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Alternative measures of productivity for four United States field crops

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ALTERNATIVE MEASURES OF PRODUCTIVITY FOR FOUR UNITED STATES FIELD CROPS

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Alternative measures of productivity for four United States field crops

by

Chang-Fu Wanglian

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CHAPTER I. INTRODUCTION

Agricultural economists have been concerned about whether or not there has been a recent plateau in crop production. Groosen (1979) suggested that growth in total agricultural productivity has begun to decline and while yields slackened off in the mid-1970s, weather also had not been as favorable as in the 1960s. Ruttan (1979) posed the possibility of a productivity lag paralleling that of 1895-1925 due to relatively high energy prices. Wittwer (1977) fluctuated between pessimism and optimism. While, he suggested that crop yields have plateaued. however, he also stated "far from achieving scientific and biological limits the world has only begun to explore the capabilities of increasing agricultural production". Heady (1980) optimistically stated that the limits to yield growth were not yet quantitatively apparent in developed countries and it was possible that other technologies could allow these high yields to be attained economically within the developing framework of resource scarcities and prices. Menz and Pardey (1983) examined the recent historical data (1954-80) on U.S. corn yields and concluded that no plateau has yet been reached.

Most of the recent doubts about the ability of field crops to sustain their growth rates have been based on observations on yields per acre. Obviously, these studies are somewhat misleading since yields per acre is not a good indicator of the limits on production. Yields per acre also change when other factors of production change. When discussing the existence of a yield plateau, the technological limits of production on an acre of land rather than the market results of producer behaviors are considered. To understand the limits to increasing production in a economic manner, the growth rate of total factor productivity rather than partial productivity measures is more relevant. Unfortunately, few studies have been done on the measurement of total factor productivity for field crops. The first purpose of this study, therefore, is to measure the changes in total factor productivity for four crops: corn, cotton, soybeans and wheat in the United States. The results of the study will provide information on the existence of an economic plateau in crop production. The second purpose of the study is to compare productivity changes among these four crops. Since the growth rates of production as well as the growth rates of prices on these crops have varied over time, one may want to know if the factors used in the production of these different crops have also varied in their efficiency over time.

The next section will show some evidence on changes in production, prices and yields per acre for corn, cotton, soybeans and wheat. Some of the questions raised from these changes will also be discussed. The next section of this chapter will briefly outline the objectives of the study, while some of the data problems faced in measuring productivity will be discussed in the fourth section. Finally, an outline of the study is given in the last section.

Historical Evidences on Crop Production

During the past three decades (1949-1982), the production growth rates of corn, cotton, soybeans and wheat in the United States are quite different. As shown in Table 1-1, the average annual growth rates of the production for corn, cotton, soybeans, and wheat are 3.24%, -0.68%, 6.76%, and 2.63%, respectively, over the period. Figure 1-1 shows these changes in crop production. During the period, the production of soybeans has grown rapidly while the production of cotton declined slightly. For the same period, moderate growth in corn and wheat production has been recorded.

An understanding of the factors that cause the growth rates of crop production to differ between crops is important in developing economic policies to encourage optimal use of society's resources. There are two major forces that cause production changes. One force is demand-pull, the other is supply-push. Demand-pull changes result when an increase in demand shifts the demand curve up causing the price of the crop to go up. The rise in price motivates producers to use more inputs and hence produce more output. The forces of supply-push are threefold. Firstly, when changes in input prices cause the usage of inputs to change and, thus, bring about changes in crop production. Secondly, technical change in the production process allows output to increase even with the same combination of inputs. Thirdly, uncertain factors such as weather, disease, etc. also affects the level of supply. Thus production may be larger or smaller due to changes in weather conditions with no real changes in input prices or the underlying

TABLE 1-1. The Growth Rates of Some Variables Relating to Crop Production (1949-1982)[a]

Crop	period		
	1945-1965 %	1966-1982 %	1949-1982 %
Corn :			
production	2.553	4.163	3.398
yield/acre	4.387	2.188	3.407
acres harvested	-1.834	1.975	-0.008
price	-2.258	6.185	2.230
Cotton :			
production	0.407	1.408	-0.653
yield/acre	4.483	0.393	1.523
acres harvested	-4.075	1.015	-2.181
price	-0.781	7.267	1.781
Soybeans :			
production	7.793	5.428	6.715
yield/acre	1.261	1.175	1.271
acres harvested	6.532	4.252	5.444
price	-0.250	7.098	3.722
Wheat :			
production	1.210	4.221	2.809
yield/acre	3.705	1.415	2.340
acres harvested	-2.495	2.801	0.468
price	-1.860	7.313	1.765

[a]The annual growth rate is calculated by estimating the regression of $\ln x = a + bt$, where x is the dependent variable and t is a trend of time. All growth rates in the following tables in the study have the same meaning.

technology.

To examine the force of demand-pull factors, comparative price changes for the four crops are shown in Table 1-1, and Figure 1-2. The changes in price among the different crops are not as large as the

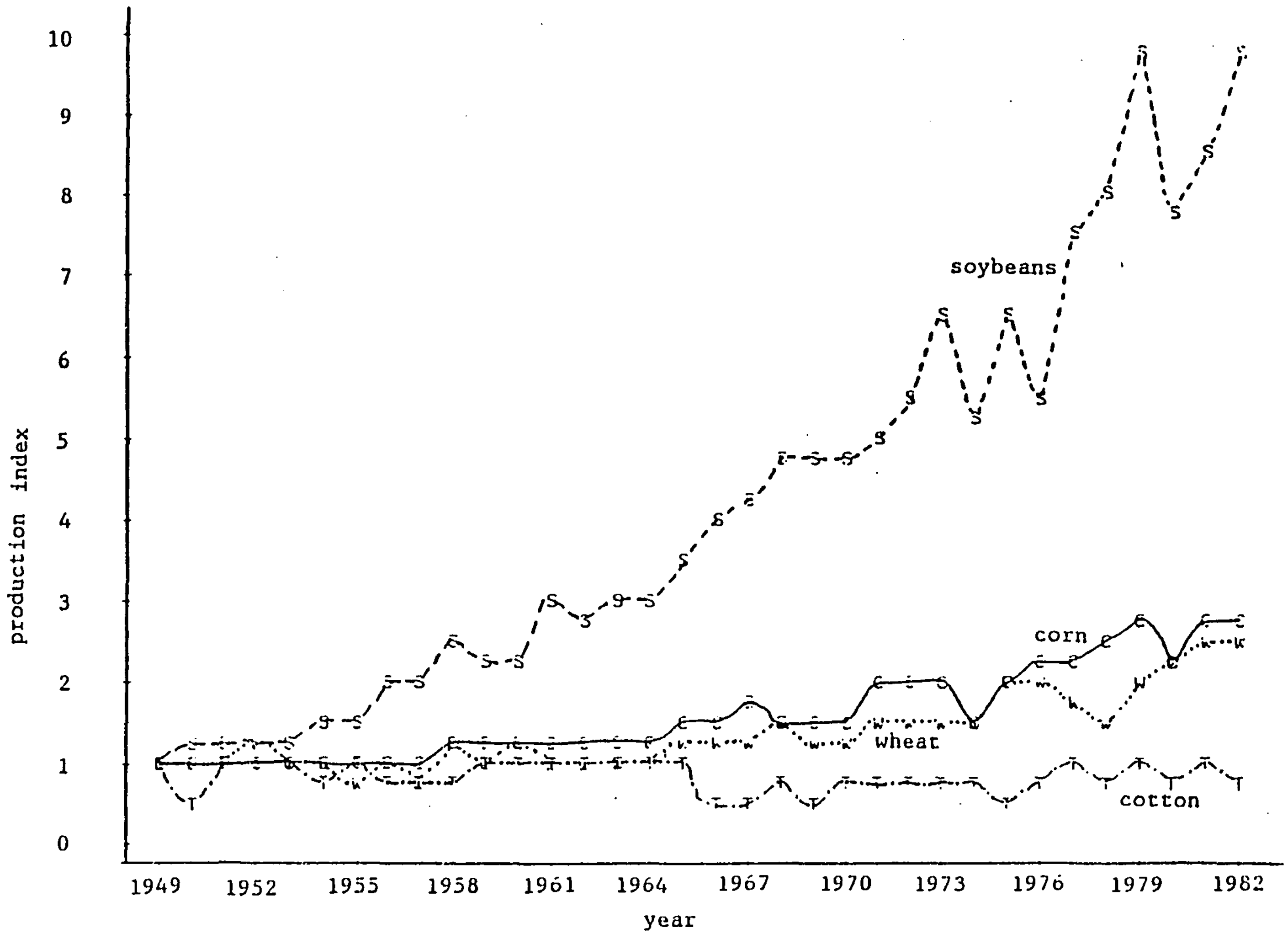

FIGURE 1-1. Changes in Production for Four U.S. Field Crops (1949-1982)

5

production changes. Although differences in the growth rates of prices among the four crops are similar to the growth rates of production, the correlations between price and production growth rates differ significantly. Table 1-2 shows the correlation between price and production for these four crops. It shows that soybeans has the highest correlation while cotton has the lowest correlation. This evidence implies that production growth might have been influenced by demand-pull factors in differing degrees. For some crops the force of demand-pull seems to be strong, while for others it is weak.

TABLE 1-2. Price and Production Correlations for Four Field Crops (1949-1982)

	production			
	wheat	soybeans	corn	cotton
wheat price	0.71832	-	-	-
soybean price	-	0.72117	-	-
corn price	-	-	0.60895	-
cotton price	-	-	-	0.27398

To analyze the forces of supply-push, one should first examine changes in the land used in producing these crops. Figure 1-3 shows comparative changes in the acres harvested for these four crops. Except for soybeans, which has a positive and high growth rate in land use, the land used in other crops do not change much or suffers a slight decline during the period. Eliminating the effects of changes in the land input

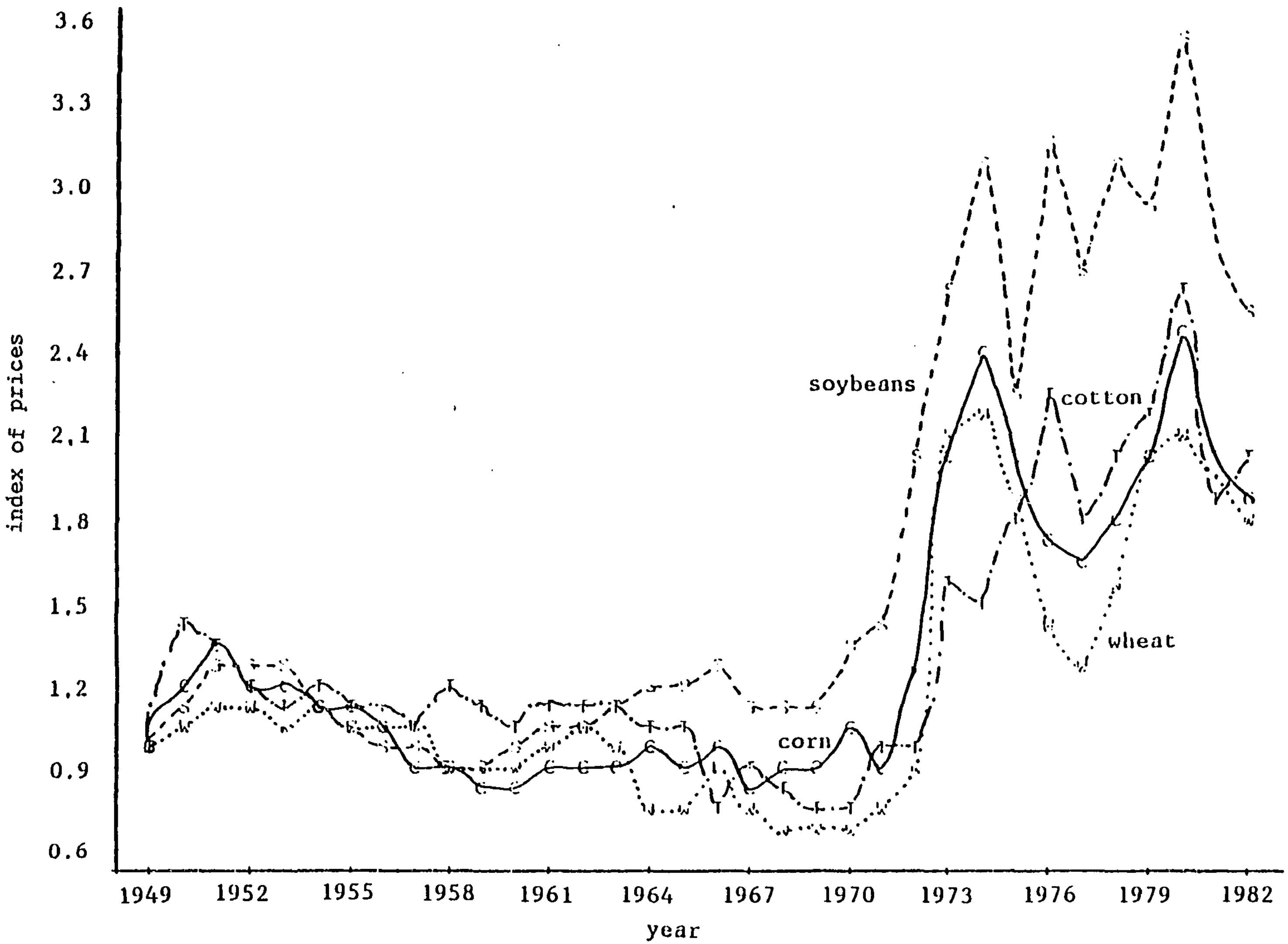

FIGURE 1-2. Changes in Price for Four U.S. Field Crops (1949-1982)

used, Figure 1-4 shows the changes in yields per acre for the crops. The growth rates of the yields of the crops under consideration shows somwhat different phenomenon when compared with the observations made in production data. Corn becomes the highest growth rate crop while cotton remains the lowest one. These differences growth rates of yields per acre may also be due to different usages of other inputs such as capital, labor, fertilizer, etc. One of the main purposes of this study is to examine the effects of these other inputs on production. This will require a method to measure that portion of production growth that is attributed to the growth of inputs as a whole. Once the growth due to input use can be determined, the residual growth factor which is due to technological change and stochastic factors can be determined. This residual measure of productivity growth is called total factor productivity. Since the stochastic factors average out in the long run, the changes in this factor over a long time period can be used to measure technical change.

Objectives of The Study

The objectives of this study are twofold.

1. To measure productivity changes in the production of corn, cotton, soybeans and wheat.

   Since productivity changes are one of the factors that lead to increases in production, the accurate measurement of productivity change can improve our understanding of changes in total output.

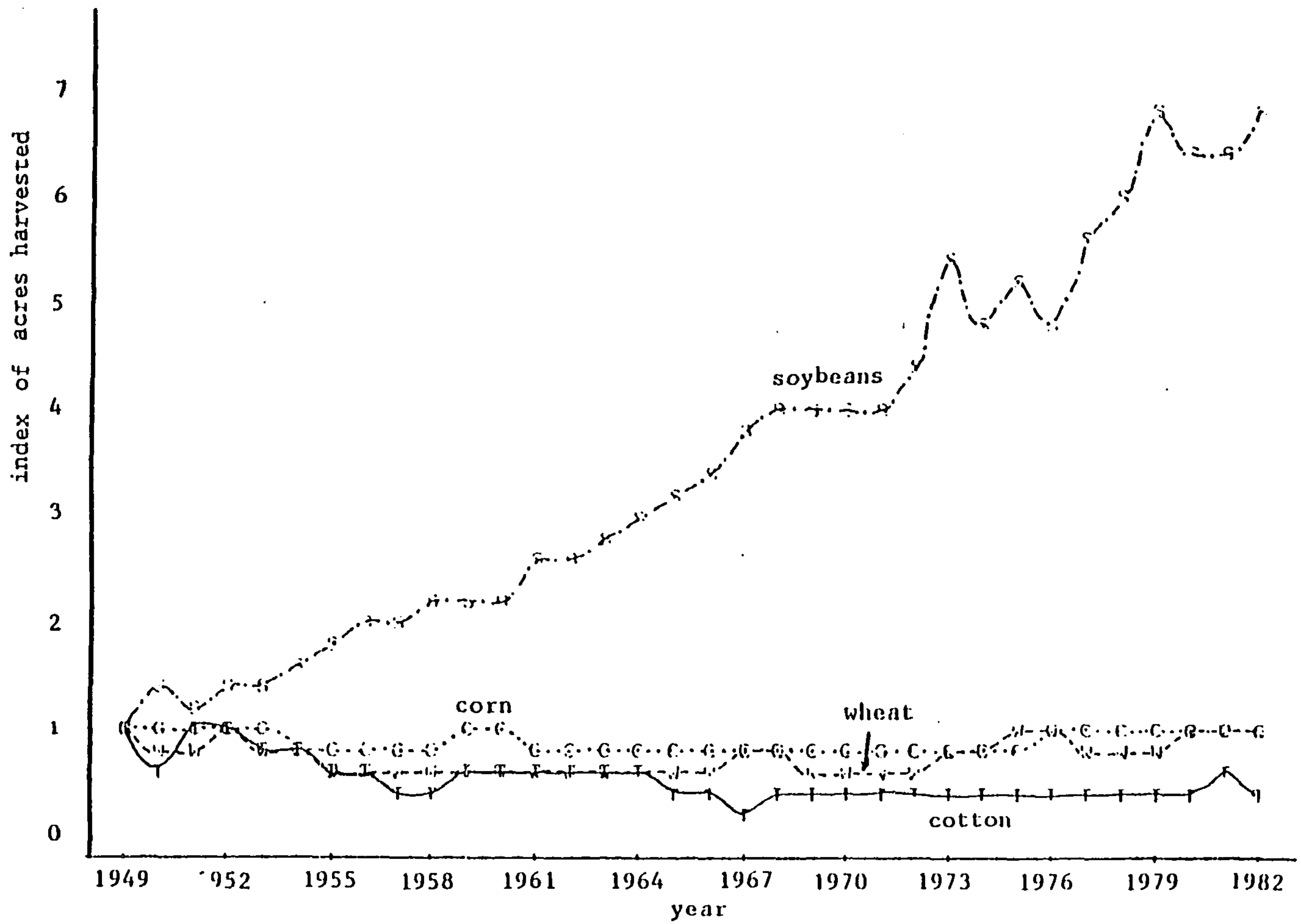

FIGURE 1-3. Comparison of Harvested Acres for Four Field Crops(1949-1982)

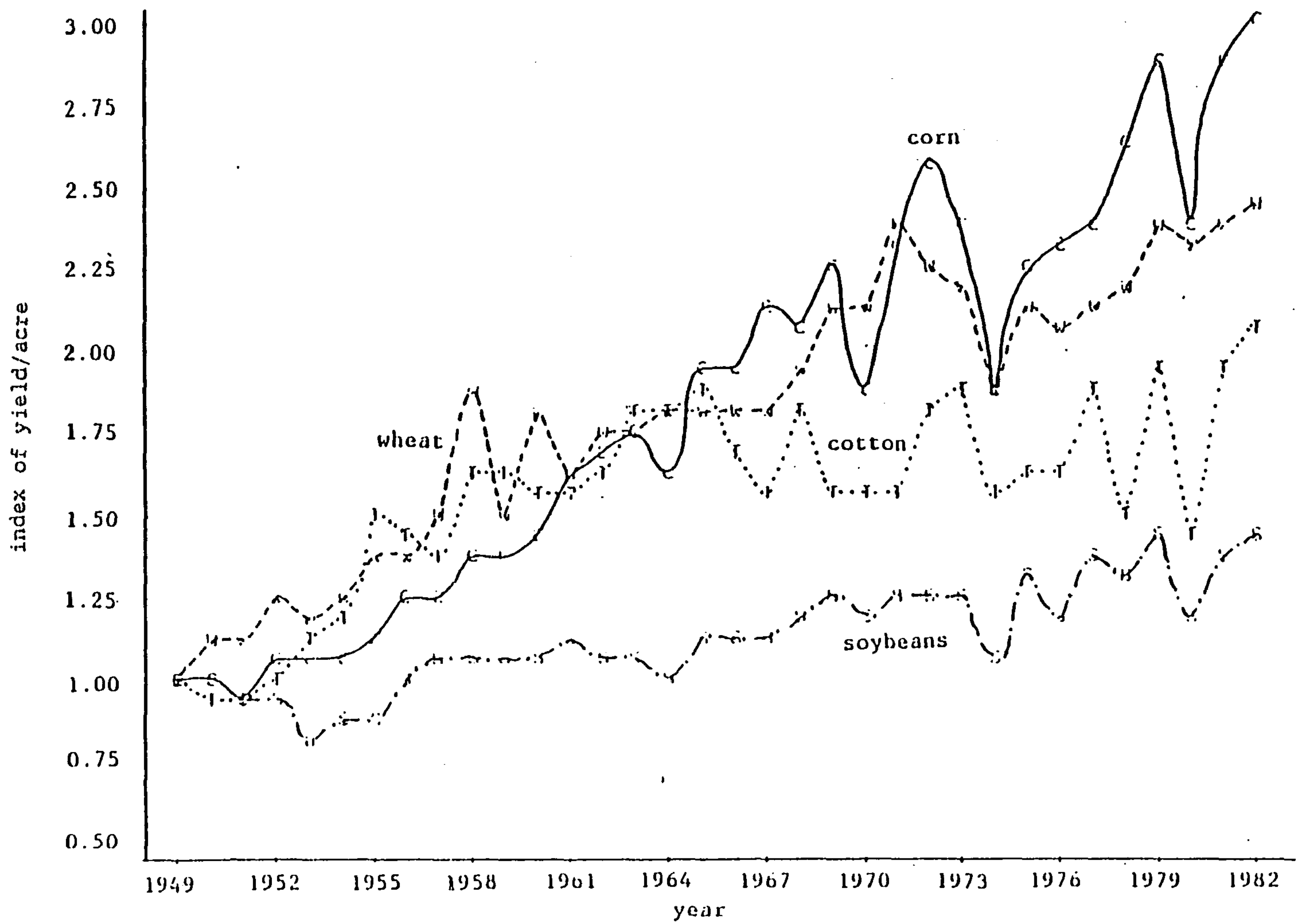

FIGURE 1-4. Comparison of yield/acre for Four Field Crops (1949-1982)

2. To compare productivity changes among the four crops.

While the first objective of this study is to measure the physical productivity change for each of the individual crops, the second objective is to measure the absolute level of productivity change for the individual crops. While physical productivity measures are useful for comparing the growth of productivity changes in different time periods and in different areas they cannot be used to compare different crops since the units of output are different. Absolute measures may be used to compare technical changes between crops. As the units and value of the outputs are different among crops, the absolute productivity measure will include the prices of outputs and inputs. Absolute measures will also have some welfare significance as explained in Chapter II.

