PESTICIDE INPUTS, HARVEST TIMING,

AND FUNCTIONAL FORMS

by

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VITA

Myra Gina Palacpac Ramos was born on February 10, 1962 in Los Baños, Laguna, Philippines, the daughter of Wilfredo Palacpac and Luisa Espiritu Palacpac. She is the eldest among five siblings. In 1978, she graduated from the University of the Philippines Rural High School. She received her B. S. Statistics degree from the University of the Philippines at Los Baños in November 1981. She married Redentor E. Ramos on October 16, 1988 and were blessed by a son named Mark John (Mijay) P. Ramos on September 4, 1989. She and her family entered the U. S. A. in August 1991 and since then, she has been working toward an M. S. degree in Applied Economics at Montana State University. She is expecting to have her second child in July 1993.

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ABSTRACT

An accurate assessment of the value of pesticides to producers gives information to policy makers which may be useful in formulating policy regarding pesticides. Since the marginal products of pesticide inputs are a function of the functional specification of the production function, it is important to accurately specify the production function. Past empirical studies have suggested that the use of the Cobb-Douglas production function overestimates pesticide productivity. In addition to the pesticide productivity issue, this study also examines the economic importance of harvest-timing in crop production; most studies of supply response have not examined the harvesting decision explicitly. Results show that any function that can approximate the true function well in the neighborhood of the sample mean will give about the same estimate of mean marginal product. Findings suggest that if the purpose of a study is to estimate the marginal productivity and elasticity of inputs at its mean level, then the choice of the functional form may not matter.

One of the purposes of this study is to reexamine the issue of relationship of pesticide productivity and functional form using primary level data on Ecuadorian potato production.

Chapter 1

INTRODUCTION

The debate surrounding the choice of functional form for determining the level of agricultural pesticide use has resulted in the examination of different specifications in estimating the pesticide productivity. According to economic theory, producers will use inputs such that the value of marginal product of each input equals its marginal factor cost. There is a disagreement, however, as to whether empirical evidence supports this theory for pesticide use. In 1963, Headley inferred that the value of marginal product of pesticide exceeds marginal factor cost, which implies that net benefit would be maximized if more pesticides are used in agricultural production. On the other hand, Carrasco-Tauber and Moffit (1992) claim that there is an abundance of anecdotal and other evidence suggesting that pesticide materials are essentially "overused".

Recently, Lichtenberg and Zilberman (1986), while contesting Headley's findings, suggested that the key feature in explaining possible overestimates of pesticide productivity in econometric studies is the functional specifications employed in these studies. They came up with an alternative model of production involving damage control inputs, such as pesticides, designed to accommodate particular characteristics of such inputs. A variety of functional forms for the model of damage control were also considered. These arguments indicate the need for further research to develop an appropriate functional form to be used in guiding research and development of pest control policy.

In addition to the pesticide productivity issue, this study will examine the economic importance of harvest timing in crop production; most studies of supply response have not examined this harvesting decision explicitly.

The purpose of this study is twofold: to address the pesticide productivity issue by reevaluating the empirical works done by Babcock, Lichtenberg, and Zilberman and by Carrasco-Tauber and Moffit in estimating marginal productivity of pesticide and to construct and estimate a well-behaved production function that would link harvest timing and pesticide functional forms. Theoretically, the timing of harvest can be included as one of the choice variables farmers should consider in maximizing expected returns. A variety of functional forms, including the specifications developed by Lichtenberg and Zilberman, will be applied in examining the productivity of harvest timing and in deriving the economic implications of such a model. The empirical analysis will be based on the data from Ecuadorian potato production from 1990-1992.

Chapter 2

LITERATURE REVIEW

This chapter presents a brief history of the development and use of various functional forms for pesticide use and crop yield response, as well as some econometric issues in specifying and estimating production models. The last part of the chapter reviews nonnested hypothesis tests that can be used to analyze the fitness of each functional form in relation to the empirical data.

Historical Perspective

In generating an appropriate functional form for production processes, the following structural properties of production functions should be considered: the existence of returns to scale defined in terms of the production function's *homogeneity* and *homotheticity*; the degree of substitutability of factors of production (elasticity of substitution, factor demand elasticities); *separability*, which is the decomposition of production relationships into nested or additive components; *flexibility*, the robustness of the technology in adapting to changing environment; and *parsimony* in parameters.

Since the development of the Cobb-Douglas production function in 1928, many theoretical and empirical studies have tended to support the hypothesis that production processes are well described by a linear homogeneous function with unitary elasticity of substitution between factors (Douglas, 1976). Despite its well-known technological restrictions, such as homogeneity, unitary elasticity of substitution, and constant input elasticity, the Cobb-Douglas is still widely used in production analysis due to its simplicity, ease of interpretation and the fact that it is parsimonious in parameters. However, economists recognized the function's limitations and began to explore alternatives. A quadratic production function, which is less restrictive in some respects than the Cobb-Douglas function, was used by Heady in 1952; Heady, Johnson, and Hardin in 1956; and then by Heady and Dillon in 1962. In 1957, the transcendental production function was introduced by Halter, Carter, and Hocking, while Arrow, Chenery, Minhas, and Solow (1961) proposed the constant elasticity of substitution (CES) function, both of which are generalizations of the Cobb-Douglas function with a non-unitary elasticity of substitution. The concept of linear-in-parameters functional forms and the property of second-order approximation at a point were initiated by Diewert (1971). He introduced the generalized linear and generalized Leontief systems, and this development was followed by the introduction of the translog functional form by Christensen, Jorgenson, and Lau (1973).

This evolution in functional forms reflects the understanding that the functional form used in production analysis affects the interpretation of the economic relationships embedded in the corresponding behavioral relationship (i. e. the firm's output supply and input demand functions [Antle and Capalbo, 1988]). Generally, it is desirable to impose as few restrictions on the functional form as possible, while maintaining a function that is empirically tractable and flexible.

Many of the functional forms developed in the economic literature are linear-in-parameters. The historic Cobb-Douglas function has the virtue of simplicity, but this simplicity comes at the cost of imposing many restrictions. This form allows free assignment of the output level, returns to scale, and distributive shares effects at a point of approximation, but allows no flexibility with respect to the substitution and own-price elasticity effects (Fuss, McFadden, and Mundlak, 1978). The translog form, a direct generalization of the Cobb-Douglas function, has been widely used as a framework for analysis of structural properties of production. This can be derived by specifying the Cobb-Douglas production elasticities to be log-linear functions of the inputs. Fuss, McFadden and Mundlak named translog as a "parsimonious flexible form", meaning it has the minimum number of parameters needed to represent economic behavior without imposing arbitrary restrictions on that behavior.

The Generalized Leontief cost function and the generalized linear production function are other examples of functions that provide second-order approximations to an arbitrary twice differentiable cost or production functions at a given vector of factor prices or inputs using a minimal number of parameters (Diewert, 1971). One may utilize either of these two functions as a functional form for a production function which will attain any given set of elasticities of substitution at a predetermined set of inputs and input prices, since elasticities of substitution are defined in terms of Hessian matrices.

The specification of flexible functional forms in production studies involves the use of an expression which locally approximates an arbitrary function. In general, such expressions can be written in the form

$$f^*(x) \approx f(x) = \Sigma\ \alpha_i\ g^i(x),$$

where f^* is the true function, f is the approximating functional form, the α_i are parameters, the g^i are known functions, and x are inputs.

A second-order Taylor series approximation can be used to generate parsimonious flexible forms; it is in the form

$$f(x) = \alpha_0 + \Sigma\ \alpha_i\ x_i + \Sigma\ \Sigma\ \alpha_{ij}\ x_i x_j, \quad i,j = 1,\ldots, n,$$

where, according to Taylor's theorem, the α_i are interpreted as first derivatives of f^* and the α_{ij} are interpreted as second derivatives of f^*. Two other types of approximations, the Laurent series and the Fourier series, were introduced by Barnett (1983) and by Gallant (1981), respectively.

According to Barnett, the principal advantage of the Laurent series over the Taylor series is that the residual term of the Laurent expansion is better behaved within the region of convergence than the remainder term of the Taylor series expansion. The full Laurent series expansion of second order is in the form

$$f(x) = \alpha_0 + \Sigma\alpha_i x_i + \Sigma\Sigma\alpha_{ij} x_i x_j - \Sigma\beta_i x_i^{-1} - \Sigma\Sigma\beta_{ij}\ x_i^{-1} x_j^{-1}, \ \ i,j = 1,\ldots,n.$$

This expansion is divided in 2 parts: the principal part composed of the first linear and quadratic terms and the analytic part composed of the second linear and quadratic terms. If the analytic part is suppressed, the full Laurent expansion would be reduced to a Taylor expansion. However, the coefficients from Taylor and Laurent series expansions are not strictly comparable[1].

The Fourier flexible form differs from other functional forms in that it has a

[1]for details, see Barnett, W. A. (1983), p. 15.

variable number of parameters. Its asymptotic properties are obtained by letting the number of parameters depend on the sample size (see Chalfant and Gallant, 1984 for a more detailed discussion on this model).

Functional Forms for Pesticides

The issues surrounding the use of agricultural pesticides have motivated a number of investigators to measure pesticide productivity by focusing largely on its contributions to harvested yield. In agricultural production, various production operations are done in stages such as planting, pest management, cultivation and harvesting. Letting $G(X)$ represent pest management as a function of inputs X, and letting Z represent the service flows from other operations, the production function is

$$Q = F[Z, G(X)].$$

Thus, the pest management inputs X are assumed to be separable from other inputs in the production process. Antle (1988) made use of this separability assumption in his analysis of California processing-tomato production.

In addition to this separability assumption, choice of the functional form for $G(X)$ is another important factor to be considered. Headley (1963) used aggregate data and the Cobb-Douglas function to conclude that chemical pesticides are a highly productive input, and that the marginal value product of pesticides exceeds marginal factor cost by a considerable amount, which implies that benefits could be increased by applying more pesticide materials in agriculture. Note that the use of the Cobb-Douglas model implies that $G(X)$ takes the form X^{α}, if X is a scalar.

