Tomatoes are characterized by a finite set (vector) of quality traits, such as color, taste, firmness, etc. For each quality trait, a single tomato will take binary values, 1 for possessing the trait and 0 otherwise. The level of each quality trait per unit, say box or kg., will thus be measured by the percentage of tomatoes having that trait. The price paid by the consumers reflects the overall quality of the product as perceived by them; however, the rewards for the individual quality traits are only implicit and cannot be directly observed in the market. The hedonic price method (Griliches 1971, S. Rosen 1974, J. Brown and H. Rosen 1982, Brown and Mendelson 1984) is applied here to estimate the hedonic price function for the quality traits of tomatoes.

Let $Z_i (i=1, \dots, n)$ denote the level of the i -th quality trait. For example, percentage of firm tomatoes, percentage of discoloration, size, color, etc. Then, following S. Rosen (1974) the competitive market price, P , can be written as a function of the quality traits $P(Z) = P(Z_1, Z_2, \dots, Z_n)$, with its partial derivatives being the implicit prices of the quality traits. These can serve as the basic price data for estimating the demand and supply of the quality traits. Furthermore, $P(Z)$ itself is required for the decision making by the marketing board.

In dealing with the price function for goods with binary quality (BQPF) major differences from Rosen's HPF should be noted: (1) full divisibility of the product, and (2) the possibility of mixing and sorting the product. In particular, the mixing of units of the product with different qualities will result in a product with quality level equal to the weighted average of the original qualities. This results in an important property: the BQPF is a strictly convex function in the quality traits. The arguments leading to this conclusion are twofold: First, the possibility of mixing two different levels of a given trait while keeping the level of other traits fixed, rules out (strict) concavity of the BQPF (on any interval of Z). However, we cannot rule out strict convexity of the function using the same argument for sorting out a given quality level, because there is no guarantee that we can do it without affecting other quality traits (because of possible interdependencies). Thus, we conclude that the BQPF should be weakly convex. Second, the law of entropy states that while increasing disorder (mixing units of different qualities) is costless, decreasing disorder (sorting) entails cost. This implies that the BQPF should be strictly convex, since the price of the unsorted product must be lower than the

average of the prices of the quality levels into which it was sorted, by at least the sorting cost.

Convexity of the BQPF will have an important implication for marketing policy: marketing two quality levels separately will yield higher profits than those obtained by marketing the product at average quality. This results from the fact that any line connecting two points of a convex function will lie entirely above the function. Thus, the average price of marketing two separate qualities will be higher than the price obtained from marketing one brand with average quality.

Another distinctive property of tomato quality price function stems from the fact that tomato quality deteriorates rapidly. Sales at different times and locations imply different markets due to the short shelf life of the tomatoes, and their rapid quality deterioration, which makes it prohibitively expensive for arbitrage. This implies that we should observe different BQPF's for different markets (in time and space), which could vary from one another because of random effects. However, such variation could also result in time because of change in supply of close substitutes, or in space due to differences in transportation costs. These differences in the BQPF's of the different markets can be represented by the price of the most abundant tomatoes in the German markets (in the relevant season), namely the Canary Island tomatoes. Thus the BQPF of the Israeli tomatoes in the German markets throughout the season will be written as $P(Z, X)$ with $\partial P / \partial X > 0$, where X denotes the price of the Canary Island tomatoes in the specific market. Empirical estimation of the BQPF for Israeli export tomatoes in the German market (March - May, 1979) yields the results presented in Table 2, and Figure 1.

Table 2. Estimation of the Hedonic Price Function

The Variable ⁽¹⁾	Coefficient	t-value ⁽²⁾
F ²	.177*10 ⁻³	1.3
F*S	-.403*10 ⁻³	4.0*
F ³	.282*10 ⁻⁴	0.3
D	.0484	4.3*
D ³	-.255*10 ⁻³	-2.13*
S	.0155	2.5*
X	2.419	7.9*
X*F ²	-.792*10 ⁻³	-.2
X*F*S	-.604*10 ⁻⁴	-1.73
X*F ² *S	-.137*10 ⁻⁴	-.5
X*F*D*S	.235*10 ⁻³	3.35*
X*F ² *D	-.524*10 ⁻⁴	-1.15
X*D	-.04405	-7.16*
X*D ³	.243*10 ⁻³	5.78*
X*D ² *S	-.749*10 ⁻⁴	-2.66*
Intercept	-.0307	-1.91
R ² = 0.948 Durbin-Watson = 2.04		

- ⁽¹⁾ F = percentage of firm tomatoes (average value in the sample=70.35)
D = 100 - percentage of discolored tomatoes (average value in the sample=86.39)
S = percentage of small tomatoes (average value in the sample=71.13)
X = price of Canary Island tomatoes (average value in the sample=3.13)
⁽²⁾ An asterisk above a t value means that the coefficient is significantly different from zero at 95% confidence level.

From Table 2, the matrix of second partial derivatives has been evaluated at the average sample values and found to be positive semi definite, and strictly positive definite when the small size trait (S) was omitted¹/. These results corroborate the theoretical arguments concerning the shape of the BQPF. Details of the data, estimation procedures, and full results appear in Section 3.

2. INTERNAL PRICING POLICY

2.1 The deterministic decision making

The problem tackled here is that of passing the appropriate market signals to the individual producers so that the overall profits are maximized.

The first issue is that of individual producers who do not directly face the market prices. This is the case since a single marketing agency ships and sells the tomatoes of all growers and cannot associate the market prices with individual growers. While the market prices respond to quality differentials, the growers face a pooling price which is the weighted average of all quality prices, without regard to the individual grower's quality of the product. This practice led to a free rider problem: each grower attempts to maximize profits by increasing quantity, regardless of quality. The existence of tradeoffs between quantity and quality leads to a reduction of quality below the level desirable to the growers as a whole. This results in price (and profit) reduction which is external to the individual grower for whom the pooling price is given, independent of his fruit's quality.

Quality tests at the packing house enable us to determine the quality vector of the produce for each grower. We are looking for a price (quality premium) as a function of quality, $\theta(Z_1, \dots, Z_n)$, which will

be paid by the marketing agency to the grower, according to his produce quality, where each quality component, Z_i , is measured on a scale between 0 and 1. The marketing agency will choose the quality premium (θ) that would have yielded a quality-quantity choice by the growers, which would maximize the total net profits of the growers facing the market hedonic price function $P(Z_1, \dots, Z_n)$.

The formal analysis follows. Denote:

$P(Z)$ - the hedonic binary quality price function (BQPF) where

$Z = Z_1, \dots, Z_n$ is a vector of quality traits.

$F(Z, L)$ - the production function - the quantity of tomatoes, with quality Z , produced per unit of land, where L is labor input employed per unit of land.

$S(Z)$ - the size of land allocated by the grower to produce tomatoes of quality Z .

N - the given number of identical growers.

$\bar{S}$ - the size of land per grower.

w - wage rate

$C(Z, S)$ - all other costs (beside labor), such as investment in capital stock, land preparation, fertilizers, etc., associated with S units of land allocated to growing produce of quality Z .

$\theta(Z)$ - the price quality function set by the marketing board.

It should be noted that $C(Z, S)$ is independent of labor. That implies the use of a given technology in which $C(Z, S)$ represents the costs of land preparation, while labor is the short run variable cost.

The problem of the marketing board is to maximize over $S(Z)$ and $L(Z)$

$$(1) \pi = N \int_0^1 [P(Z) * S * F(Z, L) - w * L * S - C(Z, S)] dZ$$

subject to:

$$(2) \int_0^1 S(Z) dZ - \bar{S} \leq 0.$$

Equation (1) describes the total profits of the N identical growers, and equation (2) is the land constraint per grower. It should be noted that the assumption of linear homogeneity in labor and land underlies our definition of $F(Z,L)$ - the quantity produced per unit of land.

The conventional assumption of declining marginal productivities is adopted here, as well as the assumption of tradeoffs between quantity and quality, i.e.,

$$(3a) \quad F_L > 0, F_{LL} < 0, F_Z < 0, F_{ZZ} < 0$$

where subscripts denote partial derivatives, e.g. the partial derivative $\partial F / \partial L$ is denoted by F_L . We also assume

$$(3b) \quad C_S > 0, C_{SS} < 0, C_Z > 0$$

Note that $C_{SS} < 0$ in (3b) implies economies to specialization in quality. In practice, special growing techniques are required for each quality, and each technique involves fixed costs in land preparation and capital stock. In addition, the use of different growing methods in close proximity may cause negative spillover effects. All this boils down to economies to specialization, which is assumed hence forth.

One way of achieving the goal of maximizing π is by direct control of each grower's choice of land (S) and labor (L) allocated to each quality. Another way is through a decentralized method of setting quality price function $\theta(Z)$, paid to the individual growers by the marketing board. The quality of the fruit is further determined in the packing house by quality control tests.

The grower allocates land and labor to each quality so as to maximize his profits π_i , where:

$$(4) \quad \pi_i = \int_0^1 [\theta(Z) * S * F(Z,L) - w * L * S - C(Z,S)] dZ$$

subject to (2).