Problem Statement

Measurement of total factor productivity

One of the most neglected subjects in agricultural economics is the study of total factor productivity for individual crops. Though there are many different methods in the economic literature that can be used to measure the total factor productivity of production, most of them are not adequate when applied to the measurement of productivity change for individual crops. This inadequacy results because the data which are required to calculate these proposed indicators are almost always unavailable.

The input allocations of labor, capital and fertilizer to individual crops are usually not available. Also, the total costs of production or profit levels for the major crops are not reported in standard agricultural time series data. These data are not available because most farmers usually don't record input allocations among crops they grow. Some authors (Thirtle 1985) have attempted to construct allocation data by using engineering estimates of input requirements for the various crops and then dividing up total use among the major users. This procedure, however, ignores difference in production requirements across time and space and optimal input allocations as prices changes. In order to measure total factor productivity on individual crops, this study will present a model, based on the basic optimizing behavior of producers, to overcome the shortage of input allocation data. This model will use the fundamental duality between the production function and supply and demand equations to estimate production parameters using price data.

Comparing productivity changes among crops

When comparing productivity changes among different products, it is unavoidable that the value of outputs and inputs should be used. Physical productivity change as discussed above is not a good indicator to use when comparing productivity changes among crops, because the value and units of outputs are different. Most works in economics use index methods to compare absolute productivity levels between products or countries (Baumol and Wolff (1984), Denny (1984)). This study will criticize these indicators in that some of them neglect changes in the value of outputs and inputs, while others, while reflecting value changes lose connection with changes in physical productivity.

This study will develop a model to overcome those two problems. The model in the study can be used to estimate not only physical productivity changes but also current changes in the value of output and inputs. Furthermore, the model also can be estimated when some input data are unavailable.

Outline of the Study

There are different approaches, based on different purposes, to measure the productivity levels of a product. This study catalogues them into the partial productivity approach and total factor productivity approach. In measuring total factor productivity, there are also several different measures. This study again classifies them into three approaches. They are the production function approach, the duality theory approach, and the index approach. All of these approaches are briefly introduced in Chapter II. Applications of these approaches are proposed, and the advantages and disadvantages of these approaches are discussed.

Chapter III develops a methodology for the measurement of total factor productivity changes for individual crop. Particular emphasis is given to the measurement of total factor productivity when some of the input quantities and prices are unavailable.

In Chapter IV, a model which can be used to measure the absolute productivity level of a sector will be developed. Based on some economic assumptions, both the market value of outputs and inputs and physical productivity are considered in the model.

Chapter V discusses the econometric estimation of total factor productivity for the four field crops following the model developed in Chapter III. The economic implications of this model and comparisons with other studies are also presented.

Chapter VI presents estimates of absolute productivity indices for the four crops following the methodologies developed in Chapter IV. Comparisons between absolute productivity indices and physical productivity measures are given for each of the four crops. The economic implications of absolute productivity are also discussed.

The last chapter first gives a brief summary of the work and then deals with some of the limitations of the model proposed in the study. Possible directions for future study are also proposed.

CHAPTER II. REVIEW OF THE LITERATURE

Measures of Productivity

To some users, the meaning of productivity is output per man-hour; to others, it is crop production per acre; and still to others, it is output per unit of total input in production. Because of this diversity of definitions, productivity is measured by different methods. In the literature, there are two main types of productivity measures, --partial productivity and total factor productivity (TFP) measures. The ratio of output to the quantity of a single input is called the partial productivity of that input and the ratio of output to all inputs combined is called total factor productivity or multifactor productivity. Let Y, K, L,and N represent output, capital input, labor input and land acreage input, respectively, for some crop. The partial productivity of this crop with respect to K, L and N, then, is Y/K, Y/L, and Y/N. As an example of total factor productivity, let the total inputs used be combined using a weighted arithmetic average of all inputs. The weights can be denoted a, b and c where $a+b+c=1$. Then the total input is given by $I = aK + bL + cN$. With this total input, total factor productivity (Y/I) is Y/(aK+bL+cN).

It can easily be seen that the partial productivity indices defined above are related to this total factor productivity index:

$$Y/K = (Y/(aK+bL+cN))(a+(bL+cN)/K)$$

$$Y/L = (Y/(aK+bL+cN))(b+(aK+cN)/L)$$

$$Y/N = (Y/(aK+bL+cN))(c+(aK+bL)/N)$$

One can see also, that this index of total factor productivity may be viewed as the weighted average of the several partial productivity indices. The weights are the same as before, but the average is a harmonic rather than an arithmetic mean (Fabricant 1942):

$$TFP = Y/(aK+bL+cN) = 1/(\ a(K/Y) + b(L/Y) + c(N/Y)\ )$$

In this section, these two measures of productivity will be discussed and a review of their usage in measuring crop productivity will be given.

Partial productivity

Conventionally, measurement of productivity for crops has focused on partial productivity measures, especially on yield per acre. Heady and Auer (1965) analyzed nine crops, and estimated yield per acre increases due to variety improvements, fertilizer use and other crop technological variables. They found that the effects, aside from weather, were all interactively important in increasing production in the immediate postwar period. Heady (1980) used yield per acre as a measure to investigate whether or not there is a plateau in crop production. Rao and Chatigeat (1981) used the gross value of output per cultivated hectare and the gross value of output per cropped hectare as productivity indices to examine the relationship between size of land holdings and agricultural productivity. Pope and Heady (1982) used yield per acre as a criterion to analyze the importance of research and development, weather, and other technical variables in crop production. Menz and Pardey (1983) also used yield per acre to investigate technical change in corn production in the United States. Wiens (1983) assessed the short-run effects of the implementation of reforms in the price adjustment system and the responsibility system in China. The indicator used to represent agricultural productivity was also per hectare yields.

Though yield per acre has an economic meaning as the average product of land, it is often misleading as a criterion of changes in economic efficiency. These shortcomings have been summarized by Heien (1983). "Historically, productivity series focused on one factor -- e.g., yield per acre, output per man hour, etc. As production and cost theory developed, the shortcomings of these partial productivity measures became evident. For example, yield per acre increases may be caused by increased use of hybrid corn, increased use of other factors, or scale effects. Furthermore, partial productivity measures have economic interpretation as average products, whereas factors are compensated in proportion to their marginal production."

Total factor productivity

Total factor productivity has been termed by Abramovitz (1956) "a measure of ignorance" and by Domar (1961) the "residual" which may be explained as "the effect of 'costless' advances in applied technology, managerial efficiency, and industrial organization (cost -- the employment of scarce resources with alternative uses -- is, after all, the touchstone of an 'input')." Solow (1957) summarized this line of thinking by conceptualizing total factor productivity changes as shifts in the production function over time, as distinct from movements along the production function attributable to increases in inputs.

Following these conventional definitions, total factor productivity, in this paper, is defined as the ratio of real output to real factor input. Real factor input is defined as a weighted average of the individual factors. The weights use are the relative shares of each input in the value of total input. If the production function has constant returns to scale and if the marginal rates of substitution are identified with the corresponding price ratios as implied by cost minimization, changes in total factor productivity using this input index may be identified with shifts in the production function (Jorgenson and Griliches, 1967). Using this definition, total factor productivity and technological change are synonymous terms.[1]

Recent studies on the measurement of total factor productivity use three approaches. They are the production function approach, the

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[1] This conceptionalization of productivity advanced as technological progress, while firmly linking productivity analysis with an underlying productivity theory, is not free of problems. Operating along a production-possibility frontier assumes the prevalence of technological efficiency (i.e., efficiency itself becomes part of the revealed technology). The empirical problems associated with this assumption are obvious. What if the production system measured is inefficient and thus "nonrepresentative" of the underlying technology? Suppose factors of production are employed wastefully because of incompetence, X inefficiencies (Leibenstein, 1966, 1975), bounded rationality (Simon, 1955), or expense-preference behavior. Changes in the degree of inefficiencies will affect a broadly defined technological change (Sudit and Finger, 1981). The shift of the production possibility frontier is also due to two factors. The most obvious factor is the combined growth of primary inputs and the realization of economies of scale and scope. A second set of factors includes the accumulation of technological knowledge, improved information, and reduced uncertainty (Hazilla and Kopp, 1984; Sato, 1983).

duality theory approach and the index approach. The first two approaches use econometric methods to estimate total factor productivity, while the last one calculates the total factor productivity by using index methods and raw data. In the subsections below, these three approaches to the measurement of total factor productivity are outlined, their applications in agriculture are briefly surveyed and the advantages and disadvantages of each are discussed.

<u>The production function approach</u> Let Y_t be the output produced by a farmer during period t and K_t, L_t, F_t, and N_t be capital input, labor input, fertilizer input and land input utilized during period t. Suppose that the farmer's technology can be represented by a production function G_t in period t. That is

$$(2\text{-}1) \quad Y_t = G_t(K_t, L_t, F_t, N_t)$$

Changes in total factor productivity in (2-1), then, are identified as the shifts in the production function or changes in the function G over time.

There are two common kinds of assumptions used when discussing shifts in the production function. One assumption is that the technological change is not embodied in inputs (disembodied technological change); that is the production function can be expressed as

$$(2\text{-}2) \quad Y_t = G(K_t, L_t, F_t, N_t \; t)$$

where t=1, 2,....,T is a variable representing the time trend and T denotes the numbers of periods for which the change of total factor productivity is measured. If the production function can be written

$$(2\text{-}2a) \quad Y_t = G(f(K_t, L_t, F_t, N_t), t)$$

then it is said to Hicks neutral. The practical implication of Hicks neutrality is that the ratio of the marginal products of any two inputs is independent of time (Lau, 1978). Using (2-2), a regression equation can be defined as below:

$$(2\text{-}3) \quad Y_t = G(K_t, L_t, F_t, N_t\ t)+ \text{error}$$

The unknown parameters which characterize G can then be estimated using time series data. Changes in the total factor productivity are estimated using the estimated relationships between output and the time trend variable. If linear regression is applied to the above equation Hicks neutrality will be implied.

A different assumption concerning technological change is that change is embodied in the inputs (embodied technological change). This assumption allows efficiencies of the inputs to change over time. The production function with embodied technological change is represented by

$$(2\text{-}4) \quad Y_t = G(A_{kt}K_t, A_{lt}L_t, A_{ft}F_t, A_{nt}N_t)$$

where A_{it}, i= k, l, f and n, are factor augmenting parameters which express the K, L, F and N inputs in efficiency unit. The idea is that because of changes in technology one unit of the input will now produce more output than previously holding everything else the same As an example; hybrid corn seed will yield more bushels per acre than the same number of kernels of a conventional seed. If all the A_{it}s are equal to each other over time, i.e., $A_{it}=A_t$, and G is homothetic so that G(X,t) = G(f(X,t),t) where X is the input vector, it is clear that equation (2-4) can be simplified to equation (2-2a) (Lau 1978, p. 204). This will then imply Hick's neutral technological change for this form (Hicks, 1964).

The estimation of the A_{it}s is a relatively difficult task. When there are only two inputs --capital and labor, the model can be estimated directly. Sato (1970) provided a method to estimate the growth rates of A_k and A_l.[2] Williams (1985) applied his method to estimate the extent of technological bias in an interregional context for U.S. manufacturing during the period 1972-1977. When the production function has more than two inputs, the primal direct approach to estimate the A_{it}s becomes very difficult. Binswanger (1974b) provided a method to estimate the A_{it}s by using the corresponding cost function. He applied this method to estimating agricultural technological changes in the United States between 1912 and 1968.

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[2] The rates of growth of the efficiencies of capital and labor are

$$\frac{\dot{A}_k}{A_k} = (s\,\frac{\dot{r}}{r} - \frac{\dot{y}}{y})/(s-1)$$

$$\frac{\dot{A}_l}{A_l} = (s\,\frac{\dot{w}}{w} - \frac{\dot{Z}}{Z})/(s-1)$$

where $\dot{A}_k = dA_k/dt$, $\dot{A}_l = dA_l/dt$, s is the elasticity of substitution, r and w stand for the prices of capital and labor inputs, and y = Y/K, Z = Y/L.

Obviously, a straight forward way to estimate productivity change is to estimate the production function directly. Jorgenson and Griliches (1967) pointed out that if the form of the production function is fully specified and this function can be observed at different times, productivity changes may be measured as the change in shift parameter in the production function over time.

But there are some limitations to estimating productivity by directly using a production function. USDA (1980) summarized three major difficulties using direct estimation. The first has to go with the functional form of the estimated production function. The popular Cobb-Douglas or CES production functions containing a shift term to represented productivity, may not accurately depict the production technology. Variable elasticity of substitution (VES), generalized Leontief, and transcendental logarithmic production functions have been used to partially solve these problems. Though each generalized form has contributed to the study of production, they all possess limitations in the study of productivity. A second problem is that even if the production function is correctly specified, the input coefficients in the production function represent a given state of technology. As technological changes take place, these coefficients will also change, unless technological change happens to be factor neutral. As a third consideration for practical purposes, the production function approach may not be a suitable device because input data over time are usually not available. Even when the input data are available, they may be correlated and make the estimation of the production function as well as productivity changes very difficult.

Many agricultural economists have used the production function approach to estimate total factor productivity changes in agriculture. Lianos (1971) used a CES production function to estimate the source of changes in the relative share of labor in the American agricultural sector. He found that the efficiency of capital is increasing faster than that of labor and that technological change in American agriculture has been labor saving. Lu (1975) studied changes in total factor productivity in U.S. agriculture by estimating a VES production function. He found that in the period 1939 - 1972, the Cobb-Douglas production function is the most appropriate form and that his results of measuring the total factor productivity in U.S. agriculture by econometric methods are not much different from the index estimated by USDA.

The duality theory approach Productivity changes can be interpreted as shifts in the production function. By the same logic, productivity changes could be viewed as shifts in the cost function. This follows directly from the fundamental duality relationship between cost and production. Since the profit function contains all the information provided by the cost function, the profit function can also be used to measure changes in productivity.

Assume the cost function is

$$C = C(Y, W, t) \qquad (2\text{-}5)$$

where C, Y are cost and output, respectively; W is a vector of input prices, $W=(W_1, \ldots, W_n)$; and t is a time trend denoting technological change. Also assume the cost function C has following properties:

(i) C is concave in W.

(ii) C is nondecreasing in W.

(iii) C is continuous.

(iv) C is linearly homogenous in W.

(v) C is nondecreasing in Y.

(vi) $\partial C/\partial W_i = X_i(Y, W, t)$

where X_i is input demand.

(vii) There in a convenient functional form for C.

If C has the above properties and all the data needed in equation (2-5) are available, by adding a error term to equation (2-5), one can estimate econometrically the unknown parameters of C. Once C has been determined, the change in total factor productivity ($\dot{T}/T$) is easily obtained as

$$\text{(2-6)} \quad \dot{T}/T = \partial \ln C(Y, W, t)/\partial t$$

The second dual approach to measuring technical change is the profit function approach. Assuming competitive profit-maximizing behavior in the output market as well as input markets, then the profit function is

$$\text{(2-7)} \quad \Pi = \Pi(P, W, t) = \text{Max}_{y,x}(P'Y - W'X : Y = f(X))$$

where P is the price of output Y and X is a vector of inputs. $X=(X_1, \ldots, X_n)$. The profit function has the following properties.

(i) convex in P and W.

(ii) linearly homogenous in P and W.

(iii) nondecreasing in P and nonincreasing in W.

(iv) continuous in P and W.

(v) Hotelling's Lemma

$$\partial \Pi / \partial P = Y(P, W, t)$$

$$\partial \Pi / \partial W_i = -X_i(P, W, t)$$

where Y(P,W,t) and $X_i(P,W,t)$ are supply function of Y and input demand function of X_i, respectively.

Similarly, one can estimate total factor productivity by

$$\text{(2-8)} \quad \dot{T}/T = \partial \ln Y(P,W,t)/ \partial t$$

Empirically, the translog function is the most popular functional form used to estimate both cost and profit functions in agricultural economics. Ball and Chambers (1982) examined the technology of the U.S. meat products industry. They estimated the translog cost function under various assumptions with annual time-series data for the period 1954-1976. They found that there exist economies of scale within the meat products industry and the potential for noncompetitive behavior. They also found that the rate of technical progress has apparently been negative. This indicates increasing average cost from technical change. Ray (1982) treated crops and livestock as two distinct outputs. He utilized a translog cost function with multi-products to measure the pairwise elasticity of substitution between inputs, the price elasticities of factor demands, and the rate of Hicks-neutral technical change. His results indicated a declining trend in the degree of substitutability between capital and labor. Price elasticity of demand for all inputs increased over time. The measured rate of technical change was 1.8% per year. Adelaja and Hoque (1985) also used a multi-product translog cost function to derive measures of marginal rates of product transformation and the input biases, product biases and rates of technological change in the West Virginia farm sector. In their model the farm sector output was also divided into two categories -- crop products and livestock products. Farm inputs used in the model were labor, fertilizer, energy, machinery, capital and miscellaneous inputs. The annual rates of technical progress estimated were at about 1% in 1964, 2% in 1969, 3% in 1974, 4% in 1978, and 5% in 1982. However, in 1959, there was technological regression in this sector of -0.5%.

Sidhu and Baanante (1981) applied the translog profit function to farm-level data from Punjab, India. They used a normalized restricted translog profit function considering wheat output, three variable inputs (labor, fertilizer and animal power) and seven fixed factors (machinery and equipment, land, various soil nutrients, schooling and irrigation area). The obtained estimates for the elasticities of wheat supply responses as well as for the three variable factor demands. They showed that the Cobb-Douglas profit function specification is not supported by the data, and that the symmetry restrictions are not rejected. They obtained a wheat supply elasticity of 0.6 and, surprisingly, they found that the output price effect is more powerful in affecting demand for labor, fertilizer and animal power than their respective prices.

Unfortunately, they didn't estimated total factor productivity changes. Antle (1984) utilized 1910-1978 time series data and a single product aggregate translog profit function to measure the structure of U.S. agricultural technology. He concluded that nonhomothetic aggregate technologies characterize the pre- and post- World War II periods and that technological change was not neutral. The pre-war technology is biased toward labor and mechanical technology and against land, whereas the postwar technology is biased against labor and toward machinery and chemicals.

Thirtle (1985) may be the first to estimate technological changes on individual field crops in the United States. He used a nested Cobb-Douglas/CES functional form for the production function and transformed it into a profit function to estimate embodied technological changes in land/fertilizer and labor/machinery inputs. The data he used were 1939-78 annual observations for wheat, corn, cotton, and soybeans. He found that the annual growth rates of land/fertilizer technological changes were 0.015, 0.011, 0.017 and 0.005 on wheat, soybeans, corn, and cotton, respectively, while the growth rates from mechanical technological changes were 0.024, 0.025, 0.063, and 0.047 on wheat, soybeans, corn, and cotton, respectively.

Though both the duality approach and primal production function approach can be used to estimate the changes of the total factor productivity, these estimates will not necessarily be the same. Total factor productivity change measured from a primal production function is the output increase which is not attributed to the increase in inputs, while total factor productivity measured from the duality approach is the cost decrease which is not due to changes in input use. Unless the functional forms used in both approaches are forms which have the characteristic of being self-dual, the results are not directly comparable.