The use of the Cobb-Douglas model to estimate pesticide productivity was criticized by Lichtenberg and Zilberman (1986). They argued that the production function should be separable, like the Cobb-Douglas, but that the pest control subfunction should behave as an abatement function. The abatement function is defined as the proportion of the destructive capacity of the damaging agent eliminated by the application of a level of control agent *X*. This definition suggests that *G(X)* will possess the properties of a cumulative probability distribution defined on the (0,1) interval, with G=1 denoting complete eradication of the destructive capacity and G=0 indicating zero elimination. The maximum destructive capacity will be monotically increasing and will approach a value of unity as damage-control agent increases (i. e. $G(X) \rightarrow 1$ as $X \rightarrow \infty$). The Cobb-Douglas function does not possess this property.

The Lichtenberg and Zilberman study thus argued that the correct specification of the damage abatement processes is important in the estimation of production functions and input productivity. The implication of their findings is that the use of a standard Cobb-Douglas specification to estimate damage control agent productivity, such as pesticide productivity, leads to overestimation of the marginal productivity of damage control agents and underestimation of the marginal productivity of other inputs. The result of such misspecification is illustrated in figure 1 which compares the standard Cobb-Douglas marginal productivity curve with the one derived from the damage control specifications. As explained by Lichtenberg and Zilberman (1986):

"The specification of damage control agent productivity proposed here suggests that the marginal product curves of the damage control agent will decline at an increasing rate in the economic region. The reason for this increasingly rapid decline lies in the specification of marginal effectiveness as a probability density: To converge, $g(X)^2$ must decline faster than 1/X and, hence, must decrease more rapidly as X gets larger. As a result, the elasticity of the marginal effectiveness curve also grows as X increases. A specification like Cobb-Douglas cannot match this behavior. Instead, a standard Cobb-Douglas specification will produce a marginal effectiveness curve whose elasticity is constant and which declines more slowly than the true marginal effectiveness curve. The Cobb-Douglas specification will produce consistent estimates of the damage control agent productivity parameter at point $e^{\bar{X}}$ which lies to the left of the average level of damage control agent use $\bar{X}$. Since the true parameter tends to decline quite rapidly, the estimated marginal product curve will lie above the true curve for levels of control agent use greater than $e^{\bar{X}}$. At average use levels, then, the estimated value of marginal damage control agent productivity *(VMP_E)* will be greater than the true value of marginal damage control agent productivity *(VMP_A)* and will appear to be greater than marginal control agent cost *(MC)*."

This damage control specification was used by Babcock, Lichtenberg and Zilberman (1992) in investigating the impacts of pesticide use on both quantity and quality of apple production in North Carolina. By directly using the exponential

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[2] $g(X) = \partial G(X)/\partial X$

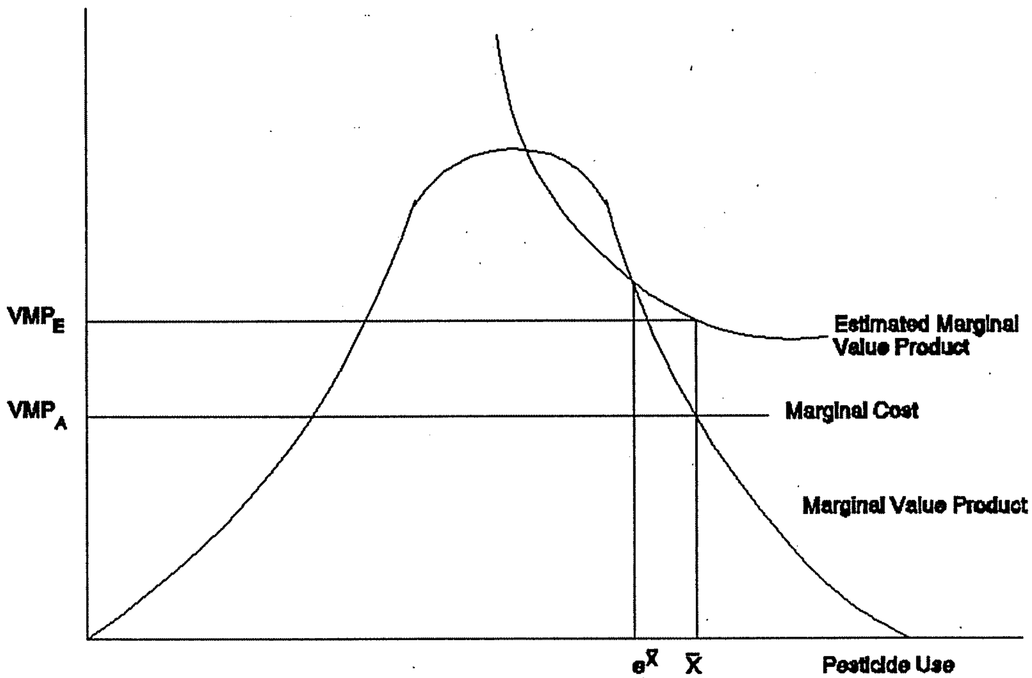

Figure 1
The impact of misspecification on damage control agent productivity estimates according to Lichtenberg and Zilberman.

specification of the damage control agent, without testing it against other production functions and other damage control specifications, their result supports the issue that the use of Cobb-Douglas function overestimates the marginal productivity of pesticides. They found out that the exponential model produced much smaller estimates of the marginal productivity of pesticides than the Cobb-Douglas.

Carrasco-Tauber and Moffit (1992) used aggregate data in estimating both Headley's specification and Lichtenberg and Zilberman's damage control specification. Results show that estimates of the value of marginal product of pesticide is fairly similar in its implications for both the Cobb-Douglas models and the weibull and logistic damage control specifications, but the exponential specification produced much smaller estimates. An Akaike information criterion was used to identify which of these models is an appropriate specification, because if the exponential form is correct, then the use of the Cobb-Douglas or the other damage control specifications would lead to much higher estimates of pesticide marginal productivity. The Akaike criterion provides little support in choosing the exponential function over the other alternatives. These results are subject to the limitations of the data and the technique used in their study. Since the data are per-farm averages, much of the variation in input and output has been lost in aggregation. Any conclusions based on this aggregative analysis may not apply to field-level situations. Also, the use of an aggregate production function will give parameters that may not be valid for individual decisions.

Crop Yield Response

The specification and estimation of yield response to input applications was the objective of early experimental research in agriculture. A key problem was to devise a functional form that would accurately represent this relationship. Some production functions such as the quadratic, show that the maximum output can be attained at a single point on the production surface. However, in many agricultural production processes, especially crop yield response to plant nutrients, it is believed that beyond some level of input use, a yield plateau will occur (Beattie and Taylor, 1985).

The first area where the plateau function was proposed was in the estimation of plant response to nutrients. According to von Liebig's "law of the minimum", crop yield is a proportional function of the scarcest nutrient available to the plant. Increasing the availability of non-limiting nutrients does not affect crop yield, thus, resulting in yield plateau. This relationship suggests a yield response specification:

$$Y = min\{f_N(N_i,u_{Ni}), f_P(P_i,u_{Pi}), f_K(K_i,u_{Ki}),\ldots\} + u,$$

where Y is the observed crop yield; $N, P, K,\ldots$, are nutrients such as nitrogen, phosphorous, potassium; u_i are parameters requiring estimation, $i=N, P, K,\ldots$; f_i are the potential yield functions, $i=N, P, K,\ldots$; and u is the disturbance term.

Frank, Beattie, and Embleton (1990) tested three functional forms (quadratic, von Liebig, and Mitscherlich-Baule) to illustrate corn yield response to nutrients, imposing specific restrictions on factor substitution and growth plateau. Their results show that Mitscherlich-Baule is favored over the two functions. However, this function supports the idea of plateau growth but suggest that corn yield response displays a nonzero elasticity of substitution ($\sigma > 0$), implying that the hypothesis of no input substitution is not supported. It is therefore an important factor to know the cost of imposing an elasticity of substitution equal to zero or no growth plateau in coming up with a well-behaved function for crop response.

von Liebig implied a "linear response and plateau" (LRP) in his model. However, Paris (1992) expands von Liebig's formulation and argued that the LRP framework is a convenient first approximation, but that linearity of the response is not an essential feature of the von Liebig hypothesis. von Liebig asserts only that the minimum nutrients and crop yield stand in *direct relation only*. It is unreasonable to deduce from this assertion that von Liebig meant to express any form of linearity between minimum nutrients and yield. Paris shows that the generalized interpretation (including non-linearity) of the von Liebig hypothesis is inconsistent neither with diminishing marginal productivity nor with the principle of decreasing returns to scale. Instead, he focusses on the specification of the von Liebig hypothesis on two issues: (1) the analytical form of the potential yield functions and; (2) the statistical specification of the experimental errors. He shows that the potential yield functions f_N, f_P, and f_K can be either linear or nonlinear without danger of misspecifying the "direct relation" between nutrients and yield expressed by von Liebig, and therefore, it follows that a wide variety of functional forms can be utilized to explain the potential yield functions, including the Mitscherlich specification. Using a sample of experimental data dealing with corn response to nitrogen (N) and phosphorous (P) collected by Heady and Pesek in the fifties, he considered five rival specifications in investigating the possibility that a more general specification of the von Liebig hypothesis might perform better than any other specification tested: a quadratic polynomial, a square-root polynomial, an LRP von liebig, a Mitscherlich-Baule, and a nonlinear von Liebig.

In conclusion, Paris said that "von Liebig's supporters and critics concentrated their attention on a linear response and plateau formation rather than the two essential features of the hypothesis represented by the nonsubstitution between inputs and by a yield plateau". Among the five specifications presented, he showed that a von Liebig model with Mitscherlich regimes is the best interpreter of the experimental data. He also derived an estimable duality relation which can be used when input prices are available.

Econometric Issues in Production Model Specification

In agriculture, both short run and long run agricultural production decisions are based on a multiperiod, dynamic optimization problems. This is because inputs are not all chosen or used simultaneously and therefore, the farmer's optimal input choices may be regarded as optimal controls in a stochastic control problem (Antle, 1983). However, in some cases, such as the case of a pest management program and harvest timing, the farmer has a predetermined schedule of actions (applications of pesticide, date of harvest, etc.). These schedules are predetermined based on a priori information available to the farmer before the production begins. Therefore, each operation will be rendered at the predetermined schedule regardless of whatever events, such as pest infestation, that may occur over time.