Obviously, the solution $\theta(Z) = P(Z)$ for all Z will satisfy the board's goal, since when $\theta(Z) = P(Z)$, the maximization of net profits by the individual grower, (equation 4), yields the maximization of the board's goal (1). Note that $\theta = P$ is only a sufficient condition and not a necessary one.

Given $\theta(Z) = P(Z)$, necessary conditions for attaining the board's, as well as the grower's goal, are:

$$\left. \begin{aligned} (5) \quad & P(Z) * F(Z, L) - C_0(Z, S) - w * L - r \leq 0 \\ (6) \quad & S(Z) * [P(Z) * F_Z(Z, L) - w] = 0 \end{aligned} \right\} \text{ for all } Z.$$

where r is the land's shadow price (Lagrange multiplier). It should be noted that while all variables are functions of Z , r is independent of Z .

The necessary conditions (5) and (6) are analyzed in Appendix 2, and yield the following:

(1) Since $c_{ss} < 0$ (increasing returns to quality specialization), only a single quality will be selected by the representative grower.

(2) The left-hand-side of equation (7) describes the marginal profits from quality improvement.

$$(7) \quad P_Z * F + P * F_Z - C_Z = 0$$

$$(7') \quad P_{ZZ} * F + 2P_Z * F_Z + P * F_{ZZ} - C_{ZZ} < 0,$$

If equation (7) holds for some Z_0 , and (7') holds as well, then Z_0 is optimal. Corner solutions ($Z = 1$ or $Z = 0$) will be optimal if inequality in (7) holds for all Z , or (7') does not hold. If negative inequality holds in (7) for all Z , $Z = 0$ is optimal, while if (7) is positive for all Z , $Z = 1$ is optimal.

To conclude this section, we have shown that $\theta(Z) = P(Z)$ is a sufficient condition for achieving the board's goal, i.e., the price offered by the board to the growers has to be specified as a function of quality and it should be equal to the market price function. Note that if

the growers were indeed identical, they would actually have received a single price. However, this is not a pooling price, since every one of them is aware that if his quality does not reach the desired level, his price will change. When growers are not identical, e.g. they differ in their production or cost function, the result $\theta(Z) = P(Z)$ still holds, yet the growers will obtain differentiated quality levels and prices.

2.2 Stochastic variation of the market price

Since tomatoes are a perishable product with a short shelf life, arbitrage over time and space is quite limited, and each point in space and time constitutes a separate market with a different price. The share of the Israeli tomatoes in the German market is relatively small, thus their market prices are not affected by their quantities. However, the prices of Israeli tomatoes are affected by the prices of close substitutes, namely other tomatoes which sell in the markets. These price functions are subject to stochastic variations due to changes in their supplied quantities, which depend on weather conditions, or due to stochastic changes in demand parameters.

Let $P(Z, X)$ be the (stochastic hedonic) market price of the Israeli tomatoes, where Z is a quality vector as before, and X is a random variable, which represents this stochastic fluctuation in the market. We selected X to be the ZMP reported price of the leading tomato brand in the market during the growing season - the price of the Canary Island tomatoes. As a result, $P(Z, X)$ is a monotone increasing function in X . Let $g(X)$ represent the density function of the Canary Island tomato price. We can now reformulate the goals of the marketing board and that of the individual grower.

The marketing board's problem is to maximize the expected profits^{2/}:

$$(8) \quad \max_{Z, L} \int_0^{\infty} g(x) * [P(Z, X) * F(Z, L) - w * L - C(Z)] dx$$

This implies that the board is risk neutral, which is plausible when the board is sufficiently large, or a government agency.

The necessary conditions for optimum are:

$$(9) \quad \bar{P} * F_L = w, \text{ where } \bar{P} = \int_0^{\infty} g(x) * P(X, Z) dx$$

$$(10) \quad \bar{P}_Z F + \bar{P} * F_Z = C_Z, \text{ where } \bar{P}_Z = \partial \bar{P} / \partial Z$$

Note that these are the same conditions as for the certainty equivalent maximization problem, which takes fixed prices equal to their expected value, $\bar{P}(Z)$. In order to achieve this goal by a decentralized solution, the marketing board has to select a price function $\theta(Z, X)$ to pay to the growers. The grower's problem is then:

$$(11) \quad \max_{Z, L} \int_0^{\infty} g(X) * U(\pi) dx,$$

where U is the utility function (assumed to be concave, concurring with risk aversion) of the individual grower, and π is the profit function of the representative grower:

$$(12) \quad \pi(Z, X) = \theta(Z, X) * F(Z, L) - w * L - C(Z)$$

The necessary conditions are:

$$(13) \quad \bar{\theta} * F_L = w$$

$$(14) \quad \bar{\theta}_Z * F + F_Z * \bar{\theta} = C_Z$$

where

$$(15) \quad \bar{\theta} = \int_0^{\infty} g(x) * u'[\pi(X)] * \theta(X) dx / \int_0^{\infty} g(x) * u'[\pi(x)] dx$$

$$\text{and } \bar{\theta}_Z = \int_0^{\infty} g(x) * u'(\pi) * \theta_Z dx / \int_0^{\infty} u'(\pi) * g(x) dx$$

Now it follows that setting $\theta(Z, X) = \bar{P}(Z)$ makes (13) and (14) identical to (9) and (10), and thus satisfies the marketing board's goal. To see that, substitute $\bar{P}$ for θ in (15), to obtain $\bar{\theta} = \bar{P}$.

This result means that the marketing board absorbs the uncertainty of the market prices, and lets the growers face a single deterministic hedonic price function at all times. Thus, the marketing board also plays

a partial role of an insurance company, pooling the risk of many growers. It is interesting to compare these results with those obtained by Leyland (1970) and Sandmo (1971) for conventional production theory that only deals with quantities of homogeneous product. Differences in risk aversion among growers, which will lead to differences in quality, disappear here when risk is eliminated by the board, and results in more homogeneous quality.

2.3 Optimal level of Quality Control

The packing house functions as an intermediate phase between the growers and the market. It provides for sorting and packing required before the fruits reach the market, as well as the option for quality control. This section deals with the determination of the optimal level of quality control in the packing house.

The marketing board has two potential markets, the local market with a fixed (low) price, and an export market with the hedonic binary quality price function (BQPF). Its decision problem is comprised of two stages:

- (1) the optimal quantity and quality levels of the fruit produced by the growers, and
- (2) the quality improvement through quality control at the packing house.

Thus, the overall goal of the marketing board is now to maximize total profits over these two stages. To obtain this goal, the board determines a price function of the intermediate quality, which is paid to the growers in a way that will motivate them to grow the desired intermediate quality. The packing house, in turn, receives the intermediate quality as a given parameter and will determine the level of quality control so as to maximize its own profit. The board has to choose a method of paying the packing house which will bring the latter to produce the desired

quality of the final good.

2.3.1 The overall maximization problem: Let V be the quality level produced by the growers, and Z (the decision variable of the packing house) be the final quality level of the fruit. For ease of exposition, it is assumed that V and Z are of a single dimension (rather than a vector). The hedonic market price function BQPF is given as before in its deterministic form $P(Z)$. The final quality Z is bounded by:

$$(16) \quad V*(1 - \alpha) \leq Z \leq 1 - \alpha,$$

where α is the proportion of fruit deteriorating during the packing process. An implicit assumption in (16) is that this deterioration in the packing house cannot be corrected by the quality control process, since it occurs during packing and sorting for size, which take place after quality control. The proportion of fruit for export is then $V*(1-\alpha)/Z$, and the remainder is sent to the local market.

Let $G(V, Z)$ be the processing cost per unit of fruit entering the packing house with quality V , and leaving it with export quality Z . It is assumed that:

$$(17) \quad G[V, (1-\alpha)*V] > 0, \quad \lim_{Z \rightarrow (1-\alpha)} G_z(V, Z) = \infty$$

$$G_v \leq 0, \quad G_z > 0, \quad G_{zz} > 0, \quad G_{vz} < 0$$

The first inequality implies that the processing cost is positive even without quality control. Positive G_z and G_{zz} imply positive increasing marginal cost of quality improvement. Negative G_v and G_{vz} imply reduction in total and marginal cost of quality improvement as a result of higher quality of the fruit entering the packing house.