Shumway, Pope, and Nash (1984) show that the dual approach to production may have some serious limitations because it does not yield allocation equations, especially when production is joint. They concluded that the dual model does not permit the extraction of equations for input allocations among products. Primal models, on the other hand, allow identification of the allocations when production is joint only because of constraints on allocatable inputs. Just, Zilberman and Hockman (1983) also pointed out that (1) duality does not yield a complete solution to the production problem and, in particular, it does not provide information needed by decision makers who must make allocation decision (2) duality also does not yield a sufficient empirical framework for analysis of policies relating to inputs on specific crops, such as wheat acreage policy, unless such policies are reflected in the sample data.

The index number approach   Numerous productivity studies have used modified Laspeyes or Paasche total factor productivity indices (Abramovitz, 1956; Fabricant, 1942; Dension, 1962, 1969; and Kendrick, 1961, 1973). Factor prices are assigned as weights to the respective inputs to obtain total factor input aggregates. Other studies have used the geometric approach to aggregate inputs in studying technical change in U.S. agriculture (Chandler, 1962; and Lave, 1964). However, the assumptions on the production function underlying these indices are very restrictive. For example, arithmetic aggregation is appropriate only when the production function has zero elasticity of substitution, and the geometric index is a natural and unambiguous measure of productivity change when the production function is of the Cobb-Douglas form (USDA, 1980).

The Divisia index is an approach that has received considerable attention recently. The Divisia index, a weighted sum of growth rates where the weights are the input component's shares in the total value of inputs used, is consistent with a wider variety of production functions than either the arithmetic or geometric indices. To derive this index let the production function be a generalized equation as in (2-2):

$$(2\text{-}2) \quad Y(t) = G(\, K(t),\ L(t),\ F(t),\ N(t),\ t\,)$$

Assume that G has constant returns to scale in production and that competitive equilibrium conditions prevail in the product and the factor markets. Following Solow (1957) and assuming that the production function G is differentiable, we can differentiate equation (2-2) with respect to t and divide both sides of the resulting identity by G. Denoting time derivatives of the variable X as $\dot{X}$, one obtains the identity

$$(2\text{-}9) \quad \frac{\dot{Y}}{Y} = s_K \frac{\dot{K}}{K} + s_L \frac{\dot{L}}{L} + s_F \frac{\dot{F}}{F} + s_N \frac{\dot{N}}{N} + \frac{\dot{G}}{G}$$

where s_i are the shares of input i in the total value of output for i=K,L,F,N. Rearranging (2-9), one obtains the Divisia index

$$(2\text{-}10) \quad D(t) = \frac{\dot{G}}{G} = \frac{\dot{Y}}{Y} - s_K \frac{\dot{K}}{K} - s_L \frac{\dot{L}}{L} - s_F \frac{\dot{F}}{F} - s_N \frac{\dot{N}}{N}$$

Sudit and Finger show that the Divisia index has a number of attractive properties. The index can be shown to be unbiased, subject to certain assumptions regarding the underlying production function, thereby eliminating index-number biases related to base-year choices. A discrete Divisia index is particularly important for macro-level analysis where aggregate variables are obtained so that they conform to Fisher's reversal rule (i.e., the product of the factor price and the quantity indices should yield the total cost ratio between any two periods).

In empirical applications, the time derivatives on the right-hand side of (2-10) are approximated by discrete differences or an index number formula. For empirical applications, see the papers by Christensen, Cummings, and Jorgenson (1980).

Though the Divisia index can be approximated by discrete differences, it is inherently a continuous index. Bigman (1980) pointed out that there are several shortcomings in this index.

1. This measure contains changes in techniques of production as well as other factors such as increasing returns to scale.
2. With the exception of the case in which technical change is Hicks neutral, the Divisia index, which is a line integral, will be path dependent (Hulten, 1973; Usher,

1974). As a consequence, the value of the measured residual will depend on the particular path of integration.

3. There is a problem in the common practice of using the value added production function for empirical analysis, since it suppresses intermediate inputs, in that these inputs might themselves be an important source of growth either directly or via changes in quantity and price which result from the technological change in the origin sector which, in turn, permits an increase in the supply of these inputs.

4. Improved technologies enable firms to increase their production and, ceteris paribus, force the price of the product to decline. By not accounting for demand conditions in the commodity markets, and ignoring the simultaneous change in quantity and price which result from the technological progress, the residual index may fail to measure the true impact of technological change.

Recent studies by Afriat, 1970; Diewert, 1976; Denny and Fuss, 1983; and Denny, 1984, show that many index number formulas not only approximate but represent exactly particular production functions. For a discrete productivity index, they found that the Tornqvist-Theil index is approximating to a Divisia index. They also found that the Tornqvist index is exact for the homogenous translog production function. The homogenous translog production function can provide a second-order approximation to an arbitrary twice differentiable homogenous production function. Diewert (1976) has used the term "superlative" to characterize index numbers which are exact for production functions having this approximation feature.

Christensen and Jorgenson (1970) proposed the following Tornqvist index of total factor productivity (TFP):

$$\text{(2-11)} \quad \ln(TFP_t/TFP_{t-1}) = \frac{1}{2}\sum_i (R_{it}+R_{i,t-1})\ln(Y_{it}/Y_{i,t-1}) - \frac{1}{2}\sum_j (S_{jt}+S_{j,t-1})\ln(X_{jt}/X_{j,t-1})$$

where the Y_i are output indices, the X_i are input indices, the R_i are output revenue shares, and S_j are input cost shares. Diewert has shown that (2-11) can be derived from a homogenous translog transformation function.

Ball (1985) used the Tornqvist index to measure total factor productivity changes in agriculture over the postwar period. He first constructed the Tornqvist output indices and input indices, and then used them to construct indices of productivity growth. Six categories of agricultural outputs are identified in his paper. They are animal products excluding dairy, fluid milk and cream, feed and food grains, other field crops, vegetables and melons, and fruits and tree nuts. Three inputs are included; labor, capital and intermediate inputs such as energy, agricultural chemical, feed and seed, and miscellaneous. The time period he estimated was from 1948 to 1979. He found that the total factor productivity grew at an average annual rate of 1.75%, compared with 1.70% per year estimated by the U.S. Department of Agriculture.

Denny (1984) showed that Tornqvist index has a number of important caveats. First, it is not possible to eliminate some assumptions about competitive behavior. To the extent that this assumption is false, an error will be introduced in the measure of productivity. Secondly, it is not possible in the quadratic framework to find a function, other than the translog, that will permit us to derive the shares of output and input from their first derivatives. Finally, although the methodology provides a quick way of ordering units by their productivity levels, it can never replace econometric or other methods of estimation in producing a detailed understanding of relative productivity levels.

Comparative Productivity Analysis

Many economists use physical productivity measures to compare productivity changes among products (sectors, regions or countries). For example, Kendrick (1983) used an arithmetic index to compare total factor productivity growth among industry groups in the United States over 1948-1979 time period. Jorgenson and Nishimizu (1978) use the Tornqvist index to compare productivity levels in Japan and the United States. Taylor and Wilkowske (1984) used translog cost and production functions together to estimate productivity growth in the Florida fresh winter vegetable industry. They also used the results to compare the productivity levels for different vegetables and regions.

Though physical productivity measures can be used to compare productivity changes among different sectors, it should be noted that physical productivity changes may be compensated for by the reallocation of factors among production processes. Thus, this physical measure does not necessarily represent the actual welfare contribution of the product to society. There are other measures which can be used to compare changes in productivity among sectors. Baumol and Wolff (1984) called these absolute productivity measures. They investigated two measures commonly used in the literature -- base year productivity measures and deflated productivity measures. They concluded that the deflated productivity index, is better than base-year index when used to compare absolute productivity among sectors. They argued that base year measure B_{fst} is only a physical productivity indicator and doesn't represent welfare change. The base-year index is given by

$$(2\text{-}12) \qquad B_{fst} = \frac{\sum_{i \varepsilon s} P_{i0} Y_{it}}{\sum_{k \varepsilon s} W_{k0} X_{kt}}$$

where s is the set of outputs produced and inputs used in sector s. Y_{it} is the quantity of the ith good produced in sector s in period t, X_{kt} is the quantity of input k it uses. P_{io} and W_{ko} are the prices of output i and input k in a base year. Baumol and Wolff (1984) showed that, under some assumptions, base-year indices can be expressed as physical productivity indices. For example, assuming all input quantities grow in some fixed proportion, e^{qt}, and outputs all grow in some other common proportion, e^{rt}, over some period t, than, (2-12) becomes

$$(2\text{-}13) \quad B_{fst} = \frac{\sum_{i\varepsilon s} e^{rt} P_{i0} Y_{i0}}{\sum_{k\varepsilon s} e^{qt} W_{k0} X_{k0}}$$

$$= (e^{rt}/e^{qt})\, B_{fso}$$

$$= e^{(r-q)t} B_{fso}$$

So, it is clear that B_{fst} will have grown at the rate (r-q), just as has physical productivity. They also suggest that B_{fst} is not a defensible measure of growth in welfare productivity. The points is that in period t the price vector P_o is a vector of obsolete prices and hence represents consumer product evaluations that are no longer relevant if tastes have changed.

Baumol and Wolff (1984) argue that the deflated productivity index D_{fst} is the "right" index of a sector's economic productivity.

The deflated index of total factor productivity is given by:

$$(2\text{-}14) \quad D_{fst} = \frac{\sum_{i\varepsilon s} (P_{it}/P_t)\, Y_{it}}{\sum_{k\varepsilon s} (W_{k0}/W_k) X_{kt}}$$

where P_{it} and W_{it} are the prices of output i and input k at time t, respectively. P_t and W_t are, respectively, any of the standard indices of the economy's overall level of output and input prices.

According to Baumol and Wolff (1984), this index tends to assign the same absolute productivity figures to all economic sectors, and certainly does so if those sectors are in perfectly competitive equilibrium. In equilibrium the zero profit condition implies that

$$(2\text{-}15) \quad \sum_{i \varepsilon s} P_{it} Y_{it} = \sum_{k \varepsilon s} W_{kt} X_{kt}$$

Substituting (2-15) into (2-14), gives

$$(2\text{-}16) \quad D_{fst} = W_t / P_t \qquad \text{for all } s$$

In competitive equilibrium, the deflated measure of productivity D_{st}, thus, do not vary from sector to sector.

Baumol and Wolff (1984) argued, however, that the measure reports a substantive piece of economic information -- the marginal welfare productivity of each sector of the economy. They reasoned that even when physical productivity in one sector grows persistently faster than in another, real productivity in the two sectors as measured by D_{fst} will begin at the same level and move together in lockstep through time. This occurs because the market mechanism readjusts the prices of the different products with their different growth rates of physical productivity so as to shift inputs and quantities consumed in such a way that the growth in marginal welfare yields of all the inputs is equalized. In effect, the competitive mechanism translates the physical growth achievements of the economy into increases in welfare contributions of inputs, and in the process, equalize them. Thus, they concluded that D_{fst} is the "right" measure of a sector's economy productivity. They also concluded that D_{fst} is just about the only measure that can claim legitimacy as a measure of absolute productivity. They said 'if it does not tend to show substantial differences in absolute productivities among industries, that is because those differences are simply not there' (p. 1029).

It is evident that the deflated productivity index cannot be used for the purposes outlined previously for this study since it does not show differences in absolute productivity among industries. The reason the deflated index does not show differences of productivity is because it is a measure of marginal social welfare. The careful reader can easily discern that the deflated productivity index is only concerned with changes in marginal social welfare. Unfortunately, changes in total social welfare, not changes in marginal social welfare, are of concern to economists. Clearly for an economy in equilibrium, the marginal value of inputs will tend to equalize among sectors, thus, the marginal social welfare of all products will also tend to be equal. If the only concern is with marginal social welfare at a point of time, then there is little to do in economics. On the contrary, if there is concern about changes in total social welfare between periods, another approach to measure factor productivity seems necessary.

Summary

In this chapter, two measures of productivity -- partial productivity and total factor productivity -- are introduced and a brief review of their usage in measuring productivity in agriculture is given. The approaches introduced in this chapter, though they can not be directly used in the measurement of individual crop productivity, provide guidance as to the concept of productivity, and its measurement.

CHAPTER III. MODELS TO MEASURE PRODUCTIVITY CHANGE

Introduction

Total factor productivity can be measured using a variety of econometric models and statistical procedures. This chapter will discuss a general form for such models, the particular needs of a model for crop production, discuss a production model that can be used when input data are unavailable and propose a specific model to measure total factor productivity for individual crops.

A General Model of Productivity Change

Suppose the production process in crop i, which allows the efficiency of capital, labor, and fertilizer to rise over time is represented by

$$(3\text{-}1) \quad Y_{it} = G(\ A_{it}K_{it},\ B_{it}L_{it},\ C_{it}F_{it},\ N_{it}\ )$$

where Y_{it} is the output level of crop i at time t; K_{it}, L_{it}, F_{it}, and N_{it} are capital, labor, fertilizer, and land used in the production of crop i at time t. A_{it}, B_{it}, and C_{it} are factor augmenting parameters which convert capital, labor and fertilizer inputs into efficiency units. Thus $A_{it}K_{it}$ represents the specific technological contribution of K_{it} units of capital to production in period t. Assume that the production function is homogenous of degree one in inputs (has constant return to scale), with positive but declining marginal products, and that factors are paid their marginal products.

To find the rate of change of technology equation (3-1) can be totally differentiated with respect to time (t). This will yield

$$\text{(3-2)} \quad \frac{dY}{dt} = \frac{\partial G}{\partial (AK)} A \frac{dK}{dt} + \frac{\partial G}{\partial (AK)} K \frac{dA}{dt} + \frac{\partial G}{\partial (BL)} B \frac{dL}{dt} + \frac{\partial G}{\partial (BL)} B \frac{dB}{dt} + \frac{\partial G}{\partial (CF)} C \frac{dF}{dt} + \frac{\partial G}{\partial (CF)} F \frac{dC}{dt} + \frac{\partial G}{\partial N} \frac{dN}{dt}$$

Use of the chain rule implies that

$$\frac{\partial G}{\partial A} = \frac{\partial G}{\partial (AK)} K \qquad \frac{\partial G}{\partial K} = \frac{\partial G}{\partial (AK)} A$$

$$\text{(3-3)} \quad \frac{\partial G}{\partial B} = \frac{\partial G}{\partial (BL)} L \qquad \frac{\partial G}{\partial L} = \frac{\partial G}{\partial (BL)} B$$

$$\frac{\partial G}{\partial C} = \frac{\partial G}{\partial (CF)} F \qquad \frac{\partial G}{\partial F} = \frac{\partial G}{\partial (CF)} C$$

Substituting (3-3) into (3-2) yields

$$\text{(3-4)} \quad \frac{dY}{dt} = \frac{\partial G}{\partial K}\frac{dK}{dt} + \frac{\partial G}{\partial K}\frac{K}{A}\frac{dA}{dt} + \frac{\partial G}{\partial L}\frac{dL}{dt} + \frac{\partial G}{\partial L}\frac{L}{B}\frac{dB}{dt} + \frac{\partial G}{\partial F}\frac{dF}{dt} + \frac{\partial G}{\partial F}\frac{F}{C}\frac{dC}{dt} + \frac{\partial G}{\partial N}\frac{dN}{dt}$$

Now the problem can be reparameterized such that the output elasticities are constants, i.e.,

$$\frac{\partial G}{\partial K}\frac{K}{Y} = a, \qquad \frac{\partial G}{\partial L}\frac{L}{Y} = b, \qquad \frac{\partial G}{\partial F}\frac{F}{Y} = c, \qquad \frac{\partial G}{\partial N}\frac{N}{Y} = d,$$

If the time derivative of a variable X is denoted by

$$\frac{dX}{dt} = \dot{X} \quad \text{(for X=Y, K, L, F, N, A, B and C)}$$

then by substituting these expressions in (3-4) and rearranging the following expression is obtained.

$$(3\text{-}5) \quad \dot{Y} = a(\frac{Y}{K})\dot{K} + a(\frac{Y}{A})\dot{A} + b(\frac{Y}{L})\dot{L} + b(\frac{Y}{B})\dot{B} + c(\frac{Y}{F})\dot{F} + c(\frac{Y}{C})\dot{C} + d(\frac{Y}{N})\dot{N}$$

Dividing both sides of (3-5) by Y yields

$$(3\text{-}6) \quad \frac{\dot{Y}}{Y} = a(\frac{\dot{K}}{K}) + b(\frac{\dot{L}}{L}) + c(\frac{\dot{F}}{F}) + d(\frac{\dot{N}}{N}) + a(\frac{\dot{A}}{A}) + b(\frac{\dot{B}}{B}) + c(\frac{\dot{C}}{C})$$

Equation (3-6) states that the rate of growth of output is influenced not only by the rates of increase of the factor inputs but also by the rates of increase of efficiencies of capital, labor and fertilizer weighted by their respective shares. Rearranging (3-6) gives the change in total factor productivity ($\dot{T}/T$).

$$(3\text{-}7) \quad \frac{\dot{T}}{T} = a(\frac{\dot{A}}{A}) + b(\frac{\dot{B}}{B}) + c(\frac{\dot{C}}{C})$$
$$= \frac{\dot{Y}}{Y} - a(\frac{\dot{K}}{K}) - b(\frac{\dot{L}}{L}) - c(\frac{\dot{F}}{F}) - d(\frac{\dot{N}}{N})$$

Since a, b, c and d can be identified with production function parameters (output elasticities) which in the case of constant returns to scale are equal to input shares all parameters in (3-7) are observable. This follows since profit maximization implies that P $(\partial G/\partial X_i) = W_i$ which in elasticity form says that $(\partial G/\partial X_i)(X_i/Y) = (W_i X_i/PY)$ where P is output price, W_i is input price and X_i is input quantity. With constant returns to scale and perfect competition PY is equal to cost and thus $(W_iX_i/PY) = (W_iX_i/cost)$. Then using (3-7), it is easy to calculate total factor productivity. Unfortunately, except for the land input, input quantity data for individual crops are unavailable as are the shares of these inputs in the total cost of production.

This lack of data occurs because a farmer often grows several crops in the same time period and does not record how many hours of labor and machine time are allocated to a particular crop. Hence, the input data for labor and capital used in producing a particular crop are not available. Therefore the approaches introduced in chapter two to estimate the total factor productivity changes on individual crops can not be used in this general model. The direct estimation of the production function to estimate a, b, c and d is not suitable because some of the input quantities are unavailable. Since actual cost of production is not available, direct estimation of the cost function or the profit function cannot be used. The indirect estimation of cost or profit function parameters through estimating supply or input demand functions is also restricted to cases where appropriate data is available. Input demand equations are generally not estimable due to a lack of quantity data while output supply equations cannot be estimated using functional forms that require information on profits such as the translog. Using any of the various indices which avoid econometric estimation by making assumptions on functional form to obtain the parameters directly also breakdown because of the lack of quantity data in equation (3-7).

The number of acres of land used in producing an individual crop is clear and easy to record. Furthermore, the prices of labor, capital and output are also available in statistical time series data. A model to use this data to construct productivity measurement would be desirable.

A Model of Production With Input Allocations Unavailable

Just, Zilberman and Hochman (1983) provide an estimation method for multicrop production functions that can be used when input allocations are not available. Their methodology is based on the following assumptions:

(a) Allocated inputs. Most agricultural inputs are allocated by farmers to specific production activities. For example, tractor and labor hours, fertilizer, and pesticides are allocated among wheat, corn, and soybean fields.

(b) Physical constraints. Physical constraints limit the total quantity of some inputs that a farmer can use in a given period of time. For example, land is often available in fixed amounts in given time periods.

(c) Output determination. Output combinations are determined uniquely by the allocation of inputs to various production activities aside from random, uncontrollable forces. For example, a farmer cannot change the output mix merely by adjusting some dials once all input allocations are determined. Alternatively, the mix of, say, wheat and corn produced on a farm is determined by the land, fertilizer, water, labor, tractor hours, etc., that are allocated to each enterprise (Just, Zilberman, and Hochman, 1983, pp. 770-771).

Their model is outlined below to demonstrate its general usefulness.