The farmer's short-run objective is the maximization of profit subject to the production function and some factors of production. Letting the production function be

$$q = q(x) + \epsilon,$$

where q is output, x denotes a vector of variable inputs, and $\epsilon \sim nid(0, \sigma^2)$, and the objective function is to

$$Max\ E(\pi) = E[pq(x) + \epsilon] - wx$$

$$= pq(x) - wx,$$

then the *first-order condition* for profit maximization is

$$\partial E(\pi)/\partial x = p\ \partial q/\partial x - w = 0.$$

Assuming second-order conditions are satisfied, input demand functions are obtained by solving the first-order conditions:

$$x^* = x(p, w).$$

From the above discussion, we know that inputs are predetermined and are therefore independent of weather, etc., such that $E(\epsilon,x) = 0$. Thus, unbiased estimates of the production function can be obtained with single-equation methods. This single equation approach has been shown valid by Hoch (1958, 1962), Mundlak and Hoch (1965), and by Zellner, Kmenta, and Dreze based on the assumption that production inputs are chosen as part of a one-period decision problem.

Hypothesis Tests for Functional Forms

In the area of consumer and production theories, a variety of functional forms such as the translog, the generalized Leontief, and the generalized Cobb-Douglas has been introduced. Many of these are of the flexible type because they do not constrain the elasticity of substitution or the type of separability. The problem of choosing the functional form is a problem of choice among competing models. Often economic theory can help in this because it can indicate what explanatory variables should be included in the model.

There are many alternative functional forms that exist for showing the relationship between the explanatory variables (inputs) and the dependent variable (output). Often, one model is a special case of another model, in which case the first is said to be *nested* in the second. In the case of *nonnested* models, the explanatory variables under one of the models are not a subset of the explanatory variables in the other, or neither model appears to be a special case of the other. Commonly used techniques in selecting one model (from nested models) in preference to the other are to use either a classical F-test or a goodness of fit criterion such as the R^2 statistic. However, an F-test of the restriction cannot be employed as a specification test for nonnested models since one model cannot be obtained from the other by imposing a restriction. On the other hand, R^2 and the adjusted R^2 can be used to compare nonnested models, but do not provide a formal statistical test. Moreover, R^2 is sensitive to the number of variables and one could simply add more variables (that may be irrelevant to the analysis) to increase R^2. If the specification problem is structured such that the competing models are nonnested, several nonnested hypothesis tests can be employed. Such tests provide a formal statistical basis for testing the specification of one model against the evidence provided by one or more nonnested alternative models.

To illustrate these tests, consider two rival models, $F(X)$ and $G(X)$ that are nonnested. First consider *F(X)* as the null hypothesis, H_o, and *G(X)* as the alternative hypothesis, H_a:

$$H_o : Y = F(X)$$

$$H_a : Y = G(X).$$

A test of H_o against H_a can be devised by using *G(X)* to determine the adequacy of *F(X)* in explaining *Y*. One approach to do this is to construct the composite model

$$Y = (1\text{-}\alpha)\ F(X) + \alpha\ G(X) + \mu, \quad 0 \leq \alpha \leq 1.$$

If the null hypothesis is true, $\alpha = 0$, and if *G(X)* contributes significantly to the explanation of *Y*, $\alpha > 0$. Thus, a test of H_o can be performed by testing for a value of α significantly different than zero.

To implement this test, known as the *J-test*, Davidson and Mackinnon (1981) show that the first step of the *J*-test is to estimate the model *G(X)* function and obtain the predicted value $\hat{Y}$ of *Y*. The next step is to estimate *F(X)*, including the predicted value, $\hat{Y}$, obtained from the alternative production function as one of the regressors, such that

$$Y = (1\text{-}\alpha)\ F(X) + \alpha\ \hat{G}(X) + \mu$$

and use the conventional *t-test* to determine if α is significantly different from zero. If it is, H_o is rejected; otherwise, H_o is not rejected. The roles of H_o and H_a are reversed and the procedure is repeated to determine whether or not H_a is rejected.

The Akaike information criterion (AIC) is a more general criterion that can be applied to any model that can be estimated by the method of maximum likelihood. The perspective of the criterion is that of model selection rather than hypothesis testing. This criterion takes the form of the error sum of squares (ESS) multiplied by a penalty factor that depends on the complexity of the model (i. e. a more complex model will reduce ESS but raise the penalty). Thus, the Akaike criterion is based on selecting the model which minimizes

$$AIC = SSE_i \exp(\frac{2k_i}{n})$$

where SSE_i, k_i, and n is the error sum of squares, number of parameters, and sample size of the model i. This criterion thus provides a trade-off between goodness of fit and model complexity. Note that in contrast to the R^2 statistics, which is a relative measure, the Akaike criterion is an absolute measure of goodness of fit.

Chapter Summary

Many functional forms exist showing the relationship between the dependent variable (output) and explanatory variables (inputs). The problem of choosing the appropriate functional form is the problem of choice among competing models. Most production analyses utilize the basic Cobb-Douglas model without attempting to test if the same marginal productivity estimates would be attained if an alternative form is used. Lichtenberg and Zilberman (1986) theoretically explained the possibility that functional specification is important when valuing pesticide productivity. In 1992, Babcock, Lichtenberg and Zilberman (BLZ) empirically test the significance of model specification using field level data. However, they (BLZ) only consider Cobb-Douglas and exponential functional forms. Consequently, Carrasco-Tauber and Moffit compared Cobb-Douglas and the damage control specifications using aggregate data.

These studies do not consider other functional forms, including flexible functional forms such as the quadratic. To accurately assess the value of pesticides, one should examine a large variety of functional forms, including flexible functional forms, using field level data.

Studies in crop response to nutrients support the idea that at some point in the production process, a "yield plateau" will be achieved and would be useful in determining a functional form for the timing of harvest.

Chapter 3

HARVEST TIMING AS AN ECONOMIC DECISION

In many agricultural production situations, farmers often face complex harvest decisions where yield varies through time and across fields, price is determined in changeable seasonal markets, and harvest activities are constrained by weather, crop price, and labor availability. The crop producers' returns depend critically upon a sequence of harvest decisions. In the first section of this chapter, a discussion of potato crop physiology and factors influencing potato growth will be presented to illustrate the importance in modeling a relationship between the harvest timing decision and yield. The conventional production model, which only includes the traditional inputs to production, will be presented next, and then the harvest timing decision will be added to the model and its economic implications will be derived.

Potato Crop Physiology

The potato plant displays a wide range of responses to changes in environments. Factors influencing the growth type of the potato crop are summarized in Table 1. However, these factors have their greatest influence in the early stages of growth. Once the crop reaches its bulking stage, the growth type is less influenced by environmental conditions. This implies that after some period during the production process, potato yield will reach its growth plateau stage. According to Paco, a researcher at the International Potato Center, experiments show that potato quality can be maintained under suitable soil moisture and temperature conditions, so that the yield of potatoes can be kept in the ground for about 8 weeks after the potato reaches its maximum potential yield. Beyond that point, the potato may lose about 5 to 10 percent per month of its yield.

Beukema and Van Der Zaag (1979) found that high yields are obtained not only if the growth rate of the tubers is high but if growth continues over a long period of time. They computed yield being equal to the production per day multiplied by the number of days the potato was grown. In determining the number of days the potato should be grown, not only the actual length of the growing period should be considered but also the potential and the available growing period of the crop. The actual growing period is the time (number of days) the crop actively grows in the field which is from planting until the senescence of the foliage. The potential and available growing periods are, respectively, the time (number of days) the crop would take to reach maturity, and the length of time during which fields are available for potato production and climatic conditions are favorable. The type of crop which should be grown depends on the available growing period. To obtain the highest possible yield, the crop type should be matched to the length of time available for the crop to grow. If the available growing period is short, i. e. if a farmer plans to harvest early, the short cycle crop often produces the highest yield. On the other hand, if the available growing period is long, a long cycle crop will yield more.

Figure 2 shows the growth of potato crop. It can be seen that after emergence, the haulm[3] and roots develop simultaneously. Haulm growth is correlated with root growth. Tuber growth may start slowly about 2-4 weeks after emergence and continue at a constant rate (i. e. bulking rate) over a fairly long period. Bulking may be as high as 800-1000 kg per hectare per day under favorable conditions.

In Figure 3, the growth patterns of short and long cycle potato crops are shown. We can see from this graph that short cycle crop demonstrates a moderate haulm growth, early tuber growth and early maturity and this type of crop produces a relatively high yield in a relatively short period of time. On the other hand, a long cycle crop develops a more extensive haulm, tuber growth begins later and maturity also comes later. Early in the growing season, this type of crop gives a relatively low yield but later on, it usually outyields the short cycle crop owing to the longer growing period. However, long cycle crops may be risky, e. g. if a long cycle crop cannot efficiently utilize the latter part of the period available for growth because of drought, blight, etc., the yield may be greatly reduced. Factors influencing the growth type of the crop are summarized in Table 1.

The growing pattern (haulm growth, stolon growth, and tuber growth) is influenced by temperature, day length, light intensity, physiological age of the seed, plant density, nitrogen supply and moisture supply. These factors may have individual influence, but there is also interaction between them that makes it difficult to define their individual effects. Furthermore, not all varieties and species react in the same way.