Let Q be the quantity of fruit produced by the growers via the production transformation function $Q = F(V, L)$ where V is the quality produced and L is the labor input (as before). In addition to $G(V, Z)$, we still have the former cost components $w*L$ and $C(V)$. The overall profit

function π_0 , can now be written as

$$(18) \quad \pi_0 = [\bar{P}(V,Z) - G(V,Z)]*F(V,L) - w*L - C(V)$$

where

$$(19a) \quad \bar{P}(V,Z) = P(Z)*V*(1-\alpha)/Z + \underline{P}*(Z-V*(1-\alpha))/Z$$

and its partial derivatives are:

$$(19b) \quad \bar{P}_V = (P(Z) - \underline{P})*(1-\alpha)/Z$$

$$(19c) \quad \bar{P}_Z = V*(1-\alpha)*[P_Z - (P(Z) - \underline{P})/Z]/Z.$$

$\bar{P}(Z)$ is the weighted average price of the fruit which enter the packing house with quality V , and is sorted into two quality levels: The first, of export quality Z , is of proportion $V*(1-\alpha)/Z$, sold for the price of $P(Z)$, and the remaining part, $[Z-V*(1-\alpha)]/Z$ of the fruit, is sold in the local market for the price $\underline{P}$. The problem now, is to maximize (18) with respect to V, Z , and L . The necessary conditions for this optimization are:

$$(20) \quad (\bar{P} - G)*F_V + (\bar{P}_V - G_V)*F - C_V = 0$$

$$(21) \quad (\bar{P}_Z - G_Z)*F = 0$$

$$(22) \quad (\bar{P} - G)*F_L - w = 0$$

We next look at the two stage problem which will lead to the same solution. The characterization and interpretation of the optimality conditions will be made after that.

2.3.2 The two stage problem: The first stage is to find the price function which the board will pay to the growers so that they produce the level of intermediate quality V which satisfies equations (20) - (22). For a given price function $\theta(V)$, the growers will maximize their profits:

$$(23) \quad \pi^g = \theta(V)*F(V,L) - w*L - C(V).$$

By differentiating (23) with respect to V and L , we obtain the necessary conditions for maximization of profits by the grower.

$$(24) \quad \theta_V*F + \theta*F_V - C_V = 0$$

$$(25) \quad \theta*F_L - w = 0$$

Obviously for equations (24) and (25) to be identical to equations (20) and (22), the marketing board must set

$$(26) \quad \theta^*(V) = \bar{P}[V, Z(V)] - G[V, Z(V)]$$

where $Z(V)$ is calculated from (21). It should be noted that since $F \neq 0$, (21) is an equation of V and Z only. Clearly, if the board pays the growers $P(Z)$ for their exported fruit, $\underline{P}$ for their fruit sold domestically, and charges them $G(V, Z)$ for sorting and packing, they in fact, will be facing the desired price $\theta^*(V)$.

Turning to the packing house, the marketing board is interested to maximize net revenue per unit of fruit for any given quality level of the entering fruit V . Let π^P be this net revenue; then

$$(27) \quad \pi^P = \bar{P}(V, Z) - G(V, Z)$$

where V is given and Z is the control instrument of the packing house. It should be noted that the cost component $G(V, Z)$ is the variable cost only, and the fixed costs of the packing house are not included in π^P . It is obvious that the necessary condition for maximizing π^P is (21).

The question is how to make maximization of π^P the goal of the packing house management. The answer is straightforward: each grower will pay the packing house a fixed proportion of π^P as a fee, in addition to $G(V, Z)$. Then, by maximizing π^P the packing house also maximizes its own earnings. This share of fixed percentage should be determined so as to cover the fixed costs and profits of the packing house. It should be noted that the profit which the packing house should share, is the revenue of the packing house minus its own variable cost only, disregarding all other costs, such as costs of production and the fixed costs of the packing house. In practice, the percentage paid often comes out of the gross revenue, which is wrong, since then the interest of the packing house would be to maximize gross revenue, disregarding the

variable costs.

2.3.3 Characterization of the solution: The production process has already been investigated in a previous section, and we concentrate here on the behavior of the packing house. The net revenue π^r of the fruit sold out of the packing house is defined in (27). Equation (21), the necessary condition for maximization of π^r can be written as follows:

$$(28) \quad \partial \pi^r / \partial Z = \pi^r_z = V * (1 - \alpha) * [P_z - (P - \underline{P}) / Z] / Z - G_z = 0$$

by differentiating π^r with respect to V we obtain $\pi^r_v = \partial \pi^r / \partial v$.

$$(29) \quad \pi^r_v = (P - \underline{P}) * (1 - \alpha) / Z - G_v > 0$$

The inequality follows since $P > \underline{P}$ and from (17). π^r_v reflect not just the marginal change in π^r_v due to a change in V when all other variables are fixed, but the envelope theorem tells us that π^r_v is also the marginal change in the optimal level of π^r (Z adjusts optimally with V) due to a marginal change in V . From equation (29) we learn that this derivative is positive, which means that π^r is a monotone increasing function of V , while Z adjusts optimally with V . Thus, there is a $\underline{V}$, $0 \leq \underline{V} \leq 1$, such that $\pi^r(V | 0 \leq V < \underline{V}) < 0$, $\pi^r(\underline{V}) = 0$, and $\pi^r(V | \underline{V} < V \leq 1) > 0$. This $\underline{V}$ is the threshold for packing the fruit. For all $V \leq \underline{V}$ the fruit should not enter the packing house at all. If the fruit could be sold for $\underline{P}$ without passing through the packing house, then $\underline{V}$ would be the V for which $\pi^r(\underline{V}) = \underline{P}$.

If $\underline{V} = 0$, then all the fruit should be passed through the packing house. If $\underline{V} = 1$ then no fruit should pass through the packing house, and all the fruit should be marketed domestically. The second order condition for an internal solution (i.e. $V < Z < 1$) is:

$$(30) \quad \pi^r_{zz} = P_{zz} * V * (1 - \alpha) / Z + 2V * (1 - \alpha) * [(P - \underline{P}) / Z - P_z] / Z^2 - G_{zz} = \\ = P_{zz} * V * (1 - \alpha) / Z - 2G_z / Z - G_{zz} < 0$$

The second equality in the chain above follows after substituting (28) into it.

When the inequality in (30) is reversed, we have a corner solution which is $Z = (1-\alpha)V$, (since $Z = 1$ is ruled out due to the assumption in (17) $G_Z(Z=1-\alpha) = 0$). Let $Z^*(V)$ be the solution to (28). It would be interesting to see how it behaved. By differentiating fully π_Z we obtain:

$$(31) \quad dZ/dV = -\pi_{ZV}/\pi_{ZZ}$$

By differentiating (28) with respect to V we obtain:

$$(32) \quad \pi_{ZV} = (1-\alpha)*[P_Z - (P - \underline{P})/Z]/Z - G_{ZV} = G_Z/V - G_{ZV} > 0$$

The second equality is obtained by substituting (28) into the preceding term. The inequality follows from our assumptions in (17). Thus, when $\pi_{ZZ} < 0$, i.e. an internal solution, from (30) $dZ/dV > 0$. When $\pi_{ZZ} \geq 0$, the solution is a corner solution, i.e. $Z = (1-\alpha)*V$. Hence in this case, $Z_V = 1-\alpha$. Therefore:

$$(33) \quad Z_V = \partial Z/\partial V > 0 \text{ for all } V.$$

3. EMPIRICAL ANALYSIS

3.1 The Data

Our data include information about the wholesale prices (in German Marks/kg) of two brands of Israeli tomatoes in Germany throughout one growing season (winter 1979). The two brands differ in their growing technology. Records include the daily sales by different wholesalers throughout Germany, as well as wholesale prices of competing tomatoes in the same markets and dates. The quality traits of these tomatoes were estimated by samples taken in the packing houses on harvest dates. The traits that were measured include percentage of: firm tomatoes, elastic tomatoes, soft tomatoes, discolored fruit, hollow fruit, and physically damaged fruit. The fruit were sorted by color intensity and by sizes,

which were also recorded in our data set. These more or less exhaust the quantitative quality traits which can be readily measured without destroying the product. Chemical content or taste of the product were not measured.

The process of obtaining the data was quite complex and involved matching of three data sets:

- (1) Quality trait levels at harvest date, by packing house, half week, and brand. Tomatoes were sampled at random from each of five packing houses, every half week to determine their quality levels.
- (2) Daily sales records of wholesalers (panelists) in Germany. These data included daily information about quantities received, and sold, quantities in stock, as well as gross revenue of daily sales (yielding average daily prices). These records supplied the information separately for the two Israeli lines in our sample.^{3/}
- (3) Linkage information; All Israeli tomatoes were sent to West Germany by air through Koln. A team was placed at Koln airport to record the identification of every delivery from Koln to all destinations in Germany. The details reported include the harvest date, packing house identification, line and size of each delivery, as well as its destination (wholesalers) and delivery date.

The matching of these three sets produced the basic data for our analysis, which included the average quality vector of the tomatoes for each sale, as well as its price. In addition, we collected data on the competing tomato prices from official publication (ZMP) which gave prices every two days in each city. The final data set included 510 observations out of a total of over 2,000 actual transactions which took place during that season. The actual transactions were made by about twenty five wholesalers in nine regions in West Germany from January through May,

1979. The transactions of any given wholesaler were not necessarily made every working day, mainly due to lack of supply. Thus our data consist of incomplete time series information.