Suppose the production problem is one of profit maximization, where the producer is constrained only by technology. The problem is given by

$$\max \quad p'y - w'x$$

$$\text{subject to} \quad y = f(X)$$

$$Xe = x$$

where $x' = (x'_v, x'_f)$ so that x_f is the $J_f \times 1$ subvector of aggregate input uses corresponding to fixed or constrained inputs; x_v is a similar $J_v \times 1$ subvector corresponding to unconstrained variable inputs, and $e = (1,1,\ldots,1)$; y and x are output and input vectors; and X gives the allocation of inputs. The associated Lagrangian for the problem is

(3-9) $$L = p'y - w'x_v - \lambda'[y - f(X)] - \phi'[Xe - x]$$

and has first-order conditions

(3-10) $$\frac{\partial L}{\partial y} = p - \lambda = 0 \qquad [\ K\ ]$$

(3-11) $$\frac{\partial L}{\partial x_v} = \phi_v - w = 0 \qquad [J_v\ ]$$

(3-12) $$\frac{\partial L}{\partial X_{\cdot j}} = \lambda' \frac{\partial f}{\partial X_{\cdot j}} - \phi_j\ e = 0 \qquad [KxJ]$$

(3-13) $\frac{\partial L}{\partial \lambda} = f(X) - y = 0$ [K]

(3-14) $x - Xe = 0$ [J]

where λ and $\phi = (\phi'_f, \phi'_v) = (\phi_1, \ldots, \phi_J)$ are vectors of shadow prices for outputs and inputs, $X_{\cdot j} = (X_{1j}, \ldots, X_{kj})$, and the numbers in brackets represent the number of equations in the particular condition. The conditions (3-10) - (3-14) give $2K+J+J_v+K\times J$ nonredundant equations in $3K+2J+J_v+K\times J-1$ variables ($\lambda, \phi, X, x_v, x_f, y$ p and w). Note that zero degree homogeneity in prices implies that (p,w) contains only J_v+K-1 exogenous variables.

According to the implicit function theorem, the number of nonredundant equations that can be expressed solely with observable variables is, at most, the number of observable variables less J+K-1. Thus, if one can find at least this many nonredundant equations that include no unobservable data, then efficient (full information) estimation of the system is possible (Just et al., 1983, p. 774). Thus if a set of equations can be defined which satisfy the conditions outlined above then productivity can be estimated even when some data are unobservable.

A New Model for Measuring Total Factor Productivity

In order to measure productivity change for an individual crop, this study first presents a relationship between output, some input prices and other input quantities which is derived from the primal production function. The spirit of this relationship is close to duality theory with fixed inputs.

Proxy variables for technological change are added to the production function and the derived output supply equation is obtained in the case when available input data are as previously described. Since the supply equation is derived by directly solving the primal problem the parameters of the production function can be obtained. This directly derived supply equation is called the derived production relationship in the sections that follow.

To formulate this derived production relationship, some basic economic assumptions are needed.

1. Independent technique: The production technique of each crop is independent from others. Thus the productivity of one crop is not influenced by the production of other crops. This assumption also implies that there is no jointness in production.
2. Rational Behavior and Perfect Markets: Rational behavior assumes that farmers are looking for maximum profit. The output they produce and the inputs they buy totally depends on the price they face. Perfect markets imply that farmers know prices and can not change them by themselves. By combining these two assumptions, we may conclude that farmers will employ inputs until their marginal revenue products are equal to their prices.
3. No fixed inputs: This assumes that the farmer can change

all his inputs in each time period. The rational of this assumption is based on the idea that farmers are able to change all their inputs (including fixed inputs, such as land and machines) from one crop to another crop. Furthermore, since the study examines the productivity change in the United States from 1946 to 1982, it is a long enough to treat all the inputs as variable inputs.

4. Hick's neutral technological change: Since there is no prior information on input efficiency change and some input data are also unavailable, it is difficult to estimate embodied technological changes. For simplicity, we assume that technological change is disembodied, and also that technological change is Hick's neutral. This means that the factor augmenting coefficients are the same for all inputs.

Based on the assumptions above, one can easily formulate a derived production relationship to estimate the underlying primal production function. Assume the production function is

$$Y(t) = f(K(t),\ L(t),\ F(t),\ N(t),\ T)$$

where Y(t) is the output in time t, K(t), L(t), F(t) and N(t) are capital, labor, fertilizer and land used in production at time t, and T represents technology. Let P, I, W and R be the prices of Y, K, L, and F, respectively. To maximize profit, one defines the following problem

$$\text{Max } \Pi(t) = P(t)Y(t) - I(t)K(t) - W(t)L(t) - R(t)F(t)$$

$$\text{s.t.} \quad Y(t) = f\,(K(t),\, L(t),\, F(t),\, N(t))$$

To solve the problem form the Lagrange function

$$(3\text{-}15) \qquad L(t) = P(t)Y(t) - I(t)K(t) - W(t)L(t) - R(t)F(t) + \lambda[\, Y(t) - f(\, K(t),\, L(t),\, F(t),\, N(t))\,]$$

The first order conditions are obtained by setting the first partial derivatives of (3-15) with respect to K, L, F and λ equal to zero:

$$(3\text{-}16) \qquad \frac{\partial L}{\partial K} = P\frac{\partial Y}{\partial K} - I = 0$$

$$(3\text{-}17) \qquad \frac{\partial L}{\partial L} = P\frac{\partial Y}{\partial L} - W = 0$$

$$(3\text{-}18) \qquad \frac{\partial L}{\partial F} = P\frac{\partial Y}{\partial F} - R = 0$$

$$(3\text{-}19) \qquad \frac{\partial L}{\partial \lambda} = Y - f(K,L,F,N) = 0$$

In (3-16)-(3-19) there are 4 equations and 9 variables (Y, K, L, F, N, P, I, W and R). If the unobservable variables are less than 4, by implicit function theorem, it is possible to use the observable variables to solve for the unobservable variables. If the unobservable variables are more than 5, unless the production technique has a separable property,[3] it impossible to express the unobservable

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[3] If the production function is separable, some equations in (3-9)-(3-13) may include less unobservable variables than the number of these equations.

variables from available variables. An example that satisfies these conditions is when the production function is a Cobb Douglas production function

$$(3\text{-}20) \qquad Y = (AK)^{a}(BL)^{b}(CF)^{c}N^{d}$$

It is assumed that A, B and C change over time to reflect technical progress. Equation (3-20) assumes that technological change is embodied. If it is assumed technological change is Hicks neutral (that is to assume A = B = C) then (3-20) can be expressed as

$$(3\text{-}20a) \qquad Y = K^{a}L^{b}F^{c}N^{d}A^{(a+b+c)}$$

where now A changes over time to reflect productivity change. If it is assumed that technology changes at some exogenous rate ρ then the equation can be rewritten as

$$(3\text{-}21) \qquad Y= K^{a}L^{b}F^{c}N^{d}(De^{\rho t})$$

where $De^{\rho t}$ denotes the disembodied technological change which grows at annual rate of ρ and $De^{\rho t} = A^{(a+b+c)}$. The logarithmic form of (3-21) is

$$(3\text{-}22) \qquad \ln Y=\ln D+a\ln K+b\ln L+c\ln F+d\ln N+\rho t$$

Assuming the first order conditions in (3-16) - (3-19) hold one obtains the three equations:

$$(3\text{-}23) \qquad P\,\frac{\partial Y}{\partial K} = PaDK^{a-1}L^{b}F^{c}N^{d}e^{\rho t} = PaYK^{-1} = I$$

$$(3\text{-}24)\qquad P\,\frac{\partial Y}{\partial L} = PDbK^{a}L^{b-1}F^{c}N^{d}e^{\rho t} = PbYL^{-1} = W$$

$$(3\text{-}25)\qquad P\,\frac{\partial Y}{\partial F} = PDcK^{a}L^{b}F^{c-1}N^{d}e^{\rho t} = PcYF^{-1} = R$$

Rearranging (3-23) to (3-25) and taking the logarithmic form yields

$$(3\text{-}26)\qquad \ln K = \ln a + \ln Y + \ln(P/I)$$

$$(3\text{-}27)\qquad \ln L = \ln b + \ln Y + \ln(P/W)$$

$$(3\text{-}28)\qquad \ln F = \ln c + \ln Y + \ln(P/R)$$

Substituting (3-26)-(3-28) into (3-22) one obtains

$$(3\text{-}29)\qquad \ln Y = \frac{\ln A + a\ln a + b\ln b + c\ln c}{1-a-b-c} + \frac{a}{1-a-b-c}\ln(P/I) + \frac{b}{1-a-b-c}\ln(P/W) + \frac{c}{1-a-b-c}\ln(P/R) + \frac{d}{1-a-b-c}\ln N + \frac{\rho}{1-a-b-c}\,t$$

This gives the logarithm of Y in term of observable variables. For estimation a disturbance term may be added to (3-29). If only the inputs of K, L, F and the price of N are unavailable, one can estimate (3-29) in the form

$$(3\text{-}30)\qquad \ln Y = \pi_0 + \pi_1\ln(P/I) + \pi_2\ln(P/W) + \pi_3\ln(P/R) + \pi_4\ln N + \pi_5 t$$

There are 6 parameters $(\pi_0,\pi_1,\pi_2,\pi_3,\pi_4,\pi_5)$ to estimate and there are 6 unknown coefficients in the primal production function (D, a,b,c,d,ρ) given by equation (3-29). The relationships of these variables to one another are given by

$$\pi_0 = \frac{\ln D+a\ln a+b\ln b+c\ln c}{1-a-b-c}$$

$$\pi_1 = \frac{a}{1-a-b-c}$$

$$\pi_2 = \frac{b}{1-a-b-c} \qquad (3\text{-}31)$$

$$\pi_3 = \frac{c}{1-a-b-c}$$

$$\pi_4 = \frac{d}{1-a-b-c} \quad .$$

$$\pi_5 = \frac{\rho}{1-a-b-c}$$

Through (3-31), estimators of $(\pi_0, \pi_1, \pi_2, \pi_3, \pi_4, \pi_5)$, may be used to obtain estimators of a, b, c, d, D and ρ. Through the derived production relationship given in (3-30), one may estimate the original production function in (3-21). Then the total factor productivity (denoted by $De^{\rho t}$) can be obtained. This gives estimates of factor productivity using only linear regression techniques.

An alternative way to estimate total factor productivity that follows from this model is to use the growth rate of variables instead of their absolute values. To see this rearrange (3-23) to (3-25) to obtain

(3-32) $K = a(V/I)$

(3-33) $L = b(V/W)$

(3-34) $F = c(V/R)$

where V = P Y is total revenue of the product. Taking the growth rate form of (3-32) - (3-34) yields

(3-35) $$\frac{\dot{K}}{K} = \frac{\dot{V}}{V} - \frac{\dot{I}}{I}$$

(3-36) $$\frac{\dot{L}}{L} = \frac{\dot{V}}{V} - \frac{\dot{W}}{W}$$

(3-37) $$\frac{\dot{F}}{F} = \frac{\dot{V}}{V} - \frac{\dot{R}}{R}$$

If (3-35) - (3-37) are substituted into (3-7) and rearranged, the following equations results

(3-38) $$\frac{\dot{Y}}{Y} = a(\frac{\dot{V}}{V} - \frac{\dot{I}}{I}) + b(\frac{\dot{V}}{V} - \frac{\dot{W}}{W}) + c(\frac{\dot{V}}{V} - \frac{\dot{R}}{R}) + d(\frac{\dot{N}}{N}) + \frac{\dot{T}}{T}$$

To estimate the change in total factor productivity, assume that $\dot{T}/T$ is that portion of output growth which is not due to changes in inputs use. Thus in a regression context $\dot{T}/T$ is the sum of intercept (A_o) and the residual. Thus if we replace $\dot{T}/T$ by an intercept and error term, (3-38) becomes an estimating equation

$$(3\text{-}39) \quad \frac{\dot{Y}}{Y} = A_o + a(\frac{\dot{V}}{V} - \frac{\dot{I}}{I}) + b(\frac{\dot{V}}{V} - \frac{\dot{W}}{W}) + c(\frac{\dot{V}}{V} - \frac{\dot{R}}{R}) + d(\frac{\dot{N}}{N}) + \text{error}$$

In (3-39), all the variables are observable. By estimating (3-39) the coefficients of the production function a, b, c and d can be obtained. Technical change, $\dot{T}/T$, can then be obtained by rearranging (3-38) using estimated coefficients.

In any given year this estimate will include productivity changes plus random factors due to weather, demand conditions, etc. Over time, however the changes in this factor will accurately reflect changes in overall productivity.

Summary

This chapter presented a general model to measure total factor productivity. The general model requires quantity data that are not usually available for individual crops and so a model to estimate production response when input allocations are unavailable was reviewed. The model by Just, Zilberman and Hochman (1983) provides a method to construct a model of technical change when input allocations are not available. Such a model was developed using the Cobb Douglas functional form. A model was also derived for the case when data are expressed in growth rate terms. This original model can be used to estimate productivity changes for individual crops.

CHAPTER IV. AN ALTERNATIVE INDEX OF ABSOLUTE PRODUCTIVITY

Introduction

Generally used physical productivity measures such as the Divisia or Tornqvist indices or other indices introduced in Chapter II can not be used in intersectoral productivity comparisons because they do not consider the relative values of inputs and outputs over time. To illustrate, suppose two different products use exactly the same input combination to produce one unit of output. Though input costs will be the same, the outputs may differ both as to quantity and value. Productivity comparisons between these two sectors will necessarily consider the market value of both outputs, and thus, must include price information. In reality, of course, the situation is more complicated since different products use different input combinations, and over time relative prices of input may change. Thus, physical productivity measures which are the ratios of output to aggregate input are not suitable for comparing productivity among sectors. To summarize, measures to compare productivity levels among sectors must include at least the following:

1. Prices of outputs and inputs.
2. Changes in physical productivity.

A Model to Compare Productivity Levels

In this chapter, a model that contains both current price and physical productivity is developed.

The model requires some basic assumptions as follow:

1. All output as well as input markets are perfectly competitive. Therefore prices of inputs and outputs represent their marginal welfare contributions to society.
2. The production functions in all sectors satisfy constant return to scale. Therefore by Euler's theorem,

   where s denotes sector s in the economy.
3. The physical productivity changes are embodied in inputs used in the production of the product and are factor augmenting in form. Therefore there exists a production function in each industry s that can be written as

   $$(4\text{-}2)\quad Y_{st} = G_s\,(A_{1t}X_{1t},\ \ldots\ ,\ A_{nt}X_{nt})$$

   where A_{it} is the embodied technological change coefficient for input X_{it} in time t.
4. All increased welfare due to technological progress is proportionally shared by the inputs which have embodied technological change. In other words, the actual input price includes the shadow price of that input and the price of efficient (technological) progress. Here, the

shadow price of the input is defined as the price of the input that would prevail if there was no technological change.

With these assumptions in mind we can proceed to develop a measure of productivity in a sector. Let the shadow price of input k which represents the input price with no technological progress, in time t be w_k, so that in equilibrium we obtain the marginal condition for profit maximization that

$$(4\text{-}3) \quad P_{st} \frac{\partial G_{st}}{\partial (A_{kt} X_{kt})} = w_{kt}$$

The actual price of input k in time t is given by W_k. In equilibrium this is equal to the marginal value product of X_{kt}.

$$(4\text{-}4) \quad W_{kt} = P_{st} \frac{\partial G_{st}}{\partial X_{kt}} = P_{st} \frac{\partial G_{st}}{\partial (A_{kt} X_{kt})} A_{kt}$$

If we compare (4-3) and (4-4) it is clear that:

$$(4\text{-}5) \quad w_{kt} = W_{kt}/A_{kt} \quad \text{or} \quad W_{kt} = w_{kt} A_{kt}$$

Using w_{kt} as the shadow price of input X_{kt}, one obtains the total opportunity cost of the product s. That is

$$(4\text{-}6) \quad \sum_{k \varepsilon s} w_{kt} X_{kt} = C_{st}$$

where $k \varepsilon s$ means that input k is used in producing product s. C_{st} represents an opportunity cost of producing Y_{st} if there is no technological progress. It can also represent the total social revenue of the product when there is no technological progress and market is in competitive equilibrium (since we assume constant returns to scale)

The ratio of actual total revenue in a period and opportunity cost C_{st} then can be looked on as an indicator of absolute productivity in sector s. That is:

$$(4\text{-}7) \qquad O_{st} = \frac{P_{st}\, Y_{st}}{\sum_{k\varepsilon s} w_{kt}\, X_{kt}} = \frac{P_{st}\, Y_{st}}{\sum_{k\varepsilon s} (W_{kt}/A_{kt})\, X_{kt}}$$

where O_{st} is the productivity index. Noting from (4-1) that PY = Σ $W_{kt}X_{kt}$ and using equation (4-6) it is clear that

$$(4\text{-}8) \qquad P\,Y - C = \sum_{k\varepsilon s} (W_{kt}-w_{kt})X_{kt}$$

Rearranging (4-8) yields

$$(4\text{-}9) \qquad C = P\,Y - \sum_{k\varepsilon s} (W_{kt}-w_{kt})X_{kt}$$

Substituting (4-9) into (4-7) gives another form for O_{st}

$$(4\text{-}10) \qquad O_{st} = \frac{P_{st}\, Y_{st}}{P_{st}\, Y_{st} - \sum_{k\varepsilon s} (W_{kt}-w_{kt})\, X_{kt}}$$

Example Use of the Proposed Model

Using the example production function of previous chapter, an example productivity measure can be developed. The example uses a Cobb Douglas production function where

$$Y = (AK)^a (BL)^b (CF)^c N^d$$

There are three basic steps in estimating the absolute productivity index.

Step 1: Estimate the technological augmenting coefficients assuming Hicks neutrality.

If technological change is Hick's neutral, then in (3-20)

$$\text{(3-20)} \qquad Y = (AK)^a (BL)^b (CF)^c N^d$$

one has A = B = C, so that the equation can be rewritten as

$$\text{(4-11)} \qquad Y = K^a\ L^b\ F^c\ N^d\ (A)^{a+b+c}$$

For simplicity, in the remaining of the chapter we will delete the subscripts of the variable. If the factor augmenting parameter A grows at a constant exponential rate then

$$\text{(4-12)} \qquad A^{a+b+c} = De^{\rho t}$$

Rearranging (4-12) yields

$$\text{(4-13)} \qquad A = D^{(1/(a+b+c))}\ e^{(\rho/(a+b+c))t}$$

From the estimation of equation (3-29) as discussed in Chapter III, the unknown parameters D, a, b, c, d and ρ are obtained. Substituting them into (4-13), an estimate of A can be obtained.

Step 2: Estimate the opportunity cost of production

To estimate the opportunity cost of production data on input quantities and the shadow prices of these inputs is needed.

The unknown input quantities K, L and F can be estimated by using equations (3-25)-(3-27) and the estimated coefficients of a, b, c and d. Since the data on P, Y and input prices I, W and R are known, the quantities of K, L and F can be estimated as

(4-14) $K = a\ Y\ (P/I)$

(4-15) $L = b\ Y\ (P/W)$

(4-16) $F = c\ Y\ (P/R)$

These of course are the input quantities implied by profit maximization using the Cobb Douglas production function specified.

The shadow prices of each input can also be estimated using (4-5) as

(4-17) $i = I/A$, $w = W/A$ and $r = R/A$

where A is estimated from (4-13).

Using the estimated results from (4-14) - (4-17), the opportunity cost (C) of production can be calculated as

(4-18) $C = i\ K + w\ L + rF + U$

following equation (4-6), where U is cost of other inputs which have no technological change.

Step 3: Estimate the absolute productivity index

Simply dividing PY by C gives absolute productivity index

$$(4\text{-}19) \qquad O = \frac{PY}{C} = \frac{P\ Y}{iK + wL + +rF + U}$$

When data on U are not available, (4-19) may not be estimated directly. An alternative way to estimate the absolute productivity index is to apply Euler's theorem for production functions with constant return to scale.

By assumption 2 above, one obtains

$$(4\text{-}20) \qquad P\ Y = IK + WL + RF + U$$

Subtracting (4-18) from (4-20) yields

$$(4\text{-}21) \qquad PY - C = (I-i)K + (W-w)L + (R-r)F$$

or

$$(4\text{-}22) \qquad C = PY - [(I-i)K + (W-w)L + (R-r)F]$$

Substituting (4-22) into (4-19) gives the absolute productivity index

$$(4\text{-}23) \qquad O = \frac{P\ Y}{PY - [(I-i)K + (W-w)L + (R-r)F]}$$

Summary

This chapter has developed a model to compare productivity levels among sectors. The index developed compares the revenue from production with the cost that would have occurred without technical progress. The reason this index can be used to represent the levels of absolute productivity in a sector is that the denominator of this ratio is the cost or social revenue of production without technical change while its numerator denotes the social revenue with technological change. So this ratio gives the change in productivity between periods. Since both numerator and denominator are expressed in current prices, the ratio represents the level of absolute productivity of sector s in period t by a current value ratio. In other words, it is how many dollars of social revenue can be obtained from one dollar's worth of inputs when technological progress occurs. Since the index is expressed in value terms it can easily be used to compare absolute levels of sectoral productivity. And since current prices are used it is not subject to the Baumol-Wolff (1984) criticism of the base year index.

CHAPTER V. ESTIMATES OF PHYSICAL PRODUCTIVITY CHANGE FOR FOUR FIELD CROPS

Introduction

In Chapter III a tentative model for measuring total factor productivity changes on individual crops was proposed. The proposed model was developed so as to overcome typical data problems. In this chapter econometric estimates of the proposed model will be presented using data on four major U.S. field crops. The estimated equations for each crop will be shown. Also, the implications of these equations will be discussed. Section II of the chapter will present the data used in the study. The sources of the data will be shown. In section III, econometric equations are introduced, and the estimated coefficients are given. The interpretation of these results and their economic implications will presented in the fourth section.