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[3] Haulm is the stalks/stems of the potato crop

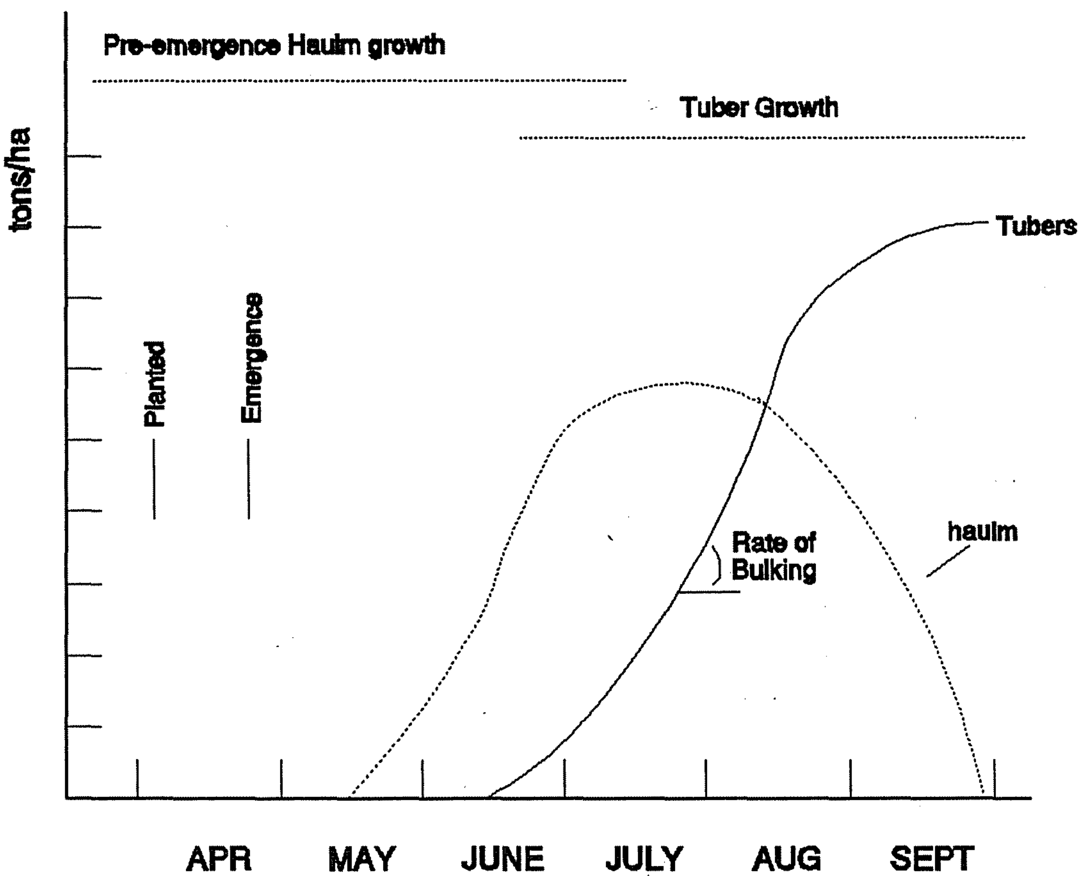

Figure 2

Growth of a potato crop

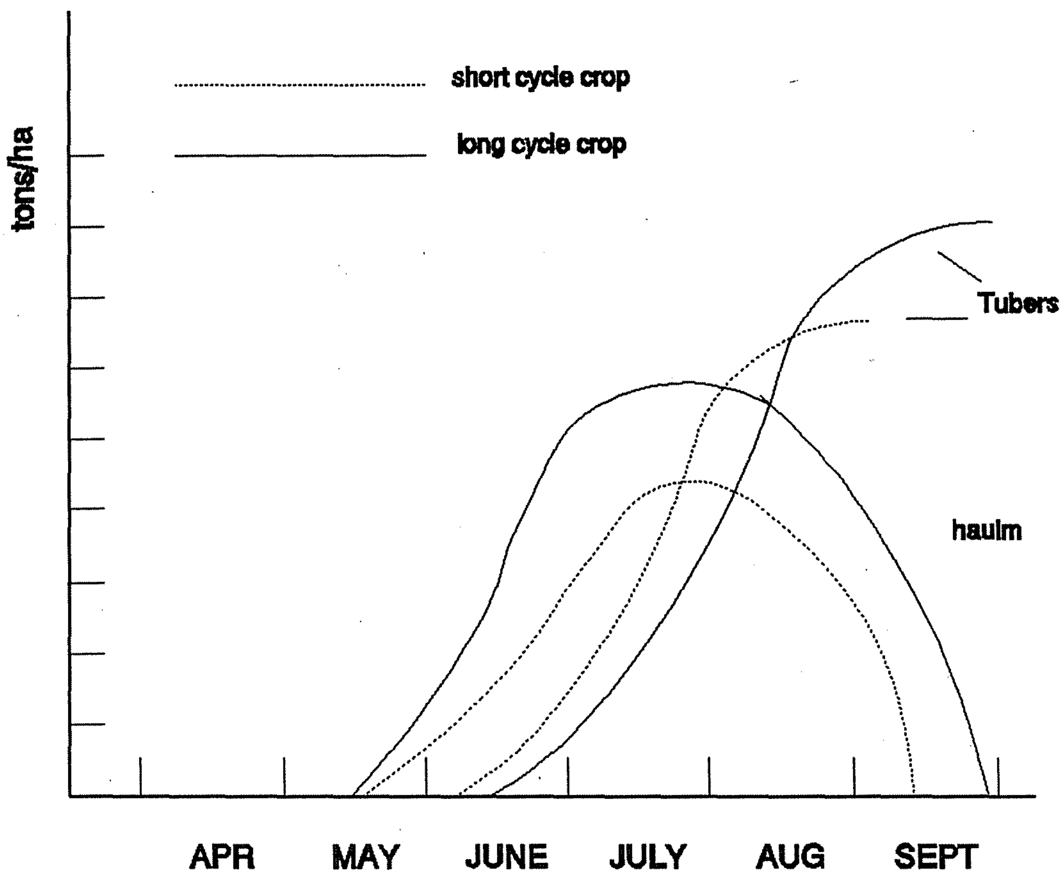

Figure 3

Growth of a short and long cycle potato crop

On the marketing side, the tuber size is an aspect to be considered because it is an important indication for "marketable yield" more than the total tuber yield. For some markets, big tubers are required (French fried, baked potatoes), and for others, smaller tubers are preferred (seed potatoes). The scheme in Figure 4 shows which factors may influence total and marketable yield (tuber size, grading of harvested tubers). This figure is a useful guide for analyzing a potato crop.

Harvesting of potatoes includes the following operations: lifting, collecting the tubers, separating the tubers/stones, and transporting. The aim of each harvesting system is to take the tubers from the soil to the store or to the market as cheaply as possible with minimum losses (e. g. quality). The harvesting system depends on: the economic situation such as machinery and labor costs; the amount of potatoes to be harvested and the time available; the size, shape and situation of the field; soil and weather conditions; and the use to be made of the potatoes (immediate consumption, storage).

Table 2 shows the yield and yield reduction (tonnes/ha) of the two crops in Fig.2, harvested on different dates. It should be noted that a crop that yields less may be compensated for by the higher prices obtained.

Early harvest of a crop may affect its quality. Immaturely harvested tubers often lead to more skin damage and results in the tubers being more easily susceptible to fungal and bacterial infections. On the other side, the disadvantage of delaying the harvest is the potential presence of soil insects or disease (various bacterial rots) that may continue to damage tubers.

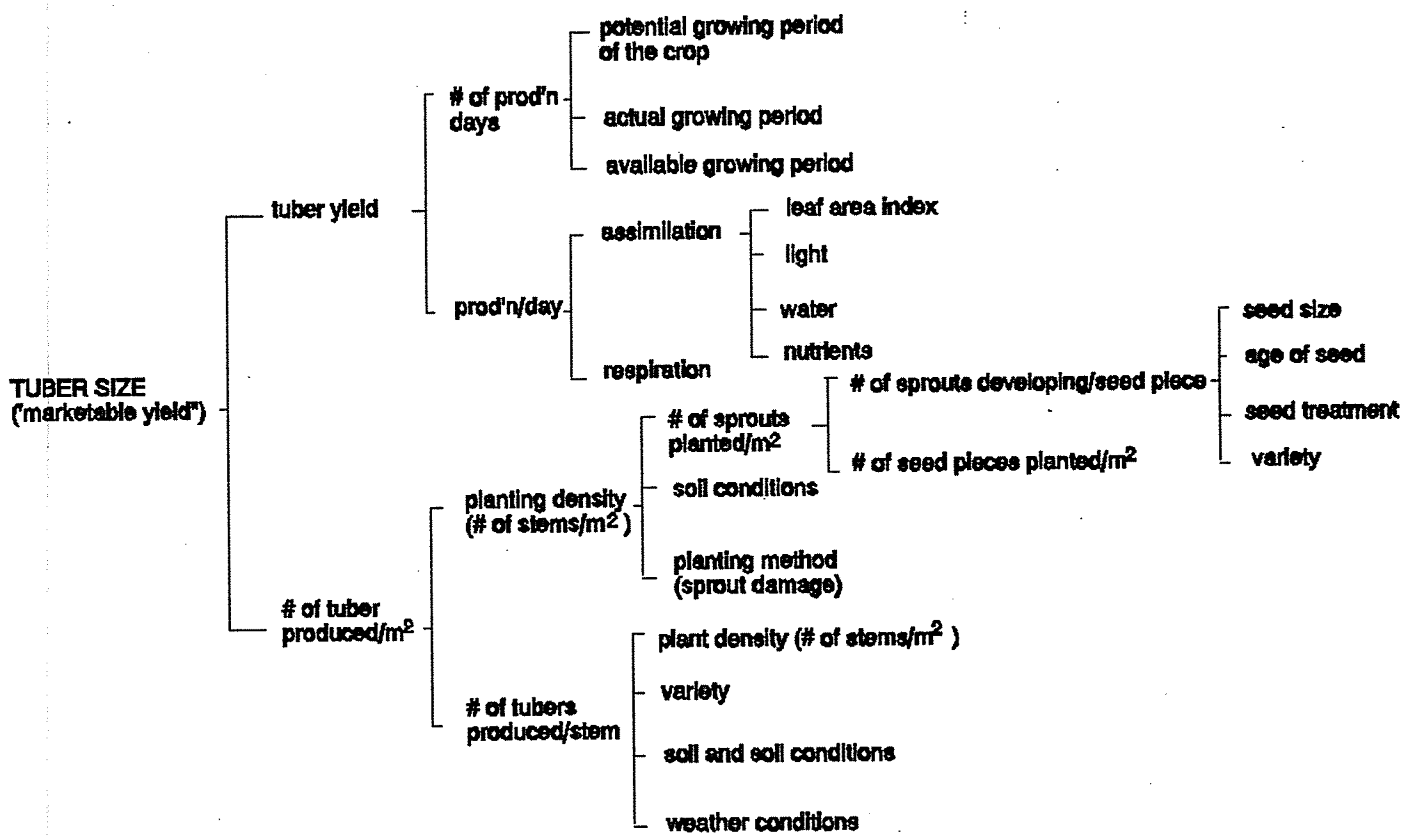

Figure 4

Factors influencing total and marketable yield

Conventional Economic Production Model

Each farmer is assumed to be risk neutral and have full information about his production possibilities, summarized by a production function relating inputs, x, to output q, and about the price of inputs, w, and price of output, p. It will be convenient if it is assumed that the production function is twice differentiable and concave. Suppose that a farmer, operating in a perfectly competitive product and factor markets, faces a concave production function

$$q = f(x_1, x_2, \ldots, x_n)$$

and desires to maximize his returns such that

$$\pi = pf(x) - \Sigma w_i x_i, \quad x = (x_1, x_2, \ldots, x_n),$$

then the *first-order conditions* for a maximum profit are

$$\partial\pi/\partial x_i = p\ \partial f/\partial x_i - w_i = 0, \quad i = 1, 2, \ldots, n.$$