3.2 The Estimation Procedure

3.2.1 The Functional Form: The outcome of section 2 is that the hedonic binary quality price function (BQPF) to be estimated is $P(Z_1, \dots, Z_n, X)$. The dependent variable is thus the price of the Israeli tomatoes, and the independent variables are quality traits, Z_i , as well as the average Canary Island tomatoes' price, X . We let the Canary Island price variable both be a shift variable and affect the coefficients (slopes) of all quality variables. An additional simplifying assumption is that the BQPF is linear in X .

The theory developed in section 2 allows us to choose any functional form as long as it is not concave in the quality variables. It stands to reason that the price function should have positive partial derivative with respect to the competitive tomatoes price (X) which is a close substitute. In order to determine the functional form of the BQPF, we used a stepwise procedure which increases the number of traits for a third degree polynomial. At each step, we added all possible combinations of a new quality variable to the ones already included. For example, if variable A is already in the model and trait B is the new one to be considered, then the following combinations are added: B , B^2 , B^3 , B^2A , BA^2 . Each trait was introduced as shown in the example, as well as its interaction with the Canary Island tomatoes' price X , and its contribution to the F -statistic was calculated. We repeated this procedure for all possible traits and selected the one with the highest F statistic.

Out of the full new set of combinations that represent the new trait thus chosen, we selected again by stepwise regression procedure the combinations that contributed significantly to the model. This procedure was then continued until we could not find a new trait with significant contribution.

The reason for using this procedure, rather than the conventional stepwise procedure is to minimize the number of traits in the model and to find the most important ones. This would later lead to a reduction in the cost of quality control in the packing house, since it requires the measurement of a smaller number of traits. It is quite possible that a different function, using different traits, could be found as well, but that would be the case in general, where one must choose between many correlated variables to be included in a model.

3.2.2 Autocorrelation: In our analysis, the conventional treatment of autocorrelation cannot be applied because of missing information, which amounts to different time intervals between consecutive transactions in the same market. The problem has been resolved by developing a method that treats autocorrelation with missing information (see Appendix 1). The accepted model of 1st order autocorrelation (AR1) is adopted here:

$$U_t = \tau U_{t-1} + e_t, \quad t=1, \dots, T,$$

where U_t is the unobserved random disturbance, τ is the autocorrelation coefficient, and the vector $e=(e_1, \dots, e_T)$ is distributed $N(0, \sigma^2 * I)$. The Generalized Least Squares (GLS) estimation procedure has been extended to the case of randomly missing information, where time intervals between consecutive observations are not fixed. This has resulted in the following transformations, for which ordinary least squares would yield GLS estimators:

$$y^*_{i,j} = (y_{i,j} - \tau^{D_i} y_{i,j-1}) / JS_i$$

$$(34) \quad X^*_{i,j} = (X_{i,j} - \tau^{D_i} X_{i,j-1}) / JS_i, \quad j=1, \dots, K; \quad i=2, \dots, I$$

$$y^*_{i,1} = y_{i,1} \sqrt{1-\tau^2}, \text{ and } X^*_{i,1} = X_{i,1} \sqrt{1-\tau^2},$$

where the index i counts the order of the observation, and D_i denotes the time interval between the i^{th} and its preceding observation, and

$$(35) \quad S_i = (1 - \tau^{2D_i}) / (1 - \tau^2).$$

Since in our case (as is usual), τ is unknown, we have used the maximum likelihood estimation method to estimate τ simultaneously with $b_1, \dots, b_K$. Ignoring constants, the log likelihood function adjusted to the missing information case, can be written (see Appendix 1):

$$(36) \quad \ln(L) = -I \ln[\sum_i (y^*_{i,1} - b_j X^*_{i,j})^2 / I] + \ln(1 - \tau^2) - \sum_i \ln(S_i),$$

where $y^*_{i,1}$ and $X^*_{i,j}$ are defined in equation (34), and S_i is defined in (35). To estimate τ and b simultaneously, we have used the search method suggested by Hildreth and Dent (1974), where the b 's were estimated for grid values of τ , and the maximum likelihood criterion was used to select the estimates.

Data were collected from nine different regions in West Germany, and we estimated the τ 's separately for each region. The τ 's were found to be significantly different from one another, and their estimates appear in Table 3.:

Table 3. Estimated serial correlation
coefficients for the regions

Region	1	2	3	4	5	6	7	8	9
τ	.99	.95	.99	.84	.11	.72	.79	.97	.83

3.3 Results

Table 2 in section 1 presents the estimates of the BQPF, and Figure 1 presents the projections of this function for each of the traits, given that all other variables are held fixed at their average values. From Table 2 we see that this model explains 95% of the price variation (R^2). The value of Durbin-Watson statistic (2.04) means that autocorrelation was completely eliminated. From Figure 1 we learn that at the range of the average plus or minus two standard deviations, the function is convex, and thus behaves according to the theory. We see that firmness affects the price positively, and discoloration - negatively, as expected (100 minus discoloration has a positive slope). We also find that the percentage of small tomatoes affects the price negatively, a fact which is confirmed by field operators.

The first partial derivatives of the BQPF with respect to the quality characteristics have been calculated at their average values From Table 2 . These derivatives are (.032, .038, -.001) for (F, D, S) respectively. Following the hedonic price theory, these values are the implicit prices of the quality characteristics. For example, an increase of 1% in firm tomatoes raises the price of tomatoes by .032 GM/kg, while a reduction of 1% in discolored tomatoes ($D = 100 - \text{discolored}$) raises the tomato price by .037 GM/kg. These values are calculated at the average sample values, but can be calculated from the same function separately for every possible quality level.

Footnotes

1/ From Table 2 and Figure 1 it can be seen that the price function is linear in S (percentage of small size tomatoes). This is apparently inconsistent with the theory which requires strict convexity. However, the tomatoes are sold in the market already sorted with respect to size, so that the prices in our data are actually linear combinations of the prices of transactions of different sizes, where each is homogeneous with respect to size. Therefore, the price function should be linear with respect to size in this case.

2/ In the previous section, we proved that the grower would allocate all his land to a single quality. Thus, the choice of the optimal quality here replaces the choice of $S(Z)$, which is now trivial, i.e., $S(Z^*) = \bar{S}$; and we assume for simplicity $\bar{S}=1$, $S(Z)=0$ for all $Z \neq Z^*$.

3/ The difference between the two lines was entirely due to differences in the growing technique. The Peretz line, grown under special stress conditions was obviously superior and obtained higher prices. Under the regime of quality pricing in subsequent years, Peretz growing techniques were fully or partially adopted by all growers.

APPENDIX 1

In this Appendix an autoregressive model, AR(1), is developed for unequal time gaps due to missing information. It is proved here that when the autocorrelation coefficient, τ is known, the estimator used in equation (34) in the text is BLUE, and when τ is unknown, the maximum likelihood estimator is the one obtained by using equation (36) in the text.

Assume the following autocorrelation AR(1) model:

$$Y = Xb + U$$

$$(A1) \quad U_t = \tau u_{t-1} + e_t, \quad t=1, \dots, T$$

$$e \sim N(0, \sigma^2 I)$$

where Y , U , and e , each are $T \times 1$ vectors, U and e are uncorrelated, b is a $K \times 1$ vector of unknown parameters, X is a $T \times K$ matrix of fixed numbers, and τ is unknown parameter.

In our problem two consecutive observations are separated by varying time intervals (say days). Let i denote the observation index, and t_i denote the number of days from the beginning to the i -th observation, and $D_i = t_i - t_{i-1}$ denote the number of days between two consecutive observations. From equation (A1) it follows that:

$$(A2) \quad U_i = \tau^{D_i} U_{i-1} + \sum_{m=0}^{D_i-1} \tau^m e_{i-m} = \tau^{D_{i-1,w}} U_{i-w} + \sum_{m=0}^{D_{i-1,w}-1} \tau^m e_{i-m}$$

where $D_{i-1,w} = \sum_{r=i-1}^w D_r$, is the number of days between the i -th and the w -th observations (assuming $i < w$). From (A2) it follows that, given $-1 < \tau < 1$:

$$(A3) \quad \text{Var}(U_i) = \sigma^2 / (1 - \tau^2)$$

is constant, and

$$(A4) \quad E U U^T = \bar{\Sigma} = \sigma^2 / (1 - \tau^2)$$

where:

$$(A5) \quad \theta = \begin{bmatrix} 1 & , & \tau^{D1.2} & , & \tau^{D1.3} & , & \dots & , & \tau^{D1.I} \\ \tau^{D1.2} & , & 1 & , & \tau^{D2.3} & , & \dots & , & \tau^{D2.I} \\ \vdots & & \vdots & & \vdots & & \vdots & & \vdots \\ \tau^{D1.I} & , & \tau^{D2.I} & , & \tau^{D3.I} & \dots & , & 1 \end{bmatrix}$$

Let:

$$(A6) \quad S_1 = (1 - \tau^{2D1}) / (1 - \tau^2)$$

$$(A7) \quad S_{1,w} = (1 - \tau^{2(D1+Rw)}) / (1 - \tau^2) = S_w + \tau^{2Dw} S_1$$