Data

Four major United States field crops are included in the study. They are corn for grain, cotton, soybeans and wheat. Annual data for the time period, 1949-1982, are used. The assumption is made that four broad input categories -- capital, labor, fertilizer and land-- represent the inputs used to produce the crops. Data are only available on the land input allocation among different crops. Acres harvested instead of areas planted is used as the land input because for some crops the data on acres planted is unavailable. The average prices received by farmers for the given year are used to represent output prices. Since data on capital, fertilizer and labor allocated to each crop is unavailable so the model using price data for these input quantities is used. Wage rates are hourly pay for hired farm workers. The price of fertilizer used in the study is a price index calculated from fertilizer prices paid by farmers. The price of capital is more problematic since data series on the rental price of capital are not generally available. One possible approach is to construct an index of the price of durable goods using USDA data. This index, however, would represent the value of the assets and not their annual user cost. The price index representing the annual user cost of durables in U.S. agriculture constructed by Ball (1985) was used in some early regressions but did not provide satisfactory results. The final models use the average interest rate on new loans by Federal Land Banks as a proxy for capital price. The results are reasonable and so the choice was at least partially substantiated. All data used were collected from Agricultural Statistics published by the United States Department of Agriculture (USDA, various issues).

Econometric Model and Results

Chapter III proposes two alternate equations, (3-30) and (3-38), for estimating total factor productivity change.

$$\text{(3-30)} \qquad \ln Y = \pi_0 + \pi_1 \ln(P/I) + \pi_2 \ln(P/W) + \pi_3 \ln(P/R) + \pi_4 \ln N + \pi_5 t$$

$$\text{(3-39)} \qquad \frac{\dot{Y}}{Y} = A_o + a\left(\frac{\dot{V}}{V} - \frac{\dot{I}}{I}\right) + b\left(\frac{\dot{V}}{V} - \frac{\dot{W}}{W}\right) + c\left(\frac{\dot{V}}{V} - \frac{\dot{R}}{R}\right) + d\left(\frac{\dot{N}}{N}\right) + \text{error}$$

In this section estimates of equation (3-39) will be used to estimate the change of total factor productivity in individual crops. Equation (3-39) was chosen because of its simple linear form and because the estimated results from (3-39) are more acceptable than those from estimation of (3-30) both as to predictive power and similarity of signs of coefficients to those predicted by economic theory.

To estimate (3-39) econometrically, we need the growth rate of each variable. Because the data collected are annual and discrete, this study uses the annual change rate as an approximation. This means that $\dot{X}/X$ is approximated by $(X_t - X_{t-1})/X_{t-1}$ for all X = Y, V, I, W, R and N. The estimated equations for the four crops are shown in Table 5-1. The variable names, descriptions and units are contained in Table 5-2. The dummy variable (DUM) is for the year 1974 when extreme drought severely affected the production of cotton and wheat. The coefficient of multiple correlation (R^2) is relatively high for each equation. The t statistics while not large are of the correct signs. Acreage as expected is a significant explanatory variable for crop production. Fertilizer price has a strong negative effect on crop production as would be predicted by theory. These coefficients are significant at the 5 % level for most of the crops except cotton. For cotton fertilizer price has postive effect on production and the coefficient is insignificant. So it is dropped in the study. The interest rate as a proxy for the user cost of capital is significant only for cotton while the price of labor is not significant in any equations. Given the fact that much farm labor is provided by the household this lack of significance of the wage rate is not surprising. This is also similar to the results found in other studies (Weaver, 1983; Shumway, 1983). While the statistical results are not extremely strong, they are good for this type of analysis and compare favorably with other studies in the literature (Binswanger, 1978; Shumway, 1983).

Factor Productivity Estimates and Economic Implications

Total factor productivity changes for the four crops over the post-war period are shown in Table 5-3. These estimates are made using the regression results in Table 5-1 and the formula in equation (3-7). The results, which are also shown in Figure 5-1 to Figure 5-5, are indices based on year 1949=1. The average annual growth rates of total factor productivity for corn, cotton, soybeans, and wheat are 3.36%, 1.33%, 2.40%, and 2.04%, respectively. The figures in any one year represent productivity change plus random factors so that the growth rates over the period are a more relevant measure of change than the

TABLE 5-1. Estimated Production Equations for Corn, Cotton, Soybeans and Wheat[a]

Corn : R^2=0.7140

$$CPOG = \underset{(2.505)}{0.032014} + \underset{(0.223)}{0.00883}\ CINWWG + \underset{(1.847)}{0.17876}\ CINREG + \underset{(2.705)}{0.26029}\ CINFIG + \underset{(1.954)}{0.42643}\ CHAG$$

Cotton : R^2=0.9255

$$TPOG = \underset{(-4.160)}{-0.2932}\ DUM + \underset{(0.354)}{0.01330}\ TINWWG + \underset{(9.607)}{0.4601}\ TINREG + \underset{(1.704)}{0.2165}\ THAG$$

Soybeans : R^2=0.8252

$$SPOG = \underset{(1.222)}{0.01932} + \underset{(0.179)}{0.00626}\ SINWWG + \underset{(1.613)}{0.13934}\ SINREG + \underset{(1.954)}{0.17134}\ SINFIG + \underset{(2.770)}{0.55650}\ SHAG$$

Wheat : R^2=0.8013

$$WPOG = \underset{(2.445)}{0.03497} - \underset{(-1.605)}{0.1845}\ DUM + \underset{(0.248)}{0.00985}\ WINWWG + \underset{(0.571)}{0.08834}\ WINREG + \underset{(2.090)}{0.3521}\ WINFIG + \underset{(3.364)}{0.63884}\ WHAG$$

[a]The numbers in parentheses represent t statistics.

figures for any one year.

Comparisons among the crops are shown in Figure 5-1. Productivity changes in these four crops seem to move in a parallel fashion even though the growth rates differ over the period. An interesting finding is that in the late 1970s and the early 1980s, total factor productivity change grows very rapidly in these four crops. The so-called plateau in productivity does not seem to exist at all.

TABLE 5-2. Description of Variables and Units used in Analysis

Variable	Description	units
CAP	Absolute productivity change for corn	Index, 1949=1
CATFP	Technological augmenting coefficient for inputs used in the production of corn	Index, 1949=1
CFER	Fertilizer used in corn production	Index, 1949=1
CFPR	Shadow price of fertilizer used in corn production	Index,1949=1
CHA	Harvested acres of corn	Million acres
CHAG	Growth rate of harvested acres of corn	per cent
CHAR	Index of corn harvested acres	Index, 1949,=1
CINC	Total revenue received from corn production	Million dollars
CINFIG	Growth rate of the difference of revenue and fertilizer price for corn	per cent
CINREG	Growth rate of the difference of revenue and interest rate for corn	per cent
CINWWG	Growth rate of the difference of revenue and wage rate for corn	per cent
CINT	Shadow price of capital used in corn production	Index,1949=1
CKAR	Index of capital used in corn production	Index, 1949=1
CLOU	Index of labor used in corn production	Index, 1949=1
COP	Corn production	Million bushel
CPOG	Growth rate of corn production	per cent
CPOR	Index of corn production	Index, 1949=1
CPR	Farmer received prices for corn	dollars
CPRR	Index of corn prices received by farmers	Index, 1949=1

TABLE 5-2 (continued)

Variable	Description	units
CSHFI	Corn fertilizer shadow price	Index, 1949=1
CSHIT	Corn capital input shadow price	Index, 1949=1
CSHWA	Corn labor input shadow price	Index, 1949=1
CTFP	Total factor productivity index for corn	Index, 1949=1
CYIELD	Yields per acre for corn	bushels
CYIEIDR	Index of yields per acre for corn	Index, 1949=1
CWAG	Shadow price of labor used in corn production	Index, 1949=1
DUM	Dummy variable, if year=1974 then DUM=1, else DUM=0	
INTE	Interest rate on Federal Land Bank loans	per cent
FPR	Index of fertilizer price	1910-1914=1
SAP	Absolute productivity change for soybeans	Index, 1949=1
SATFP	Technological augmenting coefficient for inputs used in the production of soybeans	Index, 1949=1
SFER	Fertilizer used in soybean production	Index, 1949=1
SFPR	Shadow price of fertilizer used in soybeans	Index,1949=1
SHA	Harvested acres of soybean	Million acres
SHAG	Growth rate of harvested acres of soybeans	per cent
SHAR	Index of soybean harvested acres	Index, 1949,=1
SINC	Total revenue received from soybeans production	Million dollars

TABLE 5-2 (continued)

Variable	Description	units
SINFIG	Growth rate of the difference of revenue and fertilizer price for soybeans	per cent
SINREG	Growth rate of the difference of revenue and interest rate for soybeans	per cent
SINWWG	Growth rate of the difference of revenue and wage rate for soybeans	per cent
SINT	Shadow price of capital used in soybean production	Index,1949=1
SKAR	Index of capital used in soybean production	Index, 1949=1
SLOU	Index of labor used in soybean production	Index, 1949=1
SOP	Soybeans production	Million bushel
SPOG	Growth rate of soybean production	per cent
SPOR	Index of soybean production	Index, 1949=1
SPR	Farmer received prices for soybeans	dollars
SPRR	Index of soybean prices received by farmers	Index, 1949=1
SSHFI	Soybean fertilizer shadow price	Index, 1949=1
SSHIT	Soybean capital input shadow price	Index, 1949=1
SSHWA	Soybean labor input shadow price	Index, 1949=1
STFP	Total factor productivity index for soybeans	Index, 1949=1
SYIELD	Yields per acre for soybeans	bushels
SYIEIDR	Index of yields per acre for soybeans	Index, 1949=1

TABLE 5-2 (continued)

Variable	Description	units
SWAG	Shadow price of labor used in soybean production	Index, 1949=1
TAP	Absolute productivity change for cotton	Index, 1949=1
TATFP	Technological augmenting coefficient for inputs used in the production of cotton	Index, 1949=1
TFER	Fertilizer used in cotton production	Index, 1949=1
TFPR	Shadow price of fertilizer used in cotton	Index,1949=1
THA	Harvested acres of cotton	Million acres
THAG	Growth rate of harvested acres of cotton	per cent
THAR	Index of cotton harvested acres	Index, 1949,=1
TINC	Total revenue received from cotton production	Million dollars
TINFIG	Growth rate of the difference of revenue and fertilizer price for cotton	per cent
TINREG	Growth rate of the difference of revenue and interest rate for cotton	per cent
TINWWG	Growth rate of the difference of revenue and wage rate for cotton	per cent
TINT	Shadow price of capital used in cotton production	Index,1949=1
TKAR	Index of capital used in cotton production	Index, 1949=1
TLOU	Index of labor used in cotton production	Index, 1949=1
TOP	Cotton production	Million bushel
TPOG	Growth rate of cotton production	per cent
TPOR	Index of cotton production	Index, 1949=1

TABLE 5-2 (continued)

Variable	Description	units
TPR	Farmer received prices for cotton	dollars
TPRR	Index of cotton prices received by farmers	Index, 1949=1
TSHFI	Cotton fertilizer shadow price	Index, 1949=1
TSHIT	Cotton capital input shadow price	Index, 1949=1
TSHWA	Cotton labor input shadow price	Index, 1949=1
TTFP	Total factor productivity index for cotton	Index, 1949=1
TYIELD	Yields per acre for cotton	bushels
TYIEIDR	Index of yields per acre for cotton	Index, 1949=1
TWAG	Shadow price of labor used in cotton production	Index, 1949=1
WAGE	Hourly wage rate paid by farmers	dollars
WAP	Absolute productivity changes for wheat	Index, 1949=1
WATFP	Technological augmenting coefficient for inputs used in the production of wheat	Index, 1949=1
WFER	Fertilizer used in wheat production	Index, 1949=1
WFPR	Shadow price of fertilizer used in wheat production	Index,1949=1
WHA	Harvested acres of wheat	Million acres
WHAG	Growth rate of harvested acres of wheat	per cent
WHAR	Index of harvested acres of wheat	Index, 1949,=1
WINC	Total revenue receive for wheat production	Million dollars
WINFIG	Growth rate of the difference of revenue and fertilizer price for wheat	per cent

TABLE 5-2 (continued)

Variable	Description	units
WINREG	Growth rate of the difference of revenue and interest rate for wheat	per cent
WINWWG	Growth rate of the difference of revenue and wage rate for wheat	per cent
WINT	Shadow price of capital used in wheat production	Index,1949=1
WKAR	Index of capital used in wheat production	Index, 1949=1
WLOU	Index of labor used in wheat production	Index, 1949=1
WOP	Wheat production	Million bushel
WPOG	Growth rate of wheat production	per cent
WPOR	Index of wheat production	Index, 1949=1
WPR	Farmer received prices for wheat	dollars
WPRR	Index of wheat prices received by farmers	Index, 1949=1
WSHFI	Wheat fertilizer shadow price	Index, 1949=1
WSHIT	Wheat capital input shadow price	Index, 1949=1
WSHWA	Wheat labor input shadow price	Index, 1949=1
WTFP	Total factor productivity index for wheat	Index, 1949=1
WYIELD	Yields per acre for wheat	bushels
WYIEIDR	Index of yields per acre for wheat	Index, 1949=1
WWAG	Shadow price of labor used in wheat production	Index, 1949=1
WAGE	Hourly wage rate hired by farmer	dollars

TABLE 5-3. Comparisons of Total Factor Productivity for Corn, Cotton, Soybeans and Wheat (1949-1982)

YEAR	Corn	Soybeans	Wheat	Cotton
1949	1.00000	1.00000	1.00000	1.00000
1950	0.95444	0.98791	1.04625	0.86632
1951	0.87173	0.93738	1.03268	0.78037
1952	0.95493	0.95047	1.16586	0.84987
1953	0.96684	0.86607	1.12829	0.92801
1954	0.91245	0.91211	1.13249	0.87172
1955	0.95496	0.92271	1.16782	0.91069
1956	0.99537	1.02681	1.15621	0.87049
1957	1.05030	1.10275	1.22807	0.89401
1958	1.19839	1.20012	1.46985	0.99329
1959	1.26016	1.20922	1.38128	1.06157
1960	1.29867	1.20896	1.49347	1.08823
1961	1.36081	1.24529	1.42598	1.06882
1962	1.30543	1.18102	1.42959	1.03085
1963	1.35190	1.18945	1.36576	1.09271
1964	1.27760	1.10070	1.41831	1.06831
1965	1.35338	1.15666	1.60473	1.07602
1966	1.39801	1.23631	1.64987	1.00043
1967	1.50488	1.22412	1.50532	1.05379
1968	1.57404	1.33905	1.64670	1.10192
1969	1.62292	1.38830	1.78594	1.17449
1970	1.52315	1.43452	1.88038	1.31079
1971	1.63112	1.37360	1.94867	1.28311
1972	1.83649	1.37247	1.93126	1.21635
1973	1.58309	1.27802	1.76173	1.28167
1974	1.59986	1.32838	1.49835	1.16269
1975	1.82529	1.56581	1.78064	1.13770
1976	1.93631	1.52566	1.79061	1.11835
1977	2.08254	1.49378	1.96521	1.07584
1978	2.28375	1.53993	2.12769	1.02466
1979	2.49815	1.71257	2.15435	1.25895
1980	2.50247	1.68243	2.19546	1.19643
1981	2.64108	1.78799	2.30483	1.37621
1982	2.97436	2.04086	2.43136	1.48440

[a]The numbers here are an index based on 1949=1.

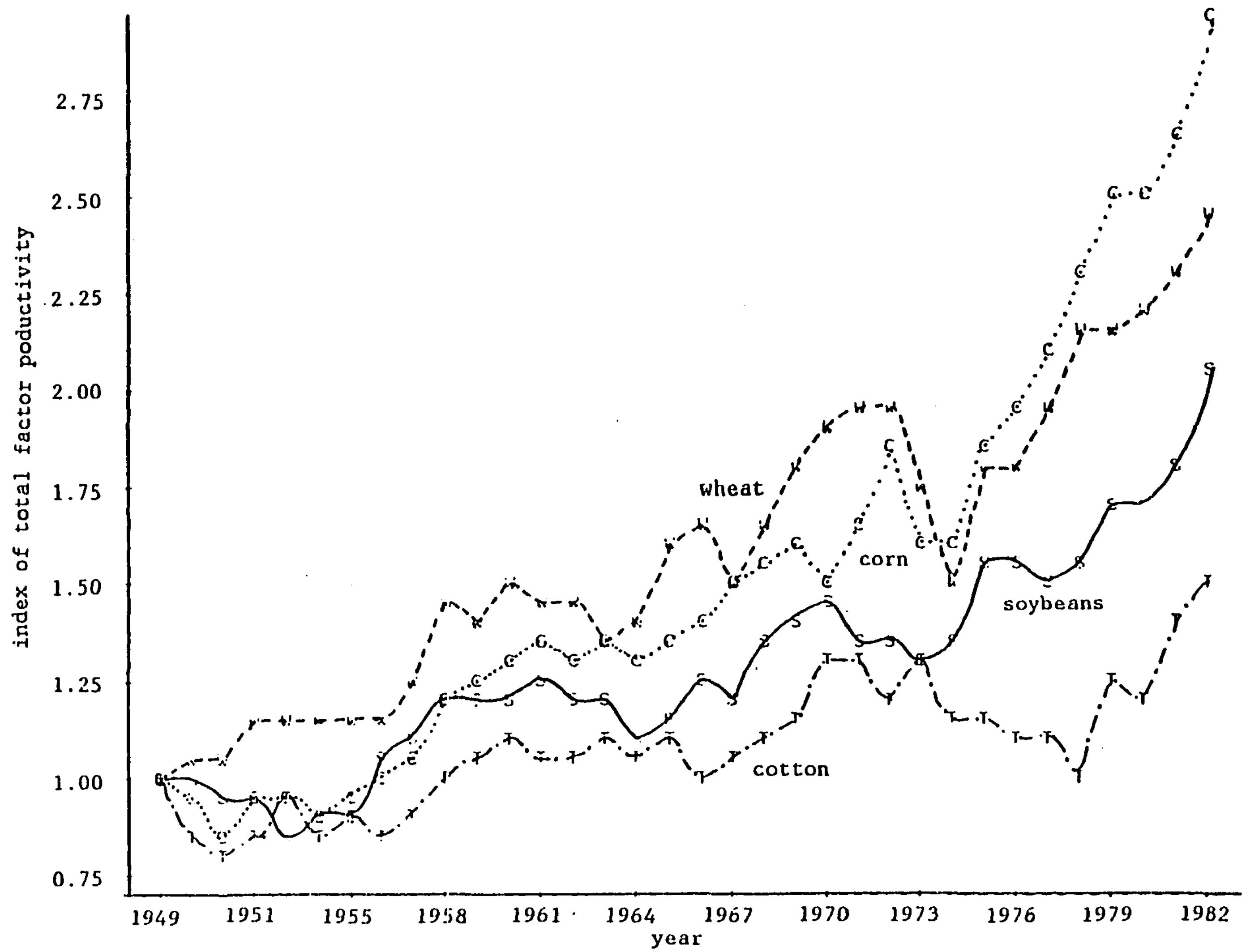

FIGURE 5-1. Comparisons of Total Factor Productivity for Corn, Cotton, Soybeans and Wheat (1949-1982)

Figures 5-2 to 5-5 show comparisons of total productivity change to changes in production and yield per acre for each crop.

For corn, it is found that the growth path of total factor productivity is very close to the growth path of production but is more smooth. Both total factor productivity and production growth are lower than the yield growth path. The higher yield growth may be due to the introduction of hybrid corn and fertilizer recommendation that often emphasize high yields/acre rather than high returns per dollar invested. The dramatic increase in fertilizer price in the 1970s may have reduced this tendency. But by 1982, these differences are very small. There may be a trend for all three of these variables to grow at the same rate in the future.

For cotton, Figure 5-3 shows that production has decreased slightly while the yield per acre has grown. The growth path of total factor productivity is between them. The decrease in production is due to declining land usage. Since total factor productivity does not grow very much over the period, the growth of yields is probably due to increases in inputs.[4]

For soybeans, the largest part of the growth of production comes from increases in land usage. Both yields and total factor productivity grow only slightly. This would seem to negate the idea that the better quality land is often devoted to soybean production.

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[4] It is also possible that the increase of yields per acre is due to the retiring of marginal land in cotton production.