Solving for x_i,

$$x_i^* = x_i^*(p, w), \quad w = (w_1, w_2, \ldots, w_n)$$

which indicate optimal factor demand is a function of product and factor prices with conventional comparative static properties (e. g. Silberberg, 1990 pp 163-166) . From this model, input and output prices are the ones affecting the optimum input level. As the above discussion indicates, a farmer also must decide when is the best time to harvest their crop to maximize his profit. Harvest timing is, of course, only one of many economic decisions the potato grower must make. Other economic choices involve outlays for disease control, availability of harvest labor, and others. The following model will include the harvest timing as a decision variable in the farmers' production function.

Timing of Harvest as One of the Decision/Choice Variables

In the Carchi province of Ecuador studied in the next chapter, the time of potato harvesting can vary by as much as two months. The crop variety, soil moisture, temperature, labor availability, and market prices are all factors that are believed to determine when the farmer harvests the crop. The farmer has a buyer or means to transport the potatoes to market before harvesting begins. Sales are thus immediate and usually some seed-sized tubers are kept by the farmer to plant the next crop. When considering whether or not to allow the crop to grow an extra period before harvesting, a rational decision requires a comparison of the benefits and costs of waiting. The costs of delaying the harvest are represented by the value of receipts that are forgone when the potato is allowed to grow for an additional period. If, instead of being allowed to grow, the crop were harvested and the proceeds are invested, it would earn interest for the farmer. Thus, the forgone return on the stock of potatoes is a cost of allowing the crop to mature or attain a higher yield. The second cost is associated with crop management such as use of control agents to protect the crop from pest infestations that can cause yield losses and reduction in quality. Lastly, the opportunity cost of the crop area and this cost is equal to the forgone return from the highest valued alternative service the crop area could have provided during the waiting period.

To illustrate the preceding concepts and to develop notations that will be useful in subsequent analysis, consider a simplified situation in which both the real rate of interest r and the real input prices w are expected to remain constant during the crop season (i. e. r and w are not a function of t). Suppose that the production function and the expected output price are both functions of the time of harvest, t, such that

(1) $$q = f(x_1, x_2, \ldots, x_n, t)$$

and $$p = p(t),$$

and that the production function is concave in the x_i and t. The farmer chooses timing of harvest, t and inputs x_i to

(2) $$Max\ \pi = p(t)q(x,t)e^{-rt} - \Sigma w_i x_i.$$

The *first order conditions* for profit maximization are

(3) $$\partial\pi/\partial x_i = p(t)q_i e^{-rt} - w_i = 0$$

(4) $$\partial\pi/\partial t = p_t q(x,t)e^{-rt} + p(t)q_t e^{-rt} - rp(t)q(x,t)e^{-rt} = 0$$

where q_i is the proportional change in output due to an additional use of input x_i, and q_t and p_t are changes in output and price, respectively, due to time change. Simplifying equation (4) by dividing it by $p(t)q(x_i,t)e^{-rt}$, the resulting equation is

$$\frac{p_t}{p(t)} + \frac{q_t}{q(x,t)} - r = 0$$

Thus, to maximize profit with respect to harvest timing, $\partial\pi/\partial t = 0$ implies that

$$\frac{1}{p}\frac{\partial p}{\partial t} = -\frac{1}{q}\frac{\partial q}{\partial t} + r$$

This equation implies that:

(a) if $\partial p/\partial t = 0$, i. e. expected price is constant, then $1/q\ \partial q/\partial t = r$, the farmer harvests where the rate of yield growth equals the real interest rate (see point *a* in Figure 5).

(b) if $\partial p/\partial t > 0$, the farmer harvests later than in (a), because the expected gain in price affects the opportunity cost of waiting. Observe that under this condition, the rational farmer could harvest where $\partial q/\partial t < 0$ (points *b* or *b'* in Figure 5).

(c) if $\partial p/\partial t < 0$, the farmer harvests earlier than in (a), because the forgone yield from an early harvest is offset by a higher price (point *c* in Figure 5).

Note that situation (c) is typical of agricultural settings where many farmers are harvesting at about the same time, and therefore price is expected to decline at harvest time. Thus, the model implies that farmers would typically harvest where $\partial q/\partial t > 0$.

Chapter Summary

Conventional production models often focus on output being a function of material inputs such as labor, fertilizers, and pesticides. These models neglect the importance of other decisions such as harvest timing. Most supply response studies account for harvest timing by assuming that the process of crop harvesting is instantaneous--that is, the exact time of harvest is assumed according to a predetermined date. The potato crop is not an exception to this assumption.

Potato crop physiology, presented in the first part of this chapter, is a useful guide in the analysis of harvest timing. Potato physiology suggests that after some point in the

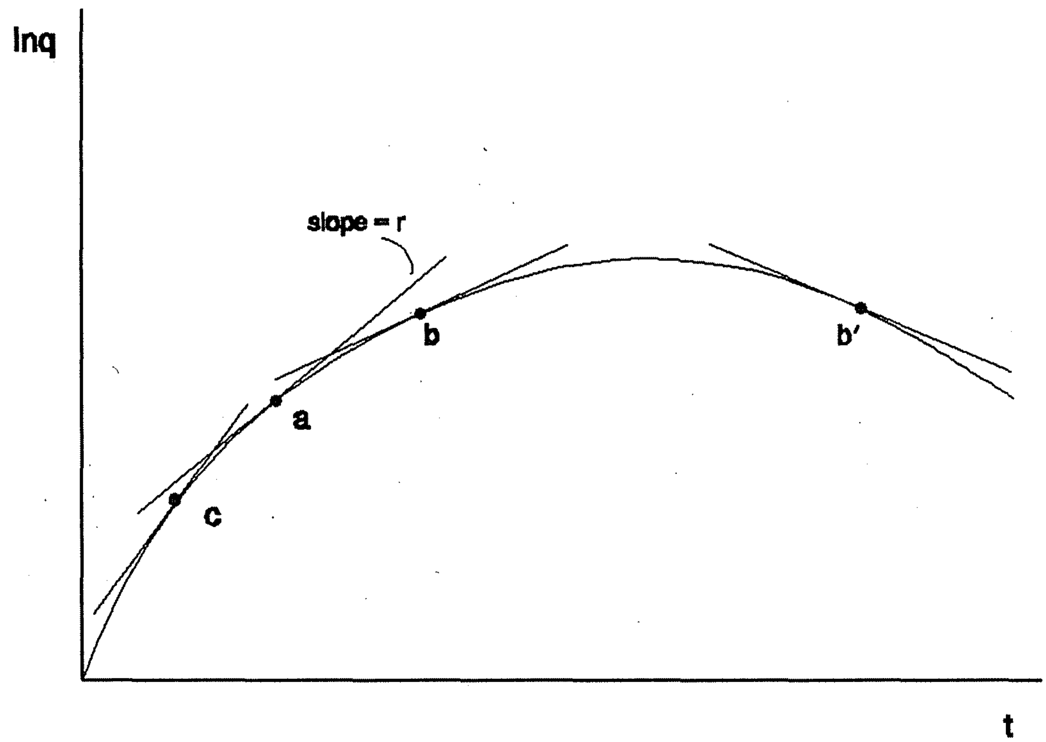

Figure 5

Equilibrium points for harvest timing

production process potato yield will achieve the maximum attainable level. This suggests that a "plateau" function may be appropriate in estimating the harvest timing decision.

Assessing the value of inputs such as pesticides requires accurate specification of production including factors like harvest timing.

Chapter 4

EMPIRICAL APPLICATION TO ECUADORIAN POTATO PRODUCTION

The preceding chapters have presented an overview of the functional forms used in estimating pesticide productivity, crop yield response, and the theoretical model for timing of harvest. In this chapter, the actual data used and the analysis of alternative functional forms are presented. The chapter is divided into 3 sections; (1) a description about the study area, the data, and the variables; (2) functional forms for pesticides; and (3) harvest timing production models.

The Study Area

In Ecuador, the potato is the fourth most valuable agricultural crop. It is an important dietary staple for urban and rural residents of the sierra and for the estimated 90,000 farmers who cultivate approximately 50,000 ha. of potatoes. Most potato farmers operate farms of less than 10 ha. Carchi Province, the study area, is an important potato zone in the northern Ecuador serving the Quito market. It is characterized by commercially-oriented production by small farmers for whom potatoes are the most important source of income. Carchi's soils are volcanic and potato production is located between 2,000 to 3,500 m elevation. Potato production in the zone is not marked by distinct seasons and mostly occurs on sloping hill sides.

The data used in this study were collected as part of a project conducted by the International Potato Center (see Crissman and Espinosa, 1992). The project involved a parcel-level monitoring of all activities, inputs, and costs associated with cropping by the sample farmers. A parcel is a unit of land during a given crop cycle. Potatoes occupy a field for about 6 months, thus, during a year, a single field may be recorded as two parcels. Forty farmers in Carchi province were monitored from April 1990 to April 1992. The data were collected on a field-specific basis, the average field size being 0.6 hectares. The data were aggregated by parcel. The final sample for both output and input data consisted of 215 parcels.

Harvesting is done by hand and is separated into lifting the tubers from the ground, sorting by size, sacking, weighing and transporting to the road. Since a typical one hectare field is steeply sloping and produces over twenty tons, this is a laborious process. Potato production requires over 130 mandays during the production cycle. As there are harvests continually during the year, fresh potatoes are always available in the local market and only small amounts are kept for home consumption.