By direct multiplication ($\theta\theta^{-1}=I$) it can be shown that:

$$(A8) \quad \theta^{-1} = \frac{1}{1 - \tau^2} \begin{bmatrix} 1/S_2 & , & -\tau^{D2}/S_2 & , & 0 & , & \dots & , & 0 & , & 0 \\ -\tau^{D2}/S_2 & , & S_{2,3}/S_2 S_3 & , & -\tau^{D3}/S_3 & , & 0 & , & \dots & , & 0 & , & 0 \\ 0 & , & -\tau^{D3}/S_3 & , & S_{3,4}/S_3 S_4 & , & -\tau^{D4}/S_4 & , & \dots & , & 0 & , & 0 \\ 0 & & & & & & & & & & & 0 \\ \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots \\ 0 & , & 0 & , & \dots & , & 0 & , & -\tau^{D1}/S_1 & , & 1/S_1 \end{bmatrix}$$

Define:

$$(A9) \quad P = \frac{1}{\sqrt{(1 - \tau)^2}} \begin{bmatrix} \sqrt{(1 - \tau^2)} & , & 0 & , & 0 & , & \dots & , & 0 \\ -\tau^{D2}/\sqrt{S_2} & , & 1/\sqrt{S_2} & , & 0 & , & 0 & , & \dots & , & 0 & , & 0 \\ 0 & , & -\tau^{D3}/\sqrt{S_3} & , & 1/\sqrt{S_3} & , & 0 & , & \dots & , & 0 & , & 0 \\ \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots \\ 0 & , & 0 & , & 0 & , & 0 & , & \dots & , & 0 & , & -\tau^{D1}/\sqrt{S_1} & , & 1/\sqrt{S_1} \end{bmatrix}$$

The matrix P defined in (A8) satisfies $P^T P = \theta^{-1}$, which can be verified by direct multiplication.

Theorem: Given the above assumptions in (A1) of autocorrelated disturbances with missing information, and if τ is known, the best linear unbiased estimator (BLUE) for the vector b is given by:

$$(A10) \quad \hat{b} = (X^T P^T P X)^{-1} X^T P^T P y$$

where P is defined in equation (A9)

The proof is immediate since the matrix P is defined in (A9) so that $P^T P = \theta^{-1}$. Therefore, the estimator defined in (A10) is the generalized least square estimator which is BLUE (Judge et al., p.115).

Now it is easy to see that the transformed variables in equation (34) in the text are obtained by the P transformation, so that the ordinary least squares estimators obtained from those transformed variables are indeed BLUE.

When τ is unknown, one cannot obtain a BLUE estimator, and several non linear least square estimators have been proposed to estimate τ and b simultaneously. We have used the maximum likelihood estimator (see e.g. Judge et.al., 1980).

For the general multivariate normal distribution, the likelihood function is well known (e.g. Judge et. al. 1980):

$$(A11) \quad L(b, \sigma^2, \tau \mid y) = 2\pi^{-I/2} |\tilde{\Sigma}|^{-1/2} \exp[-(y-Xb)^T \tilde{\Sigma}^{-1} (y-Xb)]$$

where I is the number of observations, and $\tilde{\Sigma} = EUU^T$.

In our case, using (A4) through (A7), it can be shown that:

$$(A12) \quad |\theta|^{-1} = |\theta^{-1}| = (1-\tau^2)^{I-1} / \prod_{i=1}^I S_i$$

Then, by (A4):

$$(A13) \quad |\tilde{\Sigma}|^{-1/2} = \sigma^{-I} (1-\tau^2) / \prod_{i=1}^I S_i$$

Since $P^T P = \theta^{-1}$, using the notation $X^* = PX$, $y^* = Py$, and

$U^* = y^* - X^*b$, the log of the likelihood function can be written (ignoring constants):

$$(A14) \quad \ln(L) = -I \ln(U^{*T}U^*/I) + \ln(1-\tau^2) - \sum_i \ln(S_i)$$

which is the same as equation (36) in the text.

APPENDIX 2

Consider the following optimization problem, which is the problem of both the marketing board and the growers, after the proper signals have been passed (see text). Maximize over L and S :

$$(B1) \quad \int [P(Z) * S * F(Z, L) - W * S * L - C(S, Z)] dZ$$

such that:

$$(B2) \quad \int S dZ - \bar{S} \leq 0,$$

where the functions and parameters are as defined in the text. The necessary conditions are:

$$(B3) \quad S * (P * F_L - w) = 0$$

Thus when $S(Z) = 0$, L can be any number.

$$(B4) \quad P * F(Z, L) - w * L - C_S(S, Z) - r \leq 0,$$

where r is the non-negative shadow price of the land constraint and is independent of Z . There is inequality in (B2) only when $r = 0$. The inequality in (B4) is due to an additional constraint requiring $S(Z)$ to be non negative. Whenever $S(Z)$ is strictly positive equality holds in (B4).

Except for C_S , all terms in (B4) are independent of S . Thus $C_{SS} > 0$ means increasing marginal cost of land, which implies diseconomies of specialization in quality, i.e., if we increase the amount of land allocated to a given Z the marginal cost per unit land increases. Similarly, $C_{SS} < 0$ means decreasing marginal cost of land, implying economies of specialization in quality.

We first consider the case $C_{ee} > 0$. Assume, without loss of generality, that for every Z , $0 \leq Z \leq 1$ there is a strictly positive $L(Z)$, which satisfies (B3) with $P \cdot F_L = w$. Also assume that $P \cdot F - W \cdot L - C_e(0, Z) > 0$ for all Z (If it is negative for a given Z , then from (B4) $S(Z) = 0$ for all $r \geq 0$), and let r be given at some positive value. If for $S = 0$, the left hand side (LHS) of equation (B4) exceeds zero (given r , Z , and $L(Z)$), then by increasing S we decrease the LHS, and we do so until we reach an S for which equality holds in (B4). Designate this S by $S(r, Z)$. Let $\bar{S}(r)$ be $\bar{S}(r) = \int S(r, Z) dZ$, and its partial derivative $\partial \bar{S}(r) / \partial r = S_r \leq 0$. The optimal solution is $(r^*, S^*(Z), L^*(Z))$ for all Z , where r^* is such that $\bar{S}(r^*) = \bar{S}$, $S^*(Z) = S(r^*, Z)$ and $L^*(Z) = L(Z)$.

We now show that in this case ($C_{ee} > 0$), the optimal solution is not unique at a single value of Z and it must include a segment of Z . Assume as a working hypothesis, that the solution (Z_0) is unique, we then show a contradiction. The solution (Z_0) must satisfy equations (B3) and (B4) with equality when $r=r^*$, and $\bar{S}(Z_0)=\bar{S}$:

$$(B5) \quad P \cdot F(Z_0, L(Z_0)) - w \cdot L(Z_0) - C_e(\bar{S}, Z_0) - r^* = 0$$

where $L(Z_0)$ satisfies (B3). For all other Z 's necessary conditions for optimality imply at least weak inequality in (B4) with $S(Z, r^* | Z \neq Z_0) = 0$. By substituting $\bar{S}$ with 0 in (B5) we obtain, since $C_{ee} > 0$, the following:

$$(B6) \quad P \cdot F(Z_0, L(Z_0)) - w \cdot L(Z_0) - C_e(0, Z_0) - r^* > 0$$

Now, if we replace Z_0 with Z' in (B6), then (B6) must remain positive for Z' sufficiently close to Z_0 . This contradicts (B4), for $Z' \neq Z_0$, and therefore the working hypothesis must be rejected, which implies that a whole segment of Z is optimal.

The more realistic case is the one of economies of specialization in quality, in which $C_{ee} < 0$. In this case, only a single optimal value of

Z exists. To see that we assume, as a working hypothesis, that more than one optimal value of Z exist, and prove a contradiction. Let Z_1 and Z_2 be any such pair in the optimum for which $S^*(Z_1) > 0$ and $S^*(Z_2) > 0$.

Being in the optimum, both Z_1 and Z_2 satisfy (B4) with equality, hence

$$\begin{aligned} \text{(B7)} \quad & P(Z_1) * F(Z_1, L(Z_1)) - W * L(Z_1) - C_B(S(Z_1), Z_1) = r^* = \\ & = P(Z_2) * F(Z_2, L(Z_2)) - W * L(Z_2) - C_B(S(Z_2), Z_2) \end{aligned}$$

It is easy to see, upon observing the goal function in (B1), that increasing (decreasing) the land allocated to Z_1 by one unit, increases (decreases) the value of the goal function by the amount specified on the LHS of (B7) which equals r^* , and the same is true with respect to Z_2 and the RHS of (B7). If we transfer a unit land from Z_2 to Z_1 , then the following inequalities hold:

$C_B(S(Z_1)+1, Z_1) < C_B(S(Z_1), Z_1)$ and $C_B(S(Z_2)-1, Z_2) > C_B(S(Z_2), Z_2)$ because $C_{BS} < 0$. Therefore, the equality in (B7) will now change into an inequality, and read:

$$\begin{aligned} & P(Z_1) * F(Z_1, L(Z_1)) - w * L(Z_1) - C_B(S(Z_1)+1, Z_1) > \\ \text{(B8)} \quad & P(Z_2) * F(Z_2, L(Z_2)) - w * L(Z_2) - C_B(S(Z_2)-1, Z_2) \end{aligned}$$

This means that the goal function increases by the LHS of (B8) and decreases by the RHS of (B8), i.e., the goal function increases by the difference between the LHS and the RHS of (B8), which is now positive. But this contradicts our initial assumption that we are in the optimum, since if we were, we would not have been able to improve the value of the goal function, as shown above. Hence, when $C_{BS} < 0$, it is impossible to have an optimum in which both $S^*(Z_1) > 0$ and $S^*(Z_2) > 0$, when $Z_1 \neq Z_2$. That is, all land is allocated in this case to growing only one quality, Z^* . Thus we know that $S(Z^*)=S$, all we have to determine is the value of Z^* . Hence S ceases to be a variable, and Z becomes a variable instead.