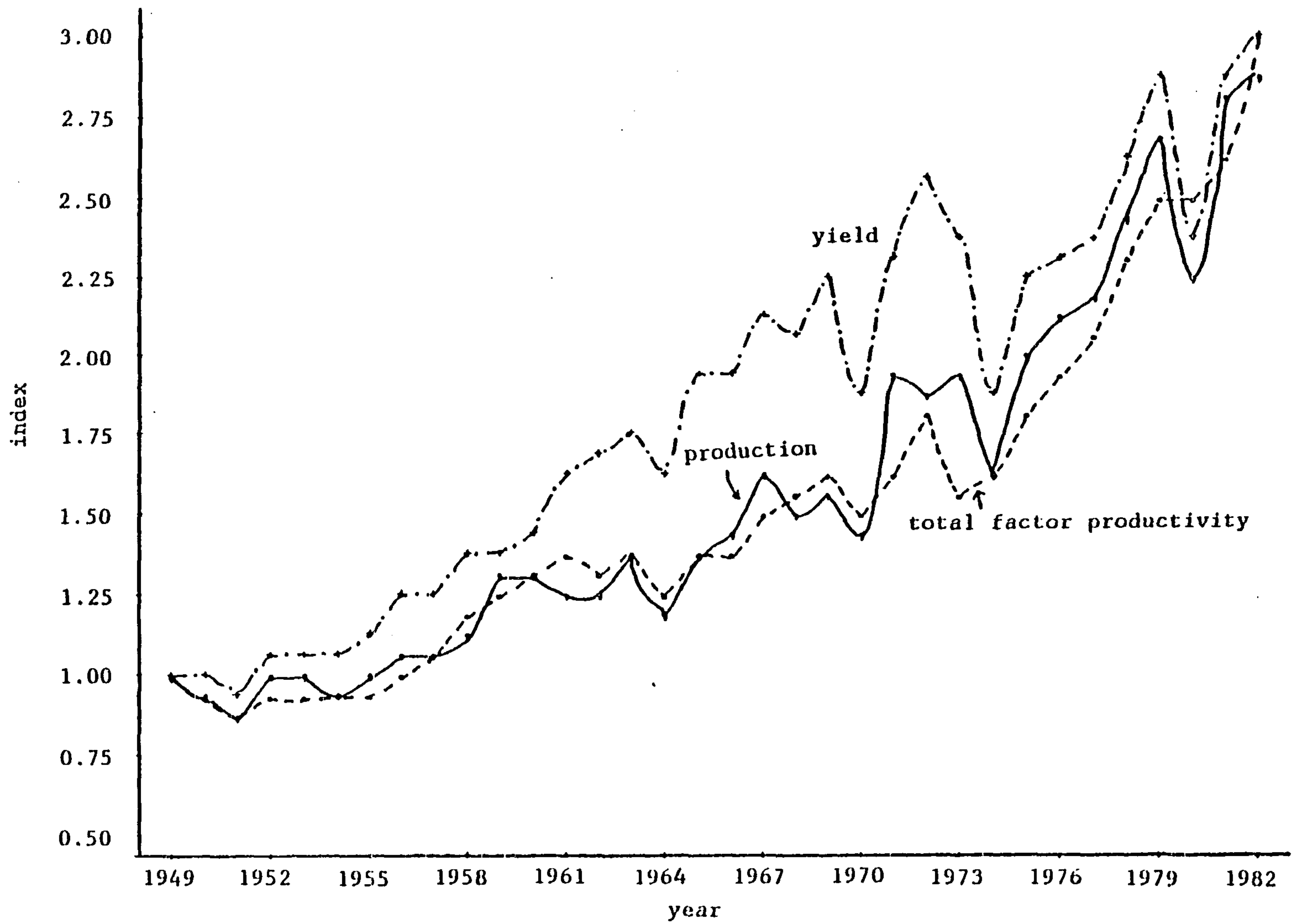

FIGURE 5-2. The Production Relationships for Corn

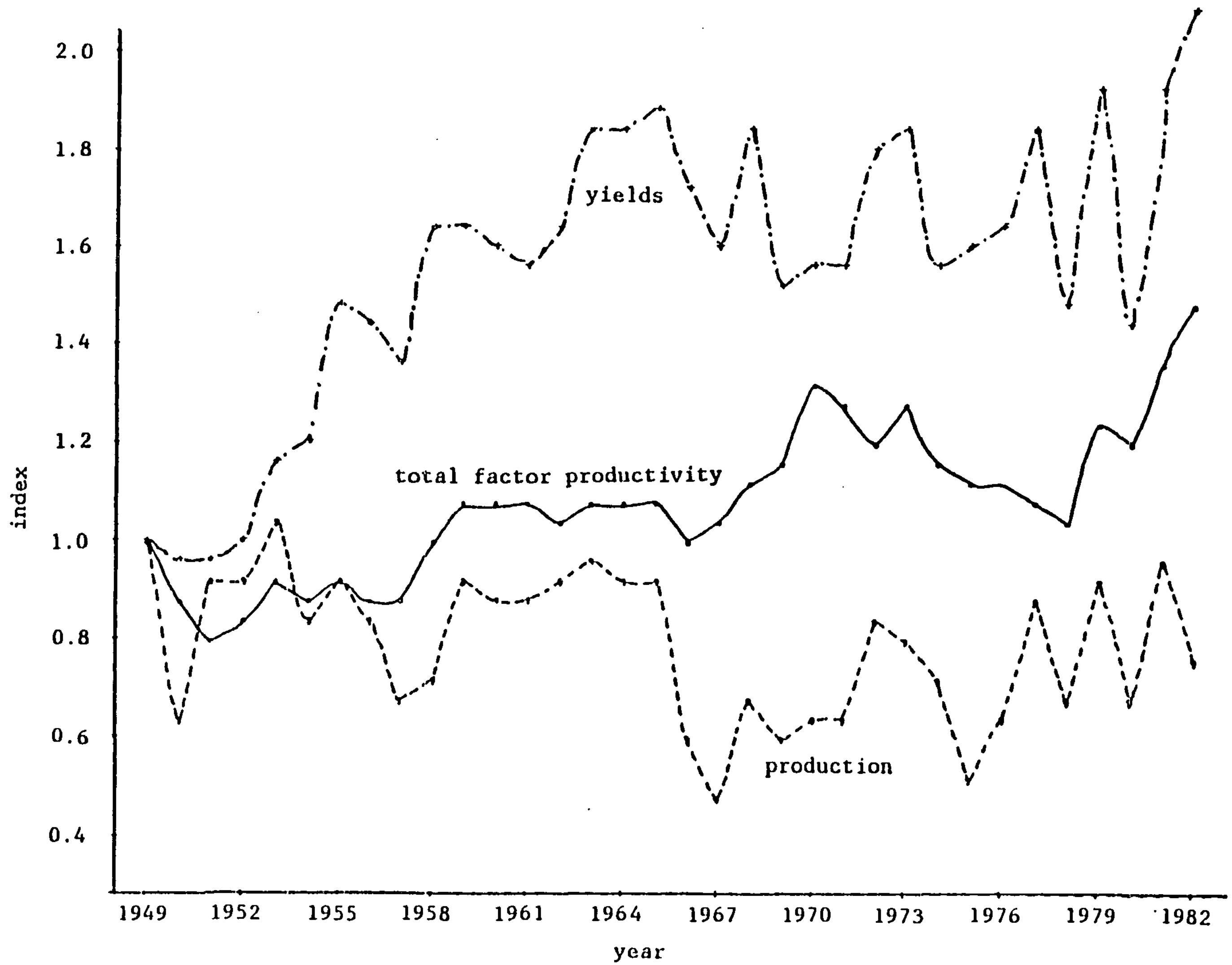

FIGURE 5-3. The Production Relationships for Cotton

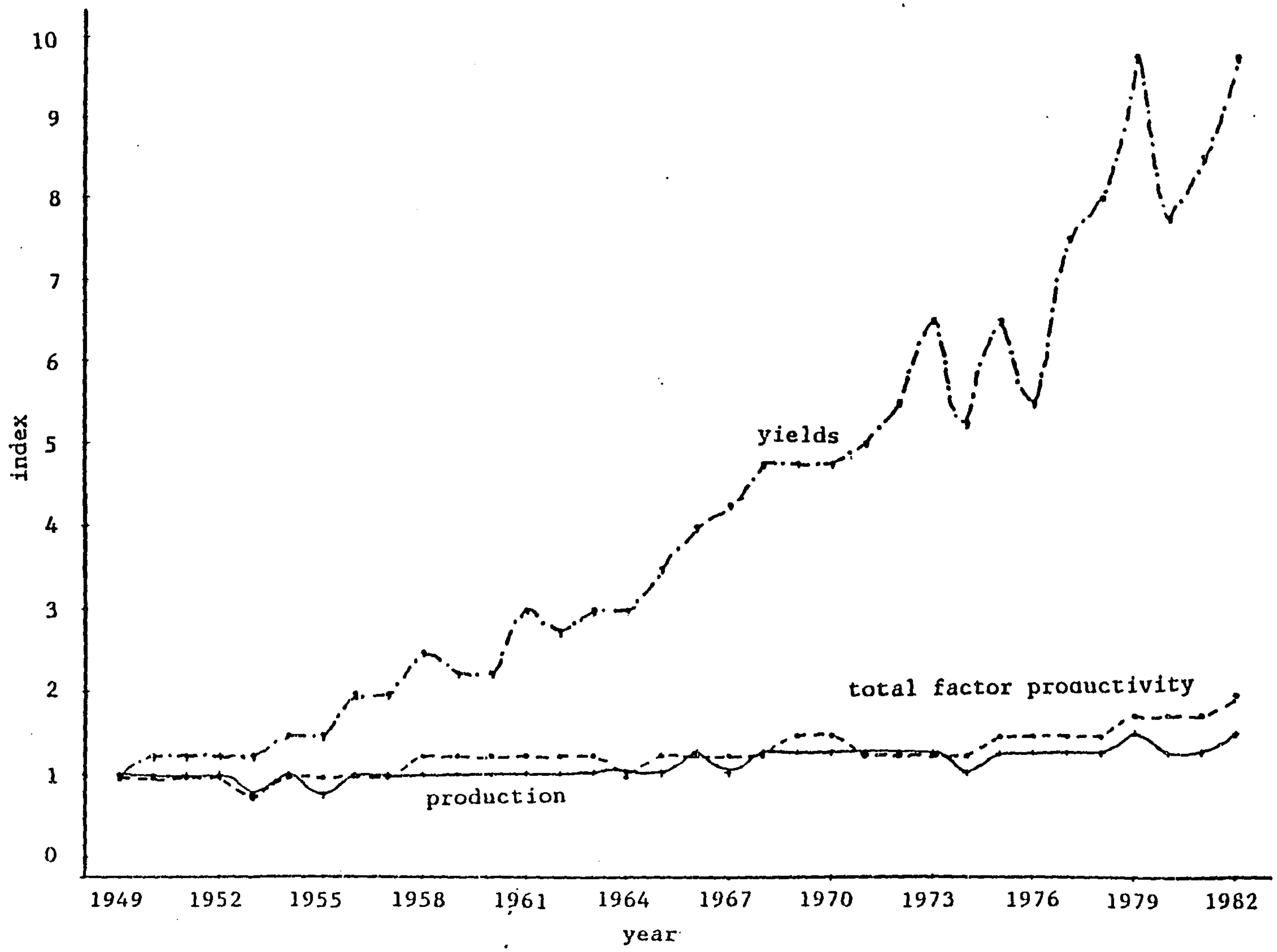

FIGURE 5-4. The Production Relationships for Soybeans

Figure 5-5 shows the production relationships for wheat. The relationship of these three variables for wheat is similar to the relationship for corn. All three variables grow in a parallel fashion and tend to move closer over time.

Comparisons of these results and the findings of Thirtle (1985) are shown in Table 5-4. Among the four crops, soybeans has the highest rate of production growth, then corn and then wheat. Cotton has a negative growth rate in production. If one considers the land used in production, one finds that soybeans again have the highest growth rate while wheat has only a slight increase. In the meantime, both corn and cotton's land usage over time has decreased. The growth rates of yields per acre for these four crops have a significantly different ranking. The growth rate for corn is the highest while soybeans becomes the lowest even though its production growth is the fastest of the group. Comparing the results found in this study and those of Thirtle's, it is interesting to note that the total factor productivity estimates of this study fall between the estimates given by Thirtle. The two studies are for different time periods and use different methods to account for unavailable data. The model in this study is based on the assumption of rational behavior of farmers in a competitive environment while Thirtle's model assumes that the unknown inputs of machinery, labor and fertilizer are used proportionally to a crops' share in the total acreage harvested. Obviously, his assumption will not be true if the market is competitive and the technological changes on different crops are not the same. This is because changes in the technology used in

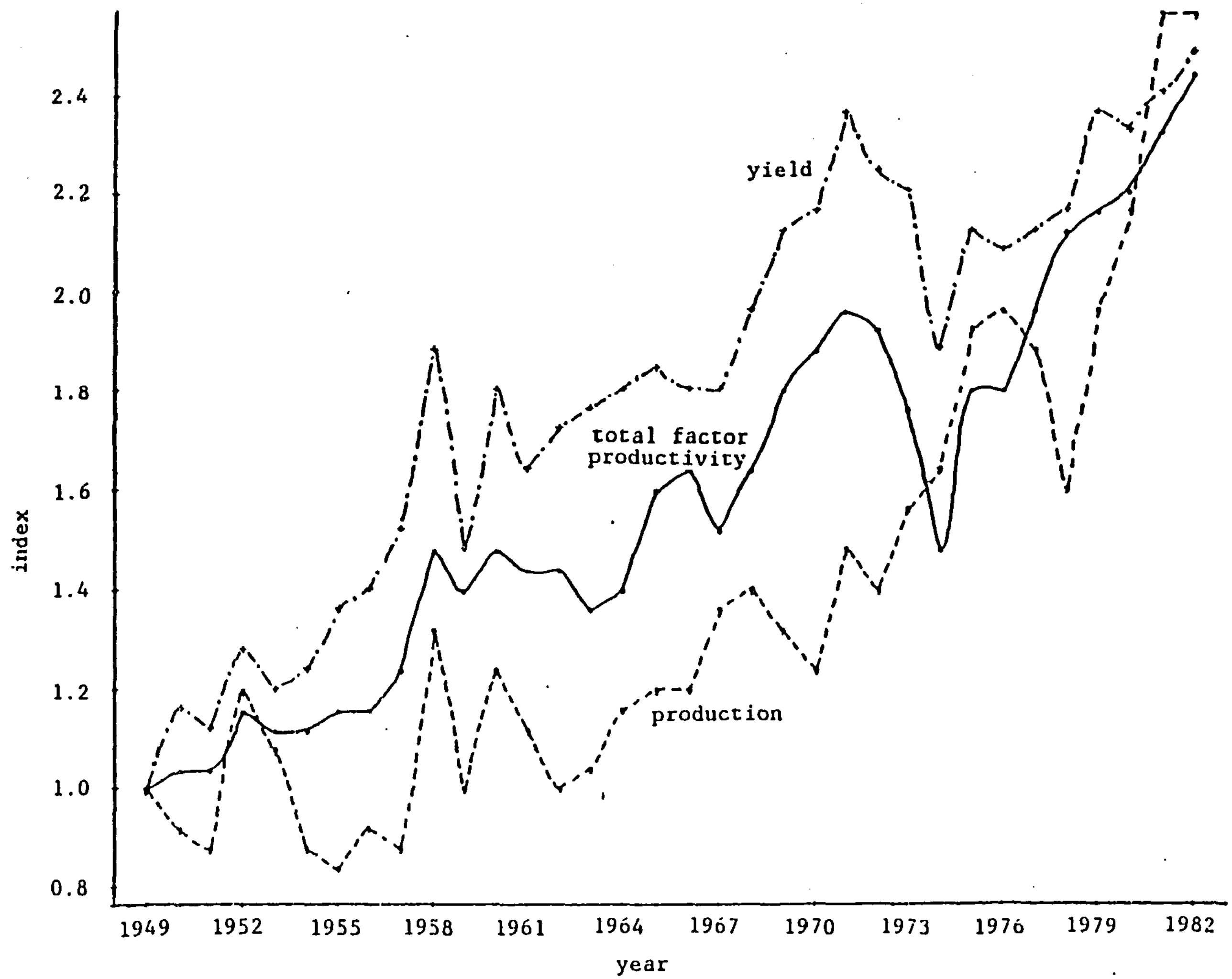

FIGURE 5-5. The Production Relationships for Wheat

crop production will cause the transfer of inputs among crops which in turn will cause changes in the share of inputs in different crops. Even so, the estimates are similar in magnitude.

TABLE 5-4. Growth Rates of Some Variables Related to Crop Production (1949-1982)

	Corn	Soybeans	Wheat	Cotton
	%	%	%	%
production	3.398	6.715	2.809	-0.653
yields per acre	3.407	1.271	2.340	1.523
acres harvested	-0.08	5.444	0.468	-2.180
total factor productity[a]	3.36	2.04	2.40	1.33
biological changes[b]	1.7	1.1	1.5	0.5
mechanical changes[b]	6.3	2.5	2.4	4.7

[a]Estimated from this study.

[b]See Thirtle (1985), the period he estimated is 1939-78.

Since Thirtle's paper is the only other study on total factor productivity for field crops, it is difficult to compare the results of this study to others for validation. But one may find it is of interest to compare the results of this study with the other findings on total factor productivity changes in agriculture as a whole.

Table 5-5 shows that other studies in agriculture give a growth rate of total factor productivity change for agriculture as a whole at around 1.75%. Comparing them to the findings of this study, one finds that except for cotton, which has only a 1.33% growth rate in its total factor productivity, the crops in this study have a higher growth rate

TABLE 5-5. Other Studies on Total Factor Productivity

Author	Sector	Growth rate
USDA(1980)	agriculture	1.70%
Ray(1982)	agriculture	1.8%
Ball(1985)	agriculture	1.75%

of total factor productivity than agriculture as a whole. In the meantime, Table 5-4 shows the growth rates of production for corn, cotton, soybeans, and wheat are 3.398%, -0.653%, 6.715% and 2.809%, respectively. It is clear that except for cotton all these crops have higher growth rates of production than the growth rate of production in agriculture as a whole. This seems plausible give the emphasis that has been placed on research in corn and wheat in particular. If it is assumed that productivity change is an important factor in causing the growth of production, then higher growth rates of total factor productivity are related to higher growth rates of production, ceteris paribus. In this sense, the findings of this study which show high growth rates in productivity are in line with aggregate data. Though this kind of comparison is not precise, it still can give some evidence to validate the findings of this study.

Summary

This chapter presented an econometric model of productivity changes for four U.S. field crops. Land allocations and fertilizer prices were found to be significant factors explaining changes in production. Using the estimates developed total factor productivity changes were computed following equation (3-7) of Chapter III. Corn had the highest rate of growth of 3.36% while cotton was lowest with 1.35% growth. Productivity in soybeans and wheat grew at rates of 2.40% and 2.04%, respectively. These results were similar to those of Thirtle's (1985) and higher than rates reported for U.S. agriculture as a whole.

CHAPTER VI. ESTIMATES OF ABSOLUTE PRODUCTIVITY LEVELS FOR FOUR FIELD CROPS

Introduction

In this chapter, the model of absolute productivity proposed in Chapter IV is estimated and analyzed. The economic meaning of the indices so calculated are explained. Comparisons between the measurements of absolute productivity changes and the physical productivity changes reported in previous chapter are presented. The next section will show the steps followed to calculate the opportunity cost for each of the crops and their absolute productivity levels over time. Comparisons between absolute productivity changes and physical productivity changes are given in the third section.

Implications of the Estimated Econometric Model

To estimate the absolute productivity change for each crop, the first step is to calculate the shadow price of each input. This represents the value of the input if there is no technical progress. By substituting the coefficients D, a, b, c and ρ as estimated in Chapter V in (4-13),

$$(4\text{-}13) \quad A_t = D^{(1/(a+b+c))} \; e^{(\rho/(a+b+c))t}$$

the augmenting technological change factor for each crop is obtained. Since Hicks neutrality is assumed this factor is the same for each input for a given crop but different among crops. The augmenting technological coefficients for each crop are shown in Table 6-1. Remember that these represent technical change plus random factors in a given year. These coefficients grow rather steadily over time reflecting improvements in the quality of inputs.

Dividing the input prices of capital, labor and fertilizer by these augmenting technological coefficients, we can find the shadow prices of each input for each crop. These shadow prices for each crop are shown in Appendix A. These shadow prices generally fall over time reflecting the improved quality of inputs. The fall is greatest for corn inputs while for cotton there is actually a slight rise in shadow prices. The labor shadow price stays close to one for soybeans and wheat while it falls for corn and rises for cotton. These general results give credence to the idea that as inputs improve in quality demand for them will increase and market price will rise.

The second step in estimating the absolute productivity indices is to estimate the unobservable inputs K, L and F which are used in the production of the crops. By using (4-14) - (4-16), the

(4-14) $K = a\,Y\,(P/I)$

(4-15) $L = b\,Y\,(P/W)$

(4-16) $F = c\,Y\,(P/R)$

estimated inputs for each crop are obtained. These are the estimated inputs assuming a Cobb Douglas technology and profit maximization. There are shown in Appendix B.