Potato prices in Ecuador fluctuate with market supply and demand both within and across the years. Potato producers experience considerable price risk. Prices can decline precipitously and suddenly and farmers can experience considerable losses. Losses can also come from yield fluctuations due to pests infestation, diseases and other possible climatical production risks such as frost and drought.

Twelve quantity variables were utilized in the econometric analysis and were all measured on a per hectare basis. The variables included are gross potato output (Q), preharvest (PL) and harvest (HL) labor, fertilizers (FR), insecticides (INS), fungicides (FUN), number of days from planting until harvest (HDAP), percentage of seed variety applied in each parcel (PS1, PS2, PS3)[4] and agroecological zone dummy variables (DZ2, DZ3, DZ4). All of these were obtained from farmers' field-specific production records. Labor variables include both family and hired labor. The amount of nitrogen, potassium, and phosphorous in each type of fertilizer were computed based on its percentage composition and then were added together to comprise the fertilizer variable. Of the dummy variables used in the analysis, it is useful to include the zone dummies in the analysis to account for the effect of the agro-climatic differences across parcels. Summary statistics are presented in Table 3.

Variation in the quality of insecticides and fungicides is a major problem in production analysis. The use of both highly concentrated pesticides, which require very low application rates, as well as the use of materials requiring much higher application rates for the same degree of pest control, means that there are large quality differences in the material used. It is hypothesized that these differences are reflected in pesticide prices. Thus, hedonic regression technique was utilized to adjust pesticides for quality. Underlying the hedonic method is the concept that market prices reflect differences associated with qualities or characteristics of the good. The price component (or implicit price) associated with each quality is measured by regressing price on indicators of quality. This implicit price can be used to quality-adjust the quantity data into a

[4] Some farmers plant more than one variety class in each parcel and since the data were aggregated by parcel, these variables (PS1, PS2, PS3) were created to indicate the percentage of the total seed applied in each parcel that is native, improved local, or national varieties, respectively.

homogeneous variable measuring pesticide input in standard efficiency units. Thus, prices were regressed on polynomial functions of observed application rates, application number, number of days between planting and pesticide application, parcel area, altitude, and potato crop variety dummy. Setting all the variables to zero except for the polynomial functions of observed application rates, the predicted values of the model were interpreted as quality factors and used to aggregate the quantities into standardized units. One hedonic model was estimated for insecticides and one for fungicides.

Potato was also classified according to quality categories and priced accordingly. The gross potato output was also quality adjusted using a hedonic regression to capture the quality differences and to carry out the analysis in quality adjusted units. The hedonic analysis showed a consistent, positive association between potato quality and price.

A test for heteroskedasticity of the production function errors was done by plotting the residual of the Cobb-Douglas production function against each of the regressors. The existence of heteroskedasticity was also investigated using the model proposed by Harvey (1976). Harvey's procedure involves regressing the log of the absolute value of the residuals of the production function on the variables in log form. The results did not indicate heteroscedasticity was a problem, so the error terms were assumed to be independently and identically distributed.

Pesticide Functional Forms

Following the functional forms proposed by Lichtenberg and Zilberman, and used by Babcock, et. al. and by Carrasco-Tauber and Moffit, we examine and test four different functional forms that could represent the productivity of insecticides and fungicides. The variables used in the following production models were scaled by their means.

The Cobb-Douglas production function is one of the functional forms that is examined in this study because it is widely used in theoretical and empirical production research. It is also relatively easy to estimate because in logarithmic form it is linear in parameters, and it can be interpreted as a first-order logarithmic approximation to the true yield function. The Cobb-Douglas production function is written as

$$(5) \qquad \ln Q = \alpha_0 + \Sigma\beta_i \ln Z_i + \Sigma\delta_i D_i + \Sigma\gamma_i \ln X_i + \mu,$$

where Q is the gross output; Z_i*'s* are other input variables (preharvest labor (PL), harvest labor (HL), fertilizer (FR) and the number of days between planting and harvest (HDAP)); D_i*'s* are percentage of seed used in each parcel (PS2 and PS3) and zone dummies (DZ2, DZ3, DZ4); X_i*'s* are the damage control agents such as insecticides (INS) and fungicides (FUN); and the error term is $\mu \sim N(0,\sigma^2)$.

The quadratic production function, a representative of the flexible functional forms, is another appealing production model because it gives a second-order local (Taylor's series) approximation to any function. This function is written as

$$(6) \qquad Q = \alpha_0 + \Sigma\alpha_i X_i + \Sigma\delta_i D_i + \Sigma\Sigma\beta_{ij} X_i X_j + \mu,$$

where X's are production inputs (including pesticide) and D_i's are dummy variables as described in the Cobb-Douglas model.

Both Cobb-Douglas and quadratic functions are linear in parameters and were therefore estimated using the ordinary least squares method.

In the case of the damage control model, let the production function be

$$(7) \qquad ln\ Q = \alpha_0 + \Sigma\alpha_i\ ln\ Z_i + \Sigma\delta_i\ D_i + \Sigma\gamma_i\ G_i(X_i) + \mu,$$

where the $G_i(X_i)$ are the damage control functions for insecticides and fungicides, that were specified as the exponential and logistic functions:

$$(8) \qquad G_i(X_i) = ln\ [1 - exp(\mu_i - \beta_i\ X_i)],$$

$$(9) \qquad G_i(X_i) = -\ ln\ [1 + exp(\mu_i - \beta_i\ X_i)], \quad i = insecticides, fungicides.$$

The production functions obtained by substituting (8) or (9) into (7) must be estimated by nonlinear methods since the abatement functions (8) and (9) are nonlinear in the parameters. Following Babcock, Lichtenberg, and Zilberman, the parameter restriction that $\gamma_i = 1$ was imposed on equation (7) to facilitate estimation. This restriction requires that damage abatement be proportional to G_i as is typically done in simulation studies of pesticide effectiveness.

Parameter estimates and statistics from the Cobb-Douglas model and from each of the damage control specifications were summarized in table 4. The estimates, standard errors (in parenthesis) and statistics for the quadratic model are:

$$Q = 0.7434 + 0.3383*PL - 0.1447*HL + 0.5719*FR + 0.0093*FUN$$
$$(1.6426) \quad (0.6699) \quad (0.4203) \quad (0.5798) \quad (0.6645)$$

$$-\ 0.3019*INS - 0.9498*HDAP - 0.0512*PL^2 + 0.1189*HL^2 + 0.0184*FR^2$$
$$(0.2353) \quad (3.2171) \quad (0.1415) \quad (0.0703) \quad (0.1404)$$

$$- 0.1585*FUN^2 - 0.0132*INS^2 + 0.7472*HDAP^2 - 0.0067*PL*HL$$
$$(0.1148) \quad (0.0110) \quad (1.6503) \quad (0.1562)$$

$$+ 0.0675*PL*FR + 0.0755*PL*FUN + 0.0165*PL*INS - 0.4571*PL*HDAP$$
$$(0.2119) \quad (0.1653) \quad (0.0783) \quad (0.6068)$$

$$- 0.1386*HL*FR + 0.1598*HL*FUN - 0.0248*HL*INS + 0.0654*HL*HDAP$$
$$(0.1466) \quad (0.1105) \quad (0.0381) \quad (0.4070)$$

$$- 0.0624*FR*FUN + 0.1488*FR*INS - 0.4283*FR*HDAP - 0.0378*FUN*INS$$
$$(0.2071) \quad (0.0718) \quad (0.6264) \quad (0.0513)$$

$$+ 0.3280*FUN*HDAP + 0.2927*INS*HDAP - 0.1359*DZ1 - 0.1246*DZ2$$
$$(0.6047) \quad (0.2470) \quad (0.0960) \quad (0.0776)$$

$$+ 0.0518*DZ3 + 0.1711*PS2 + 0.0879*PS3$$
$$(0.0737) \quad (0.0928) \quad (0.0995)$$

$$d.f. = 182 \quad R^2 = 0.3681 \quad Adj.\ R^2 = 0.2570 \quad SSE = 17.8661$$

The elasticities at the sample means, which can also be interpreted as marginal productivity because the data are scaled by the sample means, of insecticides and fungicides are shown in table 6. From this table, we can see that the elasticities of pesticides are fairly similar in its implications for all the functional forms estimated in this study. This implies that, at the mean, estimates of pesticide productivity would be very close whatever functional form is being used.

Cost minimizing producers usually operate where input elasticities equals input factor cost shares. The cost shares (Table 3) were computed and compared with the elasticites found in table 6. Results show that the elasticities are within one standard deviation of the mean value of cost shares.

To test which of the pesticide functional forms being estimated fits the data well, a J-test and an Akaike Information Criterion (AIC) were used. The value of J-test and the AIC statistic are summarized in table 7 and 9. The J-test shows that the Cobb-Douglas function is the least rejected among the four choices but the AIC is minimized if the quadratic function will be used.

Harvest Timing Functional Forms

The theory in chapter 3 showed that if farmers expect that price would decline over time (i. e. $\partial p/\partial t < 0$), they would tend to harvest earlier than the period the crop would reach its maturity and therefore, the equilibrium timing of harvest is the period where growth is still increasing ($\partial q/\partial t > 0$). It was also explained in the previous chapter that after some period in the production process, a "growth plateau" will be reached and so a "plateau" function is appropriate.

The same functional forms that were used in measuring pesticide productivity will be utilized in examining harvest timing as an economic decision. Using the traditional Cobb-Douglas production function, a search on the number of days between planting and harvest was done to determine when the potato crop reaches its highest potential yield. This will enable us to test the hypothesis that beyond some point, a yield plateau is attained (as in the von Liebig "law of the minimum" for crop yield response to plant nutrients). The results showed an increasing yield growth during the first 160 days of the crop period, at

$$ln\ Q = \alpha_0 + \Sigma\alpha_i\ ln\ X_i + \Sigma\delta_i\ D_i + \beta_1\ HDAP + \beta_2\ HDAP{*}HD + \mu,$$

where X's are production inputs (except for HDAP) and D_i's are dummy variables as described before and an additional dummy, *HD*, is created: HD=1 if number of days between planting and harvest is more than 160 days; 0 otherwise.