The single optimal quality can be determined by differentiating the goal function (B1) with $S = \bar{S}$ with respect to Z (we further assume $\bar{S} = 1$, for the sake of simplicity). The new necessary condition for an internal solution is:

$$(B9) \quad P_z * F + P * F_z - C_z = 0$$

If, however, $P_{zz} * F + P * F_{zz} + 2P_z * F_z - C_{zz} > 0$, or if the LHS of (B9) is always different from zero, then we have corner solutions, i.e., $Z^* = 1$ or $Z^* = 0$, depending at which end of the quality segment the goal function attains a higher value.

References

1. Brown, G., and R. Mendelson, The Hedonic Travel Cost Method, Rev. Econ. Stat., Vol. 66, Aug. 1984, pp.427-433.
2. Brown, J.N., and H.S. Rosen, On the Estimation of Structural Hedonic Price Models, Econometrica, Vol. 50, May 1982, pp.765-768.
3. Griliches, Z., ed., Price Indexes and Quality Change: Studies in New Methods of Measurement, Cambridge, Mass,: Harvard Univ. Press, 1971.
4. Hildreth, C., and W. Dent, "An Adjusted Maximum Likelihood Estimator" in W. Sellekaert, ed., Econometrics and Economic Theory: Essays in Honor of Jan Tinbergen, Macmillan, London, 1974, pp.3-25.
5. Hotelling, H., "Stability in the Competition", Economic Journal, Vol. 39, March, 1929, pp 41-57.
6. Judge, G.G., Griffiths, W.E., Hill, R.C., and T.C. Lee, The Theory and Practice of Econometrics, Wiley and Sons, New-York, 1980.
7. Lancaster, K., Variety, Equality and Efficiency, Columbia Univ. Press, New-York 1979.
8. Leland, H.E. Theory of the firm facing Uncertain Demand, Amer. Econ. Rev., Vol. 62, 1972, pp. 278-291.
9. Rosen, S., Hedonic Prices and Implicit Markets, J. Pol. Econ, Vol. 82 Jan/Feb. 1974, pp.34-55.
10. Sandmo, A., On the Theory of the Competitive Firm Under Price Uncertainty, Amer. Econ. Rev., Vol. 61, 1971, pp 65-73.

ESTIMATING THE RATE OF RETURN TO TOMATO BREEDING

I. Introduction

A major goal of the study is to estimate the expected rate of return from investment in the research and development of new tomato varieties by incorporating hedonic prices of tomato qualities in a simple research and development process. It has been recognized by Griliches (1971) and Rosen (1974) that hedonic prices can serve as guides for firms in deciding how their products can be improved through R and D processes. We demonstrate that the hedonic prices for characteristics are helpful in determining the expected rate of return to one type of R and D activity, i.e., tomato breeding. Knowing the magnitude of the rate of return to tomato breeding and how this rate changes with different values of exogenous parameters related to breeding helps determine how much should be invested in tomato breeding and provides the conditions under which this investment should be increased or decreased. The results of this type of analysis is useful not only for firms selling in a competitive market but also for firms selling in a monopsonistic market when either a single buyer or the government buys all the output from the farmers, thereby distorting the farmers' incentive to produce the optimum combination of quality and quantity.

The firm's profit function is defined in a way that easily allows the use of the hedonic price function. The profit function is then incorporated into a very simple R and D model that captures the essential elements of a breeding process. The R and D model essentially solves the problem of how much to invest in the breeding activity and yields an estimate of the expected rate of return to breeding. Parameter values are then obtained and used to simulate the breeding model. After obtaining the

solutions for the base case parameter values, a sensitivity analysis is performed to examine how endogenous variables change with respect to changes in exogenous parameters.

The theoretical model of a research and development process is presented in Section II. Section III explains how the different parameter values are obtained and the assumptions needed to simulate the R and D model. In Section IV the results of the simulation analysis are described and explained. Finally, the conclusion summarizes the important results of this study and their implications for public policy and private decisions.

II. A Basic R and D Model

To develop an applied R and D model, an objective function is defined allowing the use of hedonic prices for traits that are the objectives of breeding processes. To this end, a profit function is examined assuming perfect competition so that the hedonic price function can be incorporated in a simple manner. Although a monopolistic firm could have been assumed, a perfectly competitive firm is probably more appropriate in the context of tomato production where any single farmer is small enough to have no affect on the price level. Moreover, as shown below, the objective function of a perfectly competitive firm requires fewer parameter values to obtain compared to that of a monopolistic firm. To ensure a unique solution, an upward sloping cost function is also assumed. Let π be the profit from producing output q at the price level of p and cost of $c(q)$. Given the above assumption, π can be written as

$$(1) \quad \pi(q) = pq - c(q)$$

where $c(q)$ could be represented by the following functional forms:

$$(2) \quad c(q) = q^{\alpha}, \alpha > 1$$

which is a constant elastic cost function or by a quadratic cost function

$$(3) \quad c(q) = a_0 + a_1 q + a_2 q^2.$$

The price that a firm can sell its product for depends however on the quality of the product through the hedonic price function. Let the relationship between the price level and qualities or traits, z , be represented by $p(z)$, where z is a vector of traits. Then the profit function can be rewritten as

$$(1') \quad \pi(z, q) = p(z)q - c(q).$$

Maximizing (1') with respect to the output q yields the maximum profit to the firm for any given z . To obtain the exact form of the maximum profit function, assume that the hedonic price function is linear in z estimated by

$$(4) \quad p(z) = \gamma z + \varepsilon$$

where ε = a normally distributed error term, $\varepsilon \sim N(0, \sigma^2)$

$$E(p) = \gamma z$$

$$p \sim N(E(p), \sigma^2),$$

and the cost function is $c(q) = q^{\alpha}$. Then the maximum profit function can be represented by

$$(5) \quad \pi^*(z) = \gamma z^{\alpha/\alpha-1} [\alpha^{1/1-\alpha} - \alpha^{-\alpha/\alpha-1}] > 0 \text{ iff } \alpha > 1.$$

Or

$$\pi^*(z) = \gamma \delta z^\beta \quad \text{where}$$

$$\delta = [a^{1/1-a} - a^{-a/a-1}]$$

$$\beta = a/a-1.$$

Different forms of the maximum profit function can be obtained by using different forms for the hedonic price function and the firm's cost function. The maximum profit function is the main element of the objective function in the following applied breeding model.

A sequential and static search process is assumed in this simple search model, see Evenson and Kislev (1976) and Kohn and Shavell (1974). For more details on the application of this search model to agricultural breeding, see Gamponia (1985). The search process is sequential because draws or research trials are performed consecutively but static because all draws are made in a given period. The cost of a draw or a research trial, k , is assumed fixed, and the trait levels z are drawn from a known and fixed distribution, $F(z)$, $z \in (\underline{z}, \bar{z})$. Each draw is assumed independent of the other. For simplicity, assume also that z represent only one trait, e.g., tomato size.

Let z_0 be the initial level of trait of the currently used plant variety. If this plant variety is used forever, the firm's profit is $\pi(z_0)/r$, where r is the interest rate. Consider now the decision of the firm whether or not to spend the first k . The firm spends the first k if and only if

$$(6) \quad E\pi(z)/r - i \geq \pi(z_0)/r, \text{ or}$$

$$(6') \quad E\pi(z) - rk \geq \pi(z_0),$$

where E is the expectation operator and z is now random. The firm spends the first k if and only if the present value of the net expected benefit of the first trial is at least as great as the profit from using the current variety. Since $E\pi(z)$ can be written as

$$E\pi(z) = \int_{z_0}^{\bar{z}} \pi(z) f(z) dz + \pi(z_0) F(z_0),$$

(6) can be expressed as

$$(6') \quad \int_{z_0}^{\bar{z}} [\pi(z) - \pi(z_0)] dF(z) \geq rk.$$

As long as the expected net benefit of one search is greater than the search cost for any given level of trait of the current variety, another search or breeding trial is performed. Furthermore, there is a level of z , z^* , such that if the firm discovers a plant variety with a trait level z which is at least as great as z^* , there is no more incentive for the firm to perform another search. This trait level is attained when the marginal benefit and cost of another search are equal and is solved from the following equation.

$$(7) \quad \int_{z^*}^{\bar{z}} [\pi(z) - \pi(z^*)] dF(z) = rk.$$

Equation (7), is the condition for when to stop searching, is described in Lippmann and McCall (1976) and Kohn and Shavell (1974). It can be shown that the expected number of trials, $E(n)$, and the variance of the number of trials, $V(n)$, is written respectively as

$$(8) \quad E(n) = 1/(1-F(z^*))$$

$$\text{Var}(n) = 1/(1-F(z^*))^2.$$

The value of the new variety is the net increase in profit as a result of search, conditioned on search being done optimally. This is given by

$$(9) \quad \text{VNV} = E\pi(z|z \geq z^*) - \pi(z_0) - rkE(n).$$

Finally, a rate of return measure similar to the one used by Griliches (1958) in studying hybrid corn research and based upon the benefit/cost ratio can also be computed. Known as the external rate of return in agricultural research studies, this rate is computed as

$$(10) \quad r_e = [E\pi(z|z > z^*) - \pi(z_0)]/kE(n)$$

This rate is computed to provide a measure of an annual percentage return per dollar of breeding expenditures.