TABLE 6-1. The Augmenting Coefficients for Each Crop[a]

YEAR	Wheat	Soybeans	Corn	Cotton
1949	1.00000	1.00000	1.00000	1.00000
1950	0.96185	1.10272	0.71763	0.89827
1951	0.80666	1.06646	0.56724	0.72447
1952	0.84220	1.37192	0.67394	0.87886
1953	0.60625	1.27372	0.80482	0.90333
1954	0.70793	1.28424	0.70171	0.78987
1955	0.73389	1.37321	0.76797	0.87203
1956	0.99511	1.34289	0.69637	0.95443
1957	1.22732	1.52826	0.73611	1.07203
1958	1.56924	2.19653	0.90878	1.40952
1959	1.60678	1.90256	1.04074	1.57174
1960	1.60567	2.24577	1.09595	1.67898
1961	1.75790	2.02038	1.05467	1.85836
1962	1.47165	2.03176	0.97553	1.68947
1963	1.50477	1.83027	1.09917	1.82377
1964	1.15053	1.98666	1.04685	1.60010
1965	1.33510	2.56661	1.06282	1.81191
1966	1.62519	2.72697	0.90512	1.94533
1967	1.57465	2.22360	1.00710	2.27736
1968	2.04112	2.68742	1.10425	2.51107
1969	2.27798	3.19212	1.25786	2.68516
1970	2.51728	3.56700	1.56620	2.31662
1971	2.17996	3.85472	1.49634	2.68323
1972	2.17432	3.77824	1.33187	3.43754
1973	1.70221	3.04163	1.48296	2.37853
1974	1.91384	2.03169	1.19217	2.43476
1975	2.99313	2.88183	1.13807	3.20076
1976	2.75096	2.91768	1.09718	3.63540
1977	2.56962	3.54953	1.00907	4.24840
1978	2.82010	4.20133	0.90767	5.16490
1979	3.81766	4.31704	1.34605	6.02475
1980	3.60567	4.49999	1.20486	6.27163
1981	4.31944	4.99787	1.58730	7.04731
1982	6.24690	5.60726	1.85087	9.03282

[a]The numbers here are indices, 1949=1.

The results imply that the use of all inputs has dropped for corn, cotton, and wheat while it has grown significantly for soybeans. This is in line with the large increase in soybean acreage. Declines in labor and capital in the other crops also seem reasonable given relatively stable acreage and technologies which have been labor saving. The slight declines in capital on corn and wheat seem to be in line with historical observation but the large drop in capital used in cotton seems somewhat out of line, although acreage has fallen. The declines in fertilizer shown by the model do not seem to be in line with casual observation although no hard estimates on fertilizer use by crop exist. Aggregate fertilizer use over the period has increased, however, and so this seeming decline is somewhat anomalous. It may be due to improper model specification but more likely to the restrictiveness of the Cobb Douglas functional form. In addition the model estimates factor use as if farmers maximize profit and this may not be the case with regard to fertilizer use since fertilizer companies typically recommend usage higher than that implied by profit maximizing behavior.

Using the data on input prices, estimated input quantities, and the shadow prices of inputs for each crop, the absolute productivity index for each crop can be estimated using (4-23).

$$(4\text{-}23) \qquad 0 = \frac{P\,Y}{PY - [(I-i)K + (W-w)L + (R-r)F]}$$

These estimates are shown in Table 6-2. The average annual growth rates of these absolute productivity indices are shown in Table 6-3.

TABLE 6-2. Absolute Productivity Changes for Corn, Soybeans, Cotton and Wheat[a]

YEAR	Corn CAP	Soybeans SAP	Cotton TAP	Wheat WAP
1949	1.00000	1.00000	1.00000	1.00000
1950	0.95173	0.98759	0.84297	1.04378
1951	0.85445	0.92940	0.73466	1.02887
1952	0.94185	0.94394	0.81364	1.13903
1953	0.95426	0.82929	0.89701	1.10712
1954	0.89354	0.88436	0.83247	1.11068
1955	0.93833	0.89692	0.87486	1.13943
1956	0.97906	0.99844	0.82890	1.12990
1957	1.03103	1.06236	0.85491	1.18432
1958	1.14959	1.12990	0.95464	1.32497
1959	1.19463	1.13596	1.01888	1.27161
1960	1.22118	1.13579	1.04324	1.33291
1961	1.26083	1.15827	1.02516	1.29432
1962	1.22366	1.11306	0.98826	1.29642
1963	1.25361	1.11896	1.04462	1.25667
1964	1.20188	1.04326	1.02165	1.28802
1965	1.25108	1.08642	1.02879	1.37898
1966	1.27819	1.13885	0.95272	1.39887
1967	1.33549	1.13079	1.00335	1.32937
1968	1.36896	1.19284	1.04679	1.39414
1969	1.39098	1.21626	1.10748	1.44760
1970	1.34147	1.23615	1.20649	1.47934
1971	1.39075	1.20708	1.18629	1.50025
1972	1.46539	1.20653	1.13374	1.49495
1973	1.35058	1.15041	1.18228	1.43312
1974	1.35856	1.17832	1.08262	1.29641
1975	1.44498	1.26751	1.06093	1.41646
1976	1.48078	1.25271	1.04377	1.42032
1977	1.52081	1.24008	1.00427	1.47798
1978	1.56535	1.25716	0.95406	1.52226
1979	1.81120	1.30535	1.13858	1.52894
1980	1.60376	1.29708	1.08754	1.53892
1981	1.62424	1.32199	1.21236	1.56289
1982	1.66195	1.36278	1.27818	1.58718

[a]The numbers here are indices, 1949=1. Variables are defined in Table 5-2.

TABLE 6-3. Growth Rates Comparison Between TFP and AP[a]

Productivity Index	corn	Cotton	Soybeans	Wheat
AP	1.950	1.103	1.150	1.173
TFP	3.357	1.327	2.040	2.370

[a]The method to estimate the growth rate is the same as Table 1 in Chapter I.

Absolute Productivity Indices and Comparisons with Total Factor Productivity Indices

As was mentioned in Chapter II and Chapter IV, physical productivity measures may be misleading when comparing productivity levels among different products because they do not take in account the changes in the value of outputs and inputs. But when the value of outputs and inputs are considered, the allocation of inputs among different products will be implicitly considered. This will cause the magnitudes of absolute productivity changes to be less than that of total factor productivity. In fact at the margin these changes will all be equal across sectors. The indices of absolute productivity changes for the four crops are shown in Table 6-2. Figure 6-1 is the graphic interpretation of Table 6-2. It shows that the growth path of absolute productivity for each crop is very similar to the growth paths of total factor productivity estimated in the previous chapter. Corn still has the highest rate of productivity growth among these four crops while cotton maintains the lowest rate. But the growth paths of these productivity indices are more smooth and moderate than the physical productivity indices. From the annual growth rates shown in Table 6-3, one finds that the growth rates of absolute productivity changes on corn, cotton, soybeans, and wheat are 1.950%, 1.103%, 1.150%, and 1.173%, respectively, while the growth rates of total factor productivity on these crops, in turn, are 3.357%, 1.327%, 2.040%, and 2.370%. The difference of productivity changes among the crops become smaller although there still are differences. It is also clear that the ranking of the rate of productivity changes among crops does not change. The results are quite reasonable. The model proposed in this study combines two factors which influence the change in absolute productivity. One is changes in the market value of outputs and inputs. The other is changes in total factor productivity. Since the market value of the inputs used by a farmer are the same no matter which crop he grows, and since the market value of outputs for different crops differ over time, the allocation of inputs among crops may change to maximize profit. This effect will tend to equalize productivity changes among crops. But since there is a productivity difference among the different crops, this effect can only reduce the differences in productivity but not eliminate them.

Comparisons between total factor productivity changes and absolute productivity changes for each crop are presented in Figure 6-2 through Figure 6-5. For corn, Figure 6-2 shows that the growth path of both

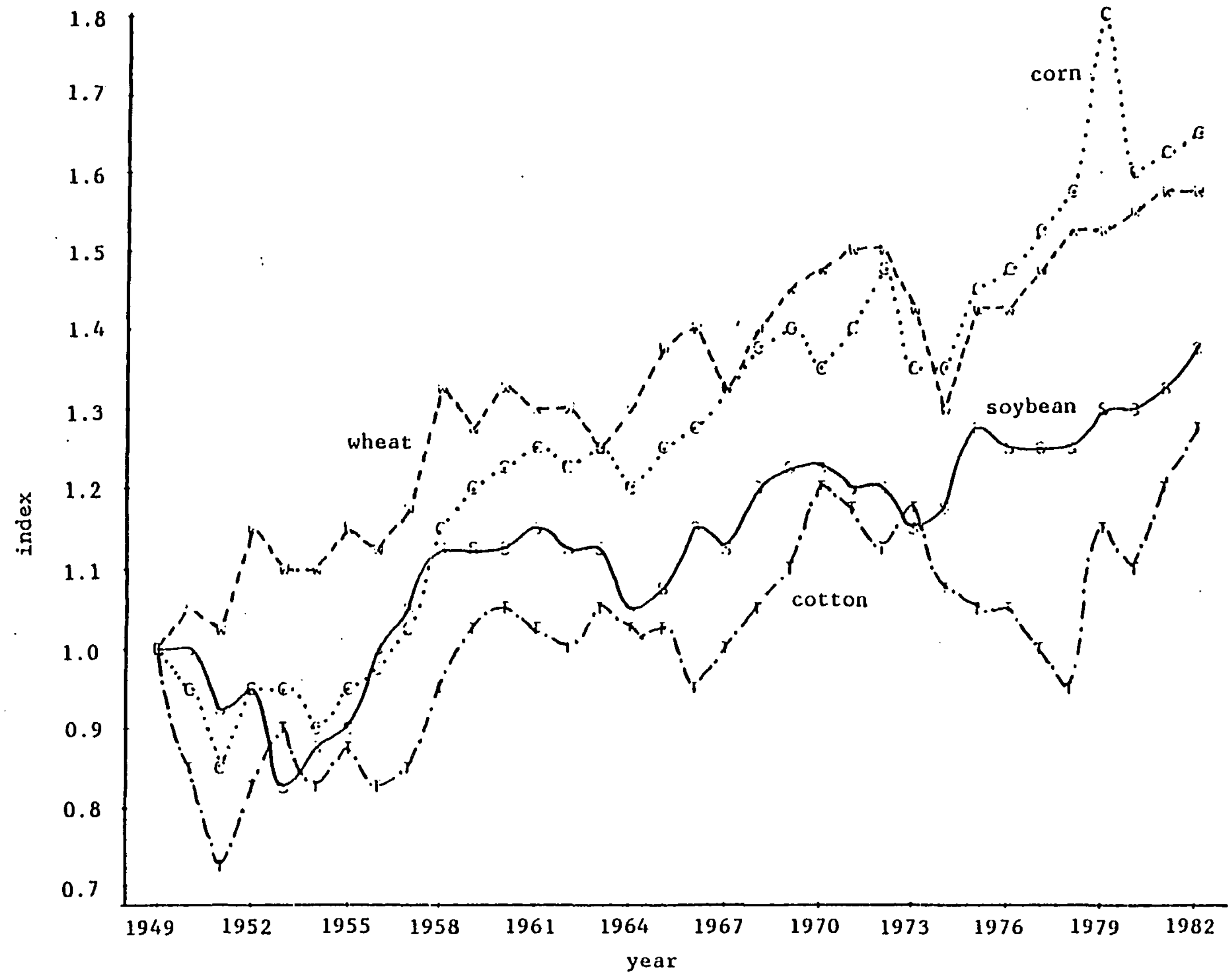

FIGURE 6-1. Comparisons of Absolute Productivity on Four Crops

productivity levels were very close before 1970. After 1970 the difference between the two paths becomes wider.

For cotton, the gap between these two productivity levels is not so large as in corn. Furthermore the two paths have grown in parallel over time.

Soybeans have the same pattern as corn. Before 1968, the two productivity levels were very close. The gap becomes large after that time. The growth paths of these two productivity levels are shown in Figure 6-4.

The growth paths of these two productivity levels for wheat are shown in Figure 6-5. It is found that gap becomes wider since the late 50s which is earlier than for the other three crops. In 1974, the gap tended to close. But after 1974, the difference increases very dramatically.

The widening in the gap between physical and absolute productivity levels in recent years is of some concern. This would imply that while physical productivity has grown in the sector, the contribution of the sector to social welfare has not grown as greatly. This may be due to the fact that increased productivity has not led to an exit of producers from the sector and the resulting drop in production. The high input price rise with moderate output price rise implies that returns in the sector have not kept par with costs and that a reduction in output may be in order.