The Cobb-Douglas function was estimated twice: one similar to the pesticide form and one with an interaction between the harvest timing variable and the dummy. This interaction was done to determine if the data conform with the von Liebig hypothesis. In the harvest timing case, the variables were also scaled by their means except for the HDAP variable. The harvest timing variable was not scaled because the functional forms using variables in logarithmic form are not independent of scaling when they interact with a dummy variable. To show the effect of scaling on variable HDAP that interacts with the dummy variable, let the production function be

$$\ln Q = \alpha_0 + \alpha_1 \ln HDAP + \alpha_2 HD{*}\ln HDAP$$

where both Q and *HDAP* are not scaled by their means and *HD* is the dummy variable described above. Let k_q *and* k_h be the means of Q and *HDA*P, respectively; then scaling the variables by their means, we get the function

$$\ln (q/k_q) = \alpha_0 + \alpha_1 \ln (HDAP/k_h) + \alpha_2 HD{*}\ln(HDAP/k_h),$$

$$\ln q - \ln k_q = \alpha_0 + \alpha_1 \ln HDAP - \alpha_1 \ln k_h + \alpha_2 HD{*}\ln HDAP - \alpha_2 HD{*}\ln k_h.$$

From this, it can be seen that collinearity could be serious.

To determine the functional form for harvest timing, HDAP variable will be treated as the "damage control" variable in the respective exponential and logistic specifications:

$$G(X) = \ln(1 - \exp(\mu - \beta HDAP)) \qquad (10)$$

(11) $$G(X) = -\ ln(1 + exp(\mu - \beta HDAP)).$$

The production functions obtained by substituting (10) or (11) into (7) must be estimated by nonlinear methods since the abatement functions (10) and (11) are nonlinear in the parameters. The same restriction and estimation as in the pesticide functional form will be used here.

Estimated coefficients for the Cobb-Douglas model, exponential and logistics specifications are shown in table 5. The coefficients, standard error (in parenthesis), and statistics for the quadratic function are given below:

$$Q = \underset{(1.6426)}{0.7434} + \underset{(0.6699)}{0.3383}*PL - \underset{(0.4203)}{0.1447}*HL + \underset{(0.5798)}{0.5719}*FR + \underset{(0.6645)}{0.0093}*FUN$$

$$- \underset{(0.2353)}{0.3019}*INS - \underset{(0.0174)}{0.0051}*HDAP - \underset{(0.1415)}{0.0512}*PL^2 + \underset{(0.0703)}{0.1189}*HL^2 + \underset{(0.1404)}{0.0184}*FR^2$$

$$- \underset{(0.1148)}{0.1585}*FUN^2 - \underset{(0.0110)}{0.0132}*INS^2 + \underset{(0.00005)}{0.00002}*HDAP^2 - \underset{(0.1562)}{0.0067}*PL*HL$$

$$+ \underset{(0.2119)}{0.0675}*PL*FR + \underset{(0.1653)}{0.0755}*PL*FUN + \underset{(0.0783)}{0.0165}*PL*INS - \underset{(0.6068)}{0.0025}*PL*HDAP$$

$$- \underset{(0.1466)}{0.1386}*HL*FR + \underset{(0.1105)}{0.1598}*HL*FUN - \underset{(0.0381)}{0.0248}*HL*INS + \underset{(0.0022)}{0.0003}*HL*HDAP$$

$$- \underset{(0.2071)}{0.0624}*FR*FUN + \underset{(0.0718)}{0.1488}*FR*INS - \underset{(0.0034)}{0.0023}*FR*HDAP - \underset{(0.0513)}{0.0378}*FUN*INS$$

$$+ \underset{(0.0033)}{0.0018}*FUN*HDAP + \underset{(0.0013)}{0.0016}*INS*HDAP - \underset{(0.0960)}{0.1359}*DZ1 - \underset{(0.0776)}{0.1246}*DZ2$$

$$+ \underset{(0.0737)}{0.0518}*DZ3 + \underset{(0.0928)}{0.1711}*PS2 + \underset{(0.0995)}{0.0879}*PS3$$

$d.f. = 182$ $R^2 = 0.3681$ $Adj.\ R^2 = 0.2570$ $SSE = 17.8661$

The elasticity of harvest timing is presented in table 6. Of particular interest here, the estimates using the exponential and logistic specifications are twice the value of estimates using the Cobb-Douglas or the quadratic functions. These estimates may be true at some point beyond the mean harvest timing. Theory in chapter 3 shows that farmers tend to harvest their crop where $\partial q/\partial t > 0$, points where estimates obtained by using the Cobb-Douglas, quadratic, exponential, and logistic functional forms would be very close.

To discriminate which harvest timing functional form fits the data well, the J-test and the AIC were also performed. Tables 8 and 9 shows the value of the J-test and the AIC statistics. Both tests reveal that the quadratic function is favored over the other functional forms.

Chapter 5

SUMMARY AND CONCLUSIONS

Various functional forms have been used in many production analyses, particularly in estimating marginal productivity of inputs. The most popular functional form that is widely used in most studies is the Cobb-Douglas production function. In 1986, Lichtenberg and Zilberman introduced the concept of damage control processes and argued that correct specification of the damage abatement function is important in the estimation of production functions and inputs productivity. Empirical studies investigated the damage abatement specifications, showing that the use of a standard Cobb-Douglas function overestimates the marginal productivity of pesticides. These studies, however, did not consider other functional forms, including flexible functional forms like the quadratic. To accurately assess the value of pesticides, one should examine a large variety of functional forms, including flexible functional forms, using field level data.

This study examines functional forms that can be used to estimate the productivity of pesticides and harvest timing. The preceding chapter shows that the marginal productivity estimates of the different functional forms are not significantly different. This result implies that functional specification does not matter in the case of Ecuadorian potato production. It is shown, therefore, that the conclusions raised by Babcock, et. al., and even by Carrasco-Tauber and Moffit, are not universally true.

Lichtenberg and Zilberman argue that the estimated curve would be like the one shown in Figure 1. A criticism of the Lichtenberg and Zilberman argument is that, if farmers are rational and risk-neutral, they will be observed on average producing where the value of marginal product of an input equals its cost. Any function that can approximate the true function well in a neighborhood of the mean will give about the same estimate of mean marginal product. Thus, an alternative to the Lichtenberg and Zilberman's hypothesis is that, at the mean, all of the functional forms produce approximately the same value (as illustrated in Figure 6).

Among the functional forms tested, the quadratic function is most preferred. Although it may not satisfy the restriction of homogeneity or homotheticity, it displays a non-unitary elasticity of substitution, parsimony in parameters and has more flexibility. The flexibility of this functional form appears to best approximate an unknown function.

The insignificance of functional specification for Ecuadorian potato production does not necessarily imply that functional specification is inconsequential for other production data. Rather, this finding shows that it is important to consider a variety of functional forms to ensure that the choice of functional form is not biasing the results. These findings do suggest, however, that if the purpose of a study is to estimate the marginal productivity and elasticity of inputs at its mean level, then the choice of the functional form may not matter. Various models will, however, yield different estimates at points far from the mean.

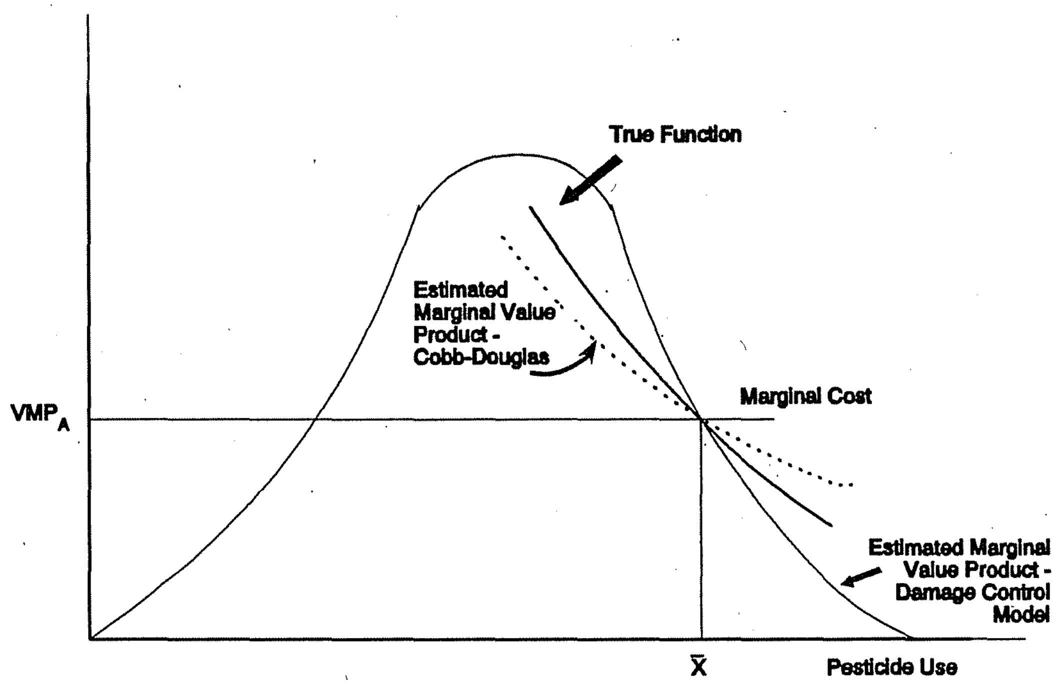

Figure 6

Damage control agent productivity estimates

There are many alternative functional forms that exist for reflecting the relationship between the production inputs and output. Therefore, future studies should test and compare a variety of functional forms to discriminate between the alternative functional forms that best fit the data and come up with a reliable result. Using a functional form that imposes arbitrary restrictions should be avoided and thus, testing the validity of using such functional forms against other functions should be performed. However, if comprehensive testing of model specification is not undertaken, then a flexible form (like the quadratic function) should be used over a restrictive form such as the Cobb-Douglas function or the exponential function.

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APPENDIX

Table 1 . Factors influencing the growth of potato crop.