The foregoing model is different from the R and D model of Evenson and Kislev (1976) in that it is a sequential search process whereas Evenson and Kislev's is a fixed sample size search process. While the search rules are essentially the same, the sequential search rule is more efficient, see Rothschild (1974) and Feinberg and Johnson (1977). Breeding for new tomato varieties can also be envisioned as a sequential process which entails selection, identification and consecutive testing of better varieties. This is especially true for tomato breeding processes that goes through preliminary, advance, and then growers trials, consecutively. The above model is thus used as the basic breeding model in the simulation analysis below.

III. Parameter Values and Method of Implementation

The parameters needed for the profit function are the coefficients of the hedonic price and cost functions. The former are obtained from Brown and Gamponia, 'Estimating the Demand for Qualities and Quantities of Agricultural Products Using the Hedonic Technique.' Specifically, parameters can be obtained for the linear, semilog and double log forms of the hedonic price function. Using the average values of the parameter values, the parameter values for the three forms of the hedonic price function are:

$$P = -.27 + .20 S - .046 M \quad R^2 = .8-.9$$

(3-10) (1-16) (4-4)

$$P = \exp(-4.12 + 1.02 S + .27 M) \quad R^2 = .8-.9$$

(4-10) (2-7) (.1-5)

$$P = e^{-3.48} S^{2.65} M^{-.26} \quad R^2 = .8-.9$$

(3-14) (2-8) (.1-5)

where S = size of tomatoes measured in diameter inches,
 M = dummy variable for maturity, 0 = mature green, 1 = vine
 ripe,
 P = price/pound

Numbers in parentheses are ranges of t-values for the parameters in absolute values.

The parameters for the linear form of the hedonic function are the base case.

The parameters of the cost function were obtained by regressing total output against total cost using time series data taken from Buccola and French (1978) study of the California tomato processing industry. The

regression results for the constant elasticity cost function is the estimated quadratic cost function had poor statistical characteristics.

$$c = q^{2.15} \\ (120-0)$$

$$c = 644.8 - .35q + .0065q^2, \\ (2-6) \quad (-.01) \quad (.01)$$

$$R^2 = .45$$

where c is total cost/acre, q is the total number of 25 pound cartons produced per acre the number in parentheses is the t -value.

Because the only measured and valued trait in the hedonic price function is size, the following R and D simulation analysis will focus only on size. Thus, tomato breeding is envisioned as breeding for size. The size of tomatoes is assumed to be normally distributed so that the only parameters needed are the mean and variance of the distribution. There were two sources of data for the mean and variance of size. The first one is the mean and variance of size of tomatoes actually sold in the market. While the variance may understate the true variance of the distribution of size which the breeder draws from, the mean reflects more accurately the value of size of the best presently available tomato varieties. The second source of data for the parameters of size distribution is the Annual Report of Canadian Tomato Cultivar Trials. The mean and variances of size from the different tomato varieties being tested at the Canadian Horticultural Station, although measured in grams rather than diameter inches, were computed and used in the simulation analysis. However, it was found that by using the variance from these data, the relative values of the variances were so large relative to the average size that the simulation results became unrealistic. For example, when the variance is very high relative to the means, the expected number of trials can become very high so that

the rate of return to breeding per acre can reach 100 percent. For the base case, the mean is 2.59 while the variance is 0.04, based on market data. Finally, the cost of a trial was assumed to be a fixed at \$20,000. Parameter values must be obtained for the profit function, the distribution of trait and the cost of a breeding trial. Published data of firms undertaking tomato breeding are not available however because firms will conceal their methods, results, and R and D expenditures to prevent competing firms from imitating their products or as part of strategic behavior. The values obtained for the various parameters are those that are easily available to the present analyst. These values could however be replaced by more realistic values if other analysts have better information.

Following the theoretical model, the net profit is computed given the values of the parameters of the hedonic and cost functions and the mean values for size. However, the hedonic function is expressed in price per pound while the cost function is expressed in total cost per acre of output. Price per pound is transformed into price per acre of output by multiplying the price per pound by the average number of pounds per acre produced in 1984 in Florida which is 22,920 lbs./acre. The average size of a farming unit is also assumed to be 200 acres. The maximum net profit for all possible values of size is first computed. Then given the cost of a trial and the distribution of size, $F(z)$, it becomes straightforward to solve for the reservation quality level z^* .

A Fortran program is created to compute the maximum profit for any given value of size. Then using a subroutine from the Institute of Mathematical and Scientific Languages to compute the cumulative density function of the normal distribution, the reservation quality level z^* is

then computed by iteration. Given the reservation quality level, the expected number and the variance of the number of trials, the value of the new variety, and the external rate of return can then be computed.

IV. Results

The simulation results for both the base case and for the sensitivity analysis are presented in Table 1. For the base case and each change in parameter value, the reservation size level, the expected number of trials or breeding experiments, the variance of the number of breeding trials, the expected value of the new variety and the external rate of return to breeding, are presented.

Given the parameters of the trait distribution and search cost, the base case results show that the firm is willing to undertake 4.0 breeding trials which will increase his net profit by \$440.0 after deducting the total cost of breeding. On a per acre basis, the annual percentage rate of return per dollars worth of breeding expenditure is about 1 percent. Note that while the parameter values may not reflect actual conditions, the external rate of return is still relatively large given that only one acre is considered here.

The sensitivity analysis shows both the magnitude of the rate of return to tomato breeding and more importantly, how the rate of breeding changes with changes in the different parameter values. The results from changes in the parameters of the profit function are first discussed followed by the results from changes in the parameters of the objective function of the R and D phase. These results are given as 2(a) to 2(d) and 2(e) to 2(g), respectively in Table 1.

Increasing the elasticity of the supply function raises the net profit per acre as can be seen by differentiating (5) with respect to α . From (5),

$$\partial \pi^* / \partial \alpha = \gamma z^\beta (\partial \delta / \partial \alpha + \gamma \beta / z (\alpha - 1)^2) > 0,$$

since

$$\partial \delta / \partial \alpha = \delta (2 \ln \alpha / \alpha - 1 + 1 - \alpha / \alpha (\alpha - 1)) > 0.$$

Thus, the expected value of the new variety (VNV) in 2(a) is higher when α is higher because the expected gross benefit of breeding is raised with increasing net profits. The reservation size level and the number of trials are consequently higher. Results 2(b) show that increases in the total number of acres per farm increases the rate of return to breeding implying that there are increasing returns to tomato breeding. Doubling the number of acres almost doubles the rate of return to breeding also. Increasing the interest rate lowers the present value of the expected benefit from breeding. Hence, there is lower incentive to do breeding as can be seen in 2(c). The rate of return is also lower. Finally, changing the parameters of the linear hedonic price function (case 2(d)) affects the rate of return to breeding in a very significant way. Shifting the intercept of the hedonic price function downwards effectively lowers the price per pound of tomatoes, hence, leads to lower net profits. Consequently, the rate of return to breeding is lower. Raising the slope of the hedonic price function increases the effective price per pound of tomatoes and consequently raises the rate of return to breeding in a dramatic way (from 1 percent to 6 percent). This result implies that one must be careful in choosing the parameters of the hedonic price function,

because slight changes in those parameters may lead to significant changes in the estimates of rate of return.

Changes in the parameters of the trait distribution and cost of a trial can cause significant changes in the rate of return to breeding as the next three results show. Reducing search cost by half, doubling the standard derivation, or increasing the mean of the trait distribution by 0.1 leads to a three to four times increase in the rate of return to breeding. This is significant because these results imply that variance increasing activities, such as the preservation of exotic plant varieties, and mean increasing activities such as the discovery and adoption of better quality tomatoes are important to current and future plant breeding.

Finally, the rate of return to breeding is computed using the semilog and double log forms of the hedonic price function. Compared to the linear hedonic price function the rate of return to breeding is about 40 percent higher for the semilog and about 40 percent lower for the double log. Again, the form of the hedonic price function can have significant effect on the estimates of rate of return to tomato breeding.

V. Conclusions

The simulation analysis showed that the magnitude of changes in the reservation quality level and the rate of return to breeding vary from one parameter change to another. However, it is very significant that an increase in the variance and mean of the distribution of quality level led to a relatively larger change in the rate of return to tomato breeding. This result demonstrates the importance of preserving diversity in the population from which sources of new varieties are selected. The analysis also showed that the model is sensitive to changes in the parameters and

forms of the hedonic price function. The analysis, however, illustrates the applicability of the search model in performing cost benefit analysis of any public or private breeding programs and in computing the expected value of the new variety. The model is simple because it assumed a static search process and the object of search is to alter one quality only. However, the general applicability of the model does not depend upon the model's assumptions. Given better information on search cost, one can also compute the minimum net profit per acre or the minimum number of acres that a firm must plant with the new variety before it becomes profitable to start breeding. Finally, the above results can be refined further by incorporating more realistic parameter values of the profit and R and D objective functions.

TABLE 1
SIMULATION ANALYSIS

	$z^*{}^3$	$E(n)$	$Var(n)$	VNV^3	$r_e(\%)^4$
1. Base Case ¹	2.62374	4.0	16.02	440.02	1.01
2. Sensitiv. Analysis					
a) $\alpha=3.0$	2.63074	5.06	25.6	737.3	1.89
$\alpha=2.0$	2.60974	2.68	7.2	121.8	.31
b) Acres = 400	2.62974	7.08	50.2	698.4	2.2
Acres = 100	2.60174	2.22	4.93	61.2	.34
c) $i = .09$	2.61374	2.98	8.9	179.2	.64
$i = .03$	2.63974	7.08	50.2	1396.8	2.2
d) $p = -.316 + .2z$	2.62074	3.65	13.3	338.	.77
$p = -.27 + .3z$	2.64274	8.0	64.0	1828.4	6.3
e) $k = 40,000$	2.60574	2.43	5.9	135.5	.23
$k = 10,000$	2.63974	7.08	50.2	698.4	4.5
f) $\sigma = .08$	2.68274	7.08	50.17	1442.2	4.6
$\sigma = .02$	2.600	2.38	5.65	61.6	.21
g) $\mu = 2.69674$	2.72474	4.13	17.08	2170.5	3.2
$\mu = 2.49674$	2.52274	3.88	15.04	395.8	.91
h) Semilog Func. ²	2.62774	4.56	20.8	568.6	1.4
Doub.-log Func.	2.61774	3.34	11.1	247.6	.58

NOTES:

- 1) Base Case Parameters are: $\alpha = 2.5$; Acres = 200; $p = -.27 + .2z$; $z \sim N(2.59674, .04^2)$; $k = 20,000$; $i = .06$.
- 2) Semilog $p = \exp(-4.12 + 1.02z)$.
Double-log $p = e^{-4.0} z^{2.65}$.
- 3) z^* = reservation size level in diameter inches; VNV = expected value of the new variety.
- 4) r_e = external rate of return.

REFERENCES

- Buccola, S.T. and B. French. 'Long-Term Contracting Strategies for Agricultural Processing Firms with Particular Reference to Farmer Cooperatives,' Giannini Foundation of Agricultural Economics, Research Report No. 328, December 1978.
- Canada Ministry of Agriculture and Food. Tomato Cultivar Trials, Horticultural Experiment Station, Simcoe, Ontario, Canada, various reports.
- Evenson, R. and Y. Kislev. 'A Stochastic Model of Applied Research,' Journal of Political Economy, April 1976.
- Feinberg, R. and W. Johnson. 'The Superiority of Sequential Search: A Calculation,' Southern Economic Journal 43 (1977): 1594-98.
- Florida Tomato Committee. Annual Reports, various years, P.O. Box 20635, Orlando, FL 32814.
- Gamponia, V. 'Optimal Rotation and Search for a Growing Asset,' Ph.D. Dissertation, University of Washington, Department of Economics, 1985.
- Griliches, Z. 'Research Costs and Social Returns: Hybrid Corn and Related Innovations,' Journal of Political Economy, October 1958.
- ____ (ed.), Price Indexes and Quality Change, Cambridge, MA: Harvard Univ. Press, 1971.
- Kohn, M. and S. Shavell, 'The Theory of Search,' Journal of Economic Theory 9, 1974: 93-123.
- Lippmann, S. and J. McCall, 'The Economics of Job Search,' Economic Inquiry, June 1976.
- Rosen, S., 'Hedonic Prices and Implicit Markets,' Journal of Political Economy, February 1974.
- Rothschild, M. 'Searching for the Lowest Price When the Distribution of Prices is Unknown,' Journal of Political Economy, July-August 1974.

f. Description of cooperation.

the cooperation included meetings and discussions between the principal investigators. The cooperating investigator has focused his efforts on the subject of R&D of tomato breeding, while the research by the Israeli team has focused on the issues of estimation of quality-price relationships and the problems of the proper transfer of the market signals to the growers.

g. Main achievements of the research.

In this research we proved the existence of a strong direct relationship between the price of tomatoes and their quality. We estimated a hedonic price function for tomatoes with $R^2 = 0.94$. The major physical attributes of tomatoes were found to influence significantly the tomatoes' price (firmness, discoloration, and size).

On a theoretical ground, we have proved in this work that in a competitive market structure, where the quality attributes are of binary nature, the price quality function is convex. This implies that marketing products with differentiated quality is more profitable than the marketing the same product of mixed quality. It is often even worthwhile to invest in sorting a mixed quality product into two or more different quality classes.

Economies of scale in the shipping and marketing processes of export produce often imply that conglomeration of several growers under a single marketing agency is preferred over each grower marketing individually. However, such an agency (A marketing board) may market the produce under a single brand name, and one or several quality classes, thus not being able to identify the contribution to the quality of the final good by each grower and

pay the appropriate quality reward of the market to the individual producers. In our research we show that:

a) In a deterministic environment each grower should be paid, the price corresponding to the quality of his individual crop, according to the price-quality function.

b) when market prices are stochastic, each grower should be paid the expected price rather than the current market price.

We investigated the operation of the packing house, and determined rules for the optimal level of sorting of tomatoes into export and local markets. We also established pricing mechanism which the packing house should use when charging the growers for sorting and packing, so that the proper incentives are maintained.

The estimation of the hedonic price function (BQPF) is based on data collected by us in the packing houses in Israel, Koln airport, and the German wholesale market, concerning quality and prices of Israeli tomatoes. The data could not be obtained for the full set of observations, so that many observations were missing, and our sample consisted of pooled time series cross-section data with missing observations. We overcame this difficulty by developing an econometric method of estimating a first order autoregressive model with missing observations.

Estimation of the rate of return to tomato breeding has shown that given the parameters of the trait distribution and search cost, the firm is willing to undertake 4 breeding trials which will increase the net profit by \$440. On a per acre basis the annual rate of return for breeding expenditure is about one percent. The results show increasing returns to tomato breeding. Sensitivity analysis shows that the estimates of the rate of

return to tomato breeding are quite sensitive to changes in some parameters of the hedonic price function.

h. Benefits to agriculture.

Quality of agricultural produce in the increasingly competitive European and American markets, is becoming a most important factor determining the willingness of the consumers to pay for agricultural goods. Quality-quantity tradeoffs in the production of most agricultural products are an important factor in the farmers' decisions. Marketing boards quite often cannot, and should not when uncertainty is involved, pass the market prices (and their response to quality) to the individual growers. Therefore, the estimation of the price quality relationships and the transfer of appropriate price signals for quality to the growers, is a key factor in the success or failure of the Israeli agricultural export.

Direct benefits of this research have been the application of these results to implementation of quality premiums paid to the growers of export tomatoes in Israel. The relative market prices obtained for Israeli export tomatoes in Germany have risen by about thirty percent since the establishment of the quality premiums, as demonstrated in Table 1 in the main body of the report (e).

The theoretical proof of the convexity of the price-quality function has supported the common knowledge in the field that quality differentiation is profitable. However, it supplies a concrete basis for the decisions about the appropriate time and extent of quality differentiation.

An important contribution of the research results to Israeli agriculture is the increased prevalence of quality pricing in many Israeli agricultural products, and the rising requests for implementation of our methodology to additional agricultural export products.

i. List of publications: The following papers resulted from the research, and were submitted for publication:

1. Gardner M. Brown and Villamor Gamponia, "Estimating the Demand for Qualities of Fresh Florida Tomatos Using the Hedonic Technique."

2. Oded Hochman and Uri Regev, "Characterization of a Hedonic Binary Quality Price Function with Application to Israeli Export Tomatoes," submitted for publication.

3. Gardner M. Brown and Villamor Gamponia, "Estimating the Rate of Return to Tomato Breeding", submitted for publication.

4. Oded Hochman and Uri Regev, "Estimation of First order Autocorrelation Process with Missing Observations", submitted for publication.