LONG CYCLE CROP	SHORT CYCLE CROP
Long day	Short day
High Temperature	Low temperature
Low Light Intensity	High light intensity
Physiologically young seed	Physiologically old seed
Low plant density	High Plant density
Heavy nitrogen dressing	Light nitrogen dressing
Liberal moisture supply	Restricted moisture supply

Source: Beukema and Van der Zaag

Table 2. Yield and yield reduction on different harvest dates of two types of potato crop.

Harvest date	short cycle crop			long cycle crop		
	Yield (t/ha)	yield reduction compared with		Yield (t/ha)	yield reduction compared with	
		potential yield	next harvest		potential yield	next harvest
August 1	26	11.5	5	19	27	7
August 10	31	6.5	4	26	20	7
August 20	35	2.5	2	33	13	6
Sept. 1	37	0.5	0.5	39	7	4
Sept. 10	37.5	-	-	43	3	3
Sept. 20	37.5	-	-	46	-	-

Source: Beukema and Van der Zaag.

Table 3. Summary Statistics of the variables used.

Variable	Mean	Std Dev	Minimum	Maximum
Output	2405640.77	874423.59	763602.22	5003424.00
Fertilizer	641.91	263.61	135.86	2355.40
Insecticides	280053.75	379754.11	11674.07	2284739.04
Fungicides	53556.37	25300.08	14502.53	164783.04
Preharvest Labor	109.47	48.74	29.65	346.16
Harvest Labor	53.23	30.92	2.00	141.66
Number of days from planting until harvest	185.54	20.89	132.00	261.00
Zone dummy 1	0.11	0.31	0	1
Zone dummy 2	0.30	0.46	0	1
Zone dummy 3	0.45	0.50	0	1
Zone dummy 4	0.08	0.27	0	1
% native variety	0.10	0.25	0	1
% local variety	0.54	0.46	0	1
% national variety	0.36	0.43	0	1
Parcel area in hectare	0.64	0.66	0.05	4.05
Insecticide Cost shares	0.08	0.04	0.01	0.33
Fungicide Cost Shares	0.15	0.05	0.05	0.32

Number of observations = 215

Source: Parcel-level survey data for Ecuador Potato Production, International Potato Center, Ecuador.

Table 4. Estimates of Pesticide functional forms for Ecuadorian Potato Production.

Coefficient	Parameter estimates using:		
	Cobb-Douglas	Exponential	Logistic
Constant	-1.1595 (0.1109)	-0.0457 (0.1349)	-0.0461 (0.1327)
Preharvest Labor	-0.1012 (0.0693)	-0.0929 (0.0692)	-0.0934 (0.0691)
Harvest labor	0.0932* (0.0291)	0.0971*** (0.0291)	0.0972*** (0.0291)
Fertilizer	0.1416** (0.0697)	0.1422** (0.0697)	0.1422** (0.0696)
Fungicides	0.1115* (0.0629)		
Insecticides	0.0416* (0.0228)		
Harvest days after planting	0.4772* (0.2447)	0.4180* (0.2459)	0.4167* (0.2457)
Dummy for zone 1 (DZ1)	-0.0957 (0.0985)	-0.1159 (0.0994)	-0.1166 (0.0994)
Dummy for zone 2 (DZ2)	-0.0662 (0.0795)	-0.0826 (0.0797)	-0.0831 (0.0797)
Dummy for zone 3 (DZ3)	0.0684 (0.0751)	0.0546 (0.0752)	0.0538 (0.0752)
% of improved local variety	0.2068** (0.0966)	0.2059** (0.0965)	0.2055** (0.09645)
% of national variety	0.1349 (0.1015)	0.1265 (0.1011)	0.1263 (0.1011)
μ_f[a]		-0.8906 (0.9983)	-0.6113 (1.1172)
β_f		2.4156 (2.7619)	2.7011 (2.8789)
μ_i		-1.5518 (0.4359)	-1.3403 (0.5176)
β_i		2.6149 (2.5075)	2.9541 (2.7211)
R^2	0.2526	0.2663	0.2667
df	203	201	201
SSE	23.1549	22.7315	22.7188

[a] Damage control coefficients correspond to those shown in equations (8) and (9) of the text.

***, **, * Significant at 1%, 5%, and 10% level, respectively.

Figures in parenthesis are standard error.

Number of observations = 215

Table 5. Estimates of Harvest-Timing functional forms for Ecuadorian Potato Production.

Coefficient	Parameter estimates using:			
	Cobb-Douglas	CD w/ dummy	Exponential	Logistic
Constant	-2.6505** (1.3004)	-3.7395** (1.4727)	1.446 (24.6638)	-0.2843 (2.4656)
Preharvest Labor	-0.1012 (0.0693)	-0.1036 (0.0690)	-0.1014 (0.0695)	-0.1014 (0.0695)
Harvest labor	0.0932*** (0.0291)	0.0921*** (0.0290)	0.0932*** (0.0292)	0.0932*** (0.0292)
Fertilizer	0.1416** (0.0697)	0.1365* (0.0695)	0.1415** (0.0699)	0.1416** (0.0699)
Fungicides	0.1115* (0.0629)	0.1174* (0.0629)	0.1116* (0.0631)	0.1114* (0.0631)
Insecticides	0.0416* (0.0228)	0.0459** (0.0229)	0.0418* (0.0230)	0.0417* (0.0229)
Harvest days after planting (HDAP)	0.4772* (0.2447)	0.7162** (0.2882)		
HDAP*D1		-0.0291 (0.0187)		
Dummy for zone 1 (DZ1)	-0.0957 (0.0985)	-0.1075 (0.0985)	-0.0962 (0.0993)	-0.0954 (0.0993)
Dummy for zone 2 (DZ2)	-0.0662 (0.0795)	-0.0753 (0.0794)	-0.0667 (0.0805)	-0.0659 (0.0805)
Dummy for zone 3 (DZ3)	0.0684 (0.0751)	0.0622 (0.0749)	0.0679 (0.0755)	0.0682 (0.0755)
% of improved local variety (PS2)	0.2068** (0.0966)	0.1970** (0.0965)	0.2067** (0.0969)	0.2070** (0.0969)
% of national variety (PS3)	0.1349 (0.1015)	0.1169 (0.1018)	0.1342 (0.1030)	0.1351 (0.1031)
μ^a			-0.1388 (3.1580)	0.7690 (1.0836)
β			0.00096 (0.0326)	0.0073 (0.0329)
R^2	0.2526	0.2615	0.2527	0.2528
df	203	202	202	202
SSE	23.1549	22.8806	23.1521	23.1491

[a] Damage control coefficients correspond to those shown in equation (10) and (11) of the text.

***, **, * Significant at 1%, 5%, and 10% level, respectively.

Figures in parenthesis are standard error.

Number of observations = 215

Table 6. Estimated Production Elasticities* for Ecuadorian Potato Production.

Inputs	Cobb-Douglas	Cobb-Douglas with dummy	Quadratic	Damage Control	
				Exponential	Logistic
Fungicides	0.1115	0.1174	0.1555	0.0919	0.0949
Insecticides	0.0416	0.0459	0.0671	0.0412	0.0398
Harvest days after planting	0.4772	0.7162[a] / 0.6871[b]	0.3525	1.1875	0.9277

* Based on parameter estimates in Tables 4 and 5 and in the text.
[a] Elasticity for farmers whose HDAP ≤ 160.
[b] Elasticity for farmers whose HDAP > 160.
Note : Computation of elasticities for:

Quadratic :

$$\epsilon=(\alpha_0+\alpha_1\bar{Z}+2\alpha_2\bar{X})\frac{\bar{X}}{\bar{Q}}$$

Exponential :

$$\epsilon=\frac{\beta\exp(\mu-\beta\bar{X})}{1-\exp(\mu-\beta\bar{X})}\bar{X}$$

Logistic :

$$\epsilon=\frac{\beta\exp(\mu-\beta\bar{X})}{1+\exp(\mu-\beta\bar{X})}\bar{X}$$

where

α_0, α_1, α_2 are coefficients from the quadratic function
μ, β are damage control coefficients from exponential and logistic functions
$\bar{X}$ and $\bar{Q}$ are input and ouput means, respectively.

Table 7. J-test for Pesticide Functional forms for Ecuadorian Potato Production.

Ho:	Ha:			
	Cobb-Douglas	Quadratic	Exponential	Logistic
Cobb-Douglas	-	0.9181*** (0.1636)	2.1811** (0.9143)	2.1661** (0.8955)
Quadratic	1.4269* (0.7879)	-	0.9547* (0.5306)	0.9591* (0.5287)
Exponential	-4.8898** (2.4782)	DNC	-	DNC
Logistic	-4.4903* (2.3087)	0.8968*** (0.1682)	DNC	-

***,**,* Significant at 1%, 5%, and 10% level, respectively

DNC Did not converge

Figures in parenthesis are standard error.

Table 8. J-test for Harvest-timing Functional forms for Ecuadorian Potato Production.

Ho:	Ha:				
	Cobb-Douglas	Cobb-Douglas w/ dummy	Quadratic	Exponential	Logistic
Cobb-Douglas	-	2.5651***	0.92***	4.23^{ns} (17.5139)	39.27^{ns} (39.0843)
CD w/ dummy	2.5651***	-	0.90*** (0.1636)	-21.27^{ns} (22.4242)	1.59^{ns} (50.3919)
Quadratic	1.43* (0.7879)	1.11** (0.5576)	-	1.43* (0.7875)	1.43* (0.7878)
Exponential	DNC	DNC	DNC	-	DNC
Logistic	95.43^{ns} (62.1887)	DNC	DNC	-227.08^{ns} (143.4169)	-

***, **, * Significant at 1%, 5%, and 10% level, respectively

DNC Did not converge

Figures in parenthesis are standard error

Table 9. Statistical identification of specifications using R^2, Adjusted R^2, and Akaike Information Criterion (AIC).

Functional Form	Pesticide			Harvest timing		
	R^2	Adj R^2	AIC	R^2	Adj R^2	AIC
Cobb-Douglas	0.2526	0.2121	25.8894	0.2526	0.2121	25.8894
Cobb-Douglas w/ dummy				0.2615	0.2176	25.8219
Quadratic	0.3681	0.2570	24.2855	0.3681	0.2570	24.2855
Exponential	0.2663	0.2188	25.8933	0.2527	0.2083	26.1282
Logistic	0.2667	0.2193	25.8788	0.2528	0.2084	26.124