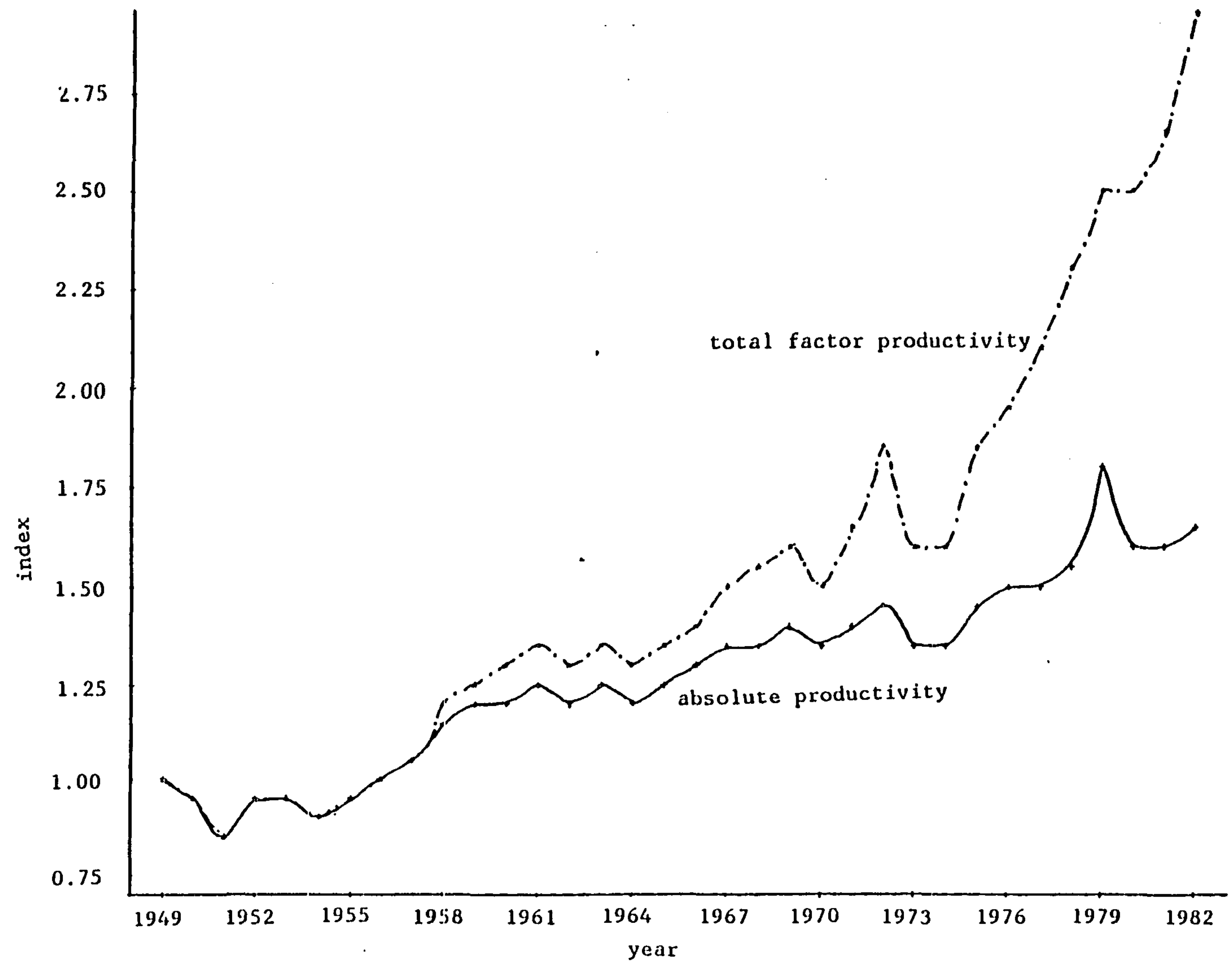

FIGURE 6-2. Comparison between TFP and AP on Corn

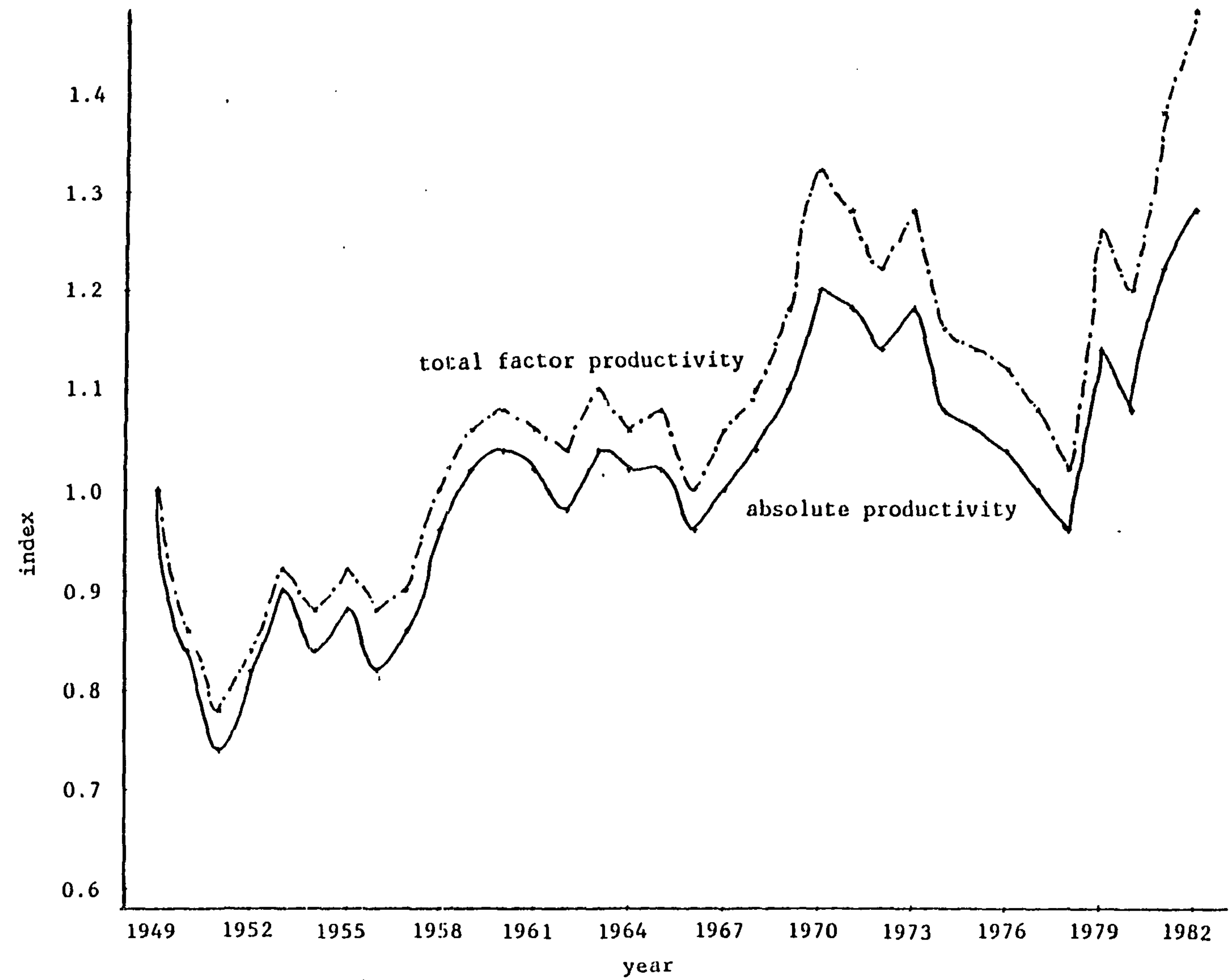

FIGURE 6-3. Comparisons between TFP and AP on Cotton

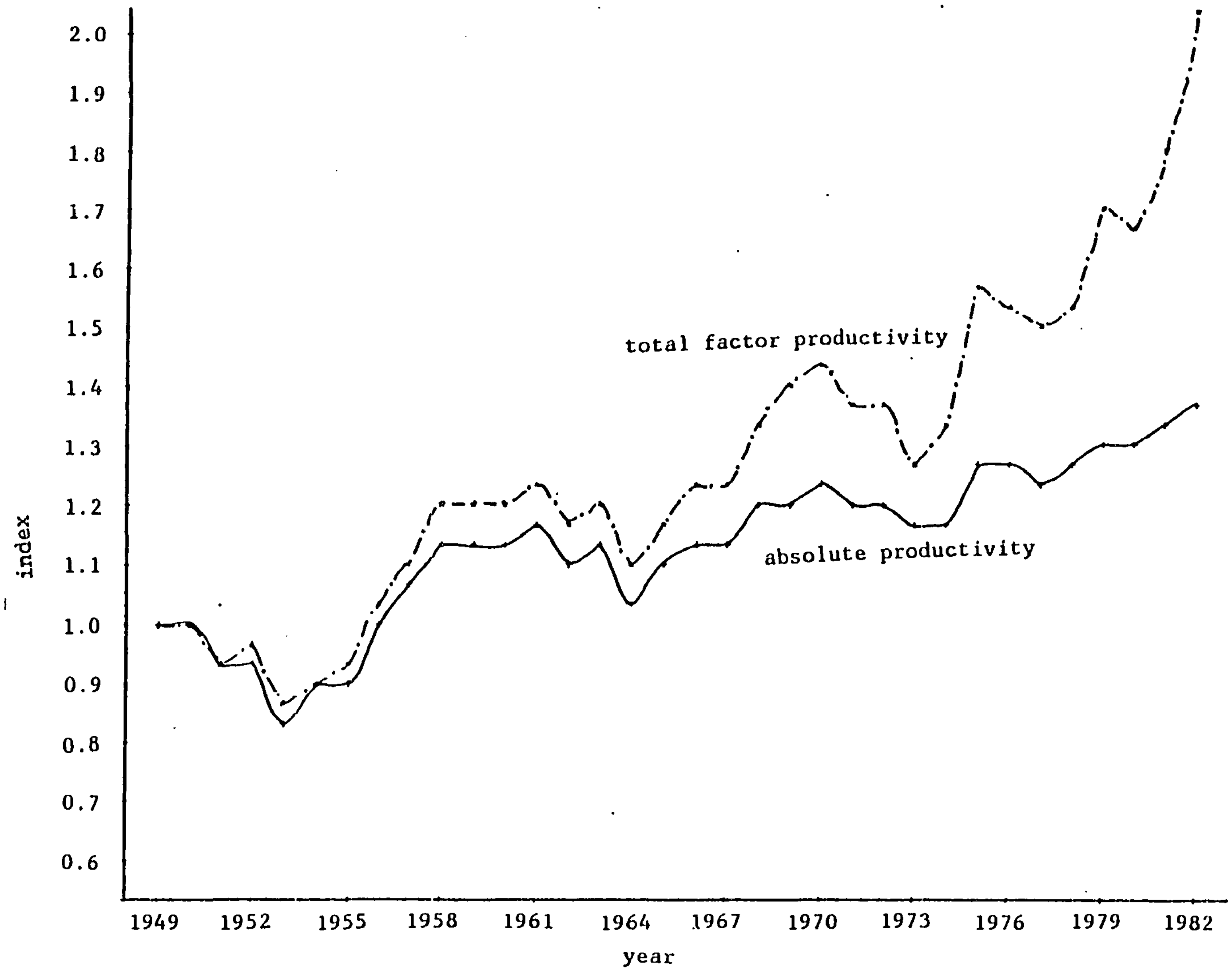

FIGURE 6-4. Comparisons between TFP and AP on Soybeans

Summary

This chapter has presented estimates of changes in absolute productivity levels for corn, cotton, soybeans, and wheat over the postwar period. These changes have been lesser in magnitude than the corresponding physical productivity estimates. They account for changes in input and output prices and represent the welfare contribution of the products to society. The increase in the gap between physical and absolute productivity measures might imply that physical productivity improvements are not as rapidly translated into welfare gains as they once were.

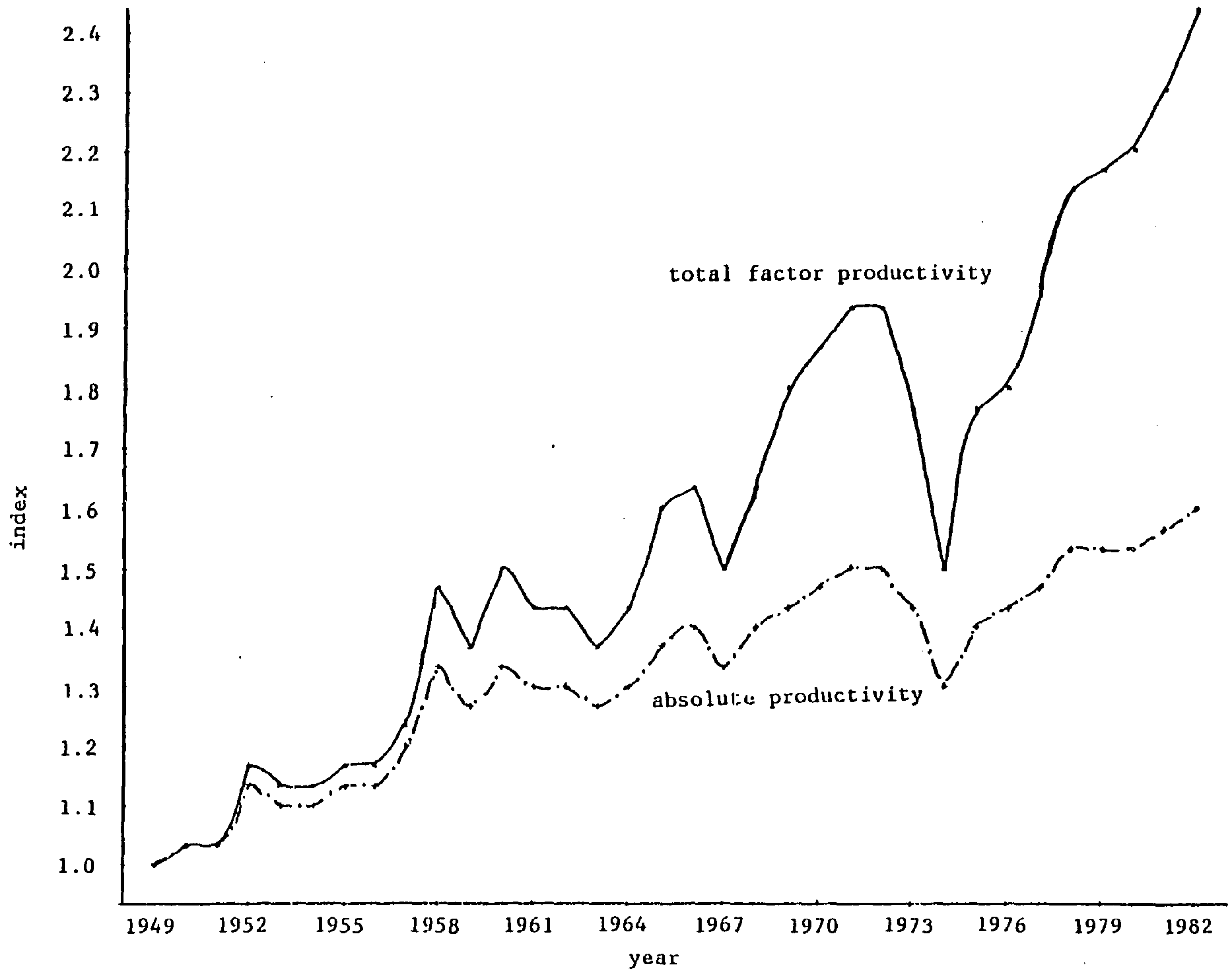

FIGURE 6-5. Comparisons between TFP and AP on Wheat

CHAPTER VII. SUMMARY AND CONCLUSION

Summary of Objectives

As many agricultural economists agree that productivity change is one of the most important sources of agricultural production growth, much time has been devoted to the study of measures of productivity growth as well as the estimation of productivity changes in agriculture. Much of the literature in the area, however, has focused on agriculture as a whole or on partial productivity for individual crops. In the area of the measurement of total factor productivity on individual crops, little work has been done. The general concern of this study is to help fill this gap. Emphasis is placed on the measurement of productivity levels for individual crops when some input data are unavailable. Also, the comparison of productivity changes among crops is considered.

The first objective of this dissertation, to measure productivity changes in individual crops, was accomplished through a model of derived production relationships as constructed in Chapter III, and estimated in Chapter V.

The second objective, to compare productivity changes among crops, was accomplished by introducing a model which considers both the change in physical productivity and the market value of output and inputs. The theoretical model was proposed in Chapter IV while its estimation was presented in Chapter VI.

Summary of Theoretical Models

In this study, the theory with respect to the measurement of total factor productivity changes for individual crops can be summarized as follows:

1. Existing measures of total factor productivity in the economic literature can not be used to directly estimate total factor productivity changes on individual crops because the data needed to do this estimation are unavailable. As a method to measure total factor productivity changes on products when some input quantities and the cost or profit from their production is unobservable, the approach proposed in this study is original. Though the model developed in the study requires some restrictive assumptions and does not give a simple index to estimate the productivity level of a product, it does provide a method to analyze productivity change.
2. The proposed method of measuring total factor productivity uses the duality between production and profit functions to derive an equation for production that depends on input quantities when data are available and input prices when quantity data are not available. In this way the derived function is a hybrid of the production and profit functions and resembles a restricted profit function with fixed inputs.

3. There are several reasons economists endeavor to estimate absolute levels of sectoral productivity.

a. Differences of absolute productivity levels can provide information on the relative efficiency of production among sectors.

b. Relative production efficiencies may direct the transfer of resources from one sector to another.

c. From analyzing differences in absolute productivity, economists may obtain information to help government decision makers choose correct policy instruments as they strive to improve the productivity level of the economy.

Few of the existing measures in economic literature can provide the above information. Physical productivity measures do provide some information but since they ignore the changes of prices of output and inputs, the results are not an accurate measure of welfare change. The deflated index as discussed by Baumol and Wolff (1984) does consider changes in the market value of outputs and inputs but fails to be connected with changes in total factor productivity. The model proposed in the study tries to combine both total factor productivity effects and market value effects. It thus provides a new approach to measure absolute productivity.

4. The proposed index of absolute productivity is based on the concept of opportunity cost in that the value of

current output is compared to the cost of production that would have occurred if there had been no technical change. Sectors with large values of output relative to these shadow costs are said to have high levels of absolute productivity.

Summary of Empirical Findings

The proposed models for total factor productivity and absolute productivity were estimated using data from four U.S. field crops. Time series data on production, land allocation and input prices for corn, cotton, soybeans and wheat were used to estimate productivity changes in the production of these crops. The results can be summarized as below:

1. Total factor productivity has grown at a rate of 3.36% for corn, 2.40% for soybeans, 2.04% for wheat, and only 1.33% for cotton.
2. The empirical findings on the changes in total factor productivity, generally match the growth path of production and yields for each crop.
3. Comparing the findings of this study with other studies on total factor productivity changes in agriculture, the results seem plausible. When compared to growth rates of total factor productivity in agriculture as a whole, the growth rates of total factor productivity for crops in this study, except for cotton are higher, but the growth rate of production on crops except cotton are also higher

than the growth rates of production in agriculture as a whole.

4. According to the findings of this study, an interesting result is that there is no plateau in the production of these four main crops. Checks with yield data show that the yield growth of some of these crops regressed in the 1970s. This caused worry of a plateau. But in the case of the growth path of total factor productivity, though in some years it falls, except for cotton, a positive growth trend is found. Considering this growth in late 1970s and more recently, the rapid growth of total factor productivity seems to imply that there will be no plateau in crop production in the near future.
5. Indexes of absolute productivity were calculated for each crop. The index was highest for corn at 1.95% and lowest for cotton at 1.10% . Absolute productivity in wheat grew at a 1.15% while soybeans productivity grew at 1.17%.
6. It is not surprising that after considering changes in the market value of outputs as well as inputs, the absolute productivity changes for each crop become more moderate and smooth than the corresponding total factor productivity estimates. The differences among crops are similar to those for total factor productivity though they are not parallel. In some years, the gap between these two measures of productivity is small and in other years,

it is large. This shows that absolute productivity is an independent measure which can be used to compare relative productivity changes for different products.

7. Using the absolute productivity index as an indicator to examine if a production or welfare growth plateau exists, the answer is that no plateau seems to exist.

Directions for Future Research

The model in this study has some restrictive assumptions. For example, in measuring the total factor productivity on individual crops the production function is assumed to Cobb-Douglas in form and technological change is assumed to be Hicks neutral. Furthermore, it is assumed that all markets for outputs as well as for inputs are perfectly competitive and that farmers are maximizing profits.

In the measurement of absolute productivity change, some assumptions are also needed. Most of the assumptions are the same as when measuring total factor productivity. One additional assumption is the assumption that the production exhibits constant returns to scale. Only when the production function is homogenous and markets are perfectly competitive (exhibit constant returns to scale), will the total cost of production be equal to the revenue of production. If this assumption is violated, the calculated index of absolute productivity change will be distorted.

The relaxing of these assumptions and the use of a more general functional form of production function would be desirable. But such extensions are difficult to implement since the approach used in this study directly solves the profit maximization problem for a given production function and then substitutes optimal quantities in terms of prices back into the original primal production function. Under this situation, only production functions which are self-dual or can be solved directly can be used.

Another important topic in the study of productivity, which is neglected in this study, is examination of those factors that cause productivity changes to differ among products and to find policy instruments which can be used to influence the progress of technology. The findings of this study, however, can be used to pursue these questions.

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APPENDIX A. THE SHADOW PRICE OF INPUTS

TABLE A-1. The Shadow Price of Inputs in Corn[a]

YEAR	CSHIT	CSHWA	CSHFI
1950	1.00000	1.00000	1.00000
1951	1.24902	1.38367	1.30879
1952	1.04463	1.19985	1.10726
1953	1.01633	1.18175	1.08417
1954	1.16233	1.33503	1.24780
1955	1.05282	1.22416	1.10878
1956	0.99421	1.17304	0.99344
1957	1.06177	1.06865	0.89029
1958	0.81848	0.84971	0.67712
1959	0.77182	0.78687	0.60326
1960	0.78678	0.75212	0.56473
1961	0.66818	0.69353	0.51694
1962	0.72977	0.77827	0.56492
1963	0.67603	0.74951	0.51990
1964	0.77053	0.87869	0.58867
1965	0.68045	0.81908	0.52330
1966	0.65868	0.82313	0.47779
1967	0.58198	0.76029	0.40265
1968	0.59971	0.74656	0.34282
1969	0.64118	0.75149	0.29736
1970	0.82492	0.92162	0.34736
1971	0.64493	0.83937	0.31153
1972	0.47523	0.69684	0.25042
1973	0.69237	1.09467	0.39339
1974	0.73606	1.20306	0.63027
1975	0.59774	0.98835	0.62365
1976	0.52446	0.95255	0.46673
1977	0.43479	0.87946	0.39057
1978	0.35594	0.77886	0.32006
1979	0.00000	0.00000	0.00000
1980	0.36369	0.75973	0.35509
1981	0.35208	0.73891	0.33902
1982	0.29907	0.59378	0.26519

[a]The numbers here are indices, 1950=1.

TABLE A-2. The Shadow Price of Inputs in Cotton[a]

YEAR	TSHIT	TSHWA	TSHFI
1950	1.00000	1.00000	1.00000
1951	1.27443	1.41180	1.33541
1952	1.08832	1.25002	1.15356
1953	0.91133	1.05966	0.97216
1954	1.04525	1.20054	1.12211
1955	0.95506	1.11050	1.00583
1956	1.08862	1.28443	1.08778
1957	1.23535	1.24334	1.03582
1958	1.01417	1.05289	0.83902
1959	0.93121	0.94936	0.72784
1960	0.96294	0.92052	0.69118
1961	0.94059	0.97627	0.72768
1962	1.00969	1.07679	0.78161
1963	0.89611	0.99352	0.68915
1964	0.94090	1.07298	0.71883
1965	0.92676	1.11557	0.71272
1966	1.13099	1.41335	0.82038
1967	1.05139	1.37350	0.72742
1968	1.08951	1.35627	0.62280
1969	1.09349	1.28159	0.50712
1970	0.97480	1.08905	0.41047
1971	0.92392	1.20244	0.44629
1972	0.97990	1.43684	0.51636
1973	0.88718	1.40265	0.50408
1974	1.20096	1.96288	1.02833
1975	1.34305	2.22069	1.40126
1976	1.38829	2.52148	1.23546
1977	1.46245	2.95809	1.31370
1978	1.61808	3.54063	1.45497
1979	1.20217	2.61932	1.06257
1980	1.51239	3.15933	1.47662
1981	1.24884	2.62090	1.20248
1982	1.16603	2.31511	1.03393

[a]The numbers here are indices, 1950=1.

TABLE A-3. The Shadow Price of Inputs in Soybeans[a]

YEAR	SSHIT	SSHWA	SSHFI
1950	1.00000	1.00000	1.00000
1951	1.20115	1.33062	1.25863
1952	1.16726	1.34069	1.23724
1953	1.62155	1.88547	1.72979
1954	1.38865	1.59496	1.49078
1955	1.33953	1.55754	1.41074
1956	1.02106	1.20472	1.02028
1957	0.99307	0.99950	0.83268
1958	0.78721	0.81725	0.65125
1959	0.80843	0.82418	0.63188
1960	0.88093	0.84212	0.63232
1961	0.75636	0.78505	0.58516
1962	0.89708	0.95669	0.69444
1963	0.87733	0.97269	0.67471
1964	1.14746	1.30853	0.87665
1965	0.98883	1.19028	0.76046
1966	0.84424	1.05501	0.61239
1967	0.90128	1.17740	0.62356
1968	0.79001	0.98345	0.45160
1969	0.80929	0.94851	0.37532
1970	0.81290	0.90818	0.34230
1971	0.85000	1.10625	0.41058
1972	0.80450	1.17964	0.42394
1973	1.03594	1.63784	0.58861
1974	1.00269	1.63883	0.85857
1975	0.68445	1.13172	0.71412
1976	0.74213	1.34790	0.66044
1977	0.76973	1.55694	0.69145
1978	0.69802	1.52740	0.62766
1979	0.56812	1.23783	0.50215
1980	0.67736	1.41499	0.66135
1981	0.61510	1.29090	0.59227
1982	0.46305	0.91937	0.41059

[a]The numbers here are indices, 1950=1.

TABLE A-4. The Shadow Price of Inputs in Wheat[a]

YEAR	WSHIT	WSHWA	WSHFI
1950	1.00000	1.00000	1.00000
1951	1.04160	1.15387	1.09145
1952	0.82151	0.94355	0.87076
1953	0.88484	1.02885	0.94391
1954	0.87760	1.00797	0.94214
1955	0.82074	0.95431	0.86437
1956	0.86745	1.02346	0.86678
1957	0.91432	0.92024	0.76665
1958	0.64476	0.66936	0.53340
1959	0.78274	0.79800	0.61180
1960	0.72209	0.69027	0.51830
1961	0.75449	0.78310	0.58370
1962	0.74494	0.79445	0.57666
1963	0.82695	0.91683	0.63596
1964	0.76185	0.86879	0.58205
1965	0.58970	0.70984	0.45351
1966	0.57683	0.72084	0.41841
1967	0.73172	0.95589	0.50625
1968	0.68790	0.85633	0.39323
1969	0.66211	0.77601	0.30707
1970	0.65769	0.73477	0.27694
1971	0.55111	0.71724	0.26621
1972	0.53079	0.77829	0.27970
1973	0.66466	1.05084	0.37765
1974	1.08286	1.76985	0.92721
1975	0.81500	1.34756	0.85033
1976	0.80220	1.45699	0.71390
1977	0.63885	1.29219	0.57387
1978	0.53716	1.17540	0.48302
1979	0.57598	1.25495	0.50910
1980	0.62223	1.29983	0.60752
1981	0.60946	1.27905	0.58684
1982	0.59142	1.17424	0.52443

[a]The numbers here are indices, 1950=1.

APPENDIX B. THE ESTIMATED INPUTS USED IN FOUR U.S. FIELD CROPS

TABLE B-1. The Estimated Inputs used in Corn Production[a]

YEAR	Capital CKAP	Labor CWAG	Fertilizer CFER
1949	1.00000	1.00000	1.00000
1950	0.99888	0.98441	1.04050
1951	1.12814	1.00360	1.12148
1952	1.22944	1.05490	1.20824
1953	1.11902	0.94843	1.09271
1954	1.14387	0.98147	1.10991
1955	1.17147	0.99290	1.15869
1956	1.26462	1.05630	1.31834
1957	1.01792	0.99672	1.26457
1958	0.91603	0.86956	1.15340
1959	0.94601	0.91448	1.26077
1960	0.89012	0.91765	1.29178
1961	0.83747	0.79518	1.12761
1962	0.94591	0.87411	1.27285
1963	1.05311	0.93610	1.42643
1964	0.93116	0.80471	1.26960
1965	1.18127	0.96712	1.60002
1966	1.06806	0.84229	1.53378
1967	1.18365	0.89293	1.78211
1968	0.83654	0.66226	1.52439
1969	0.79781	0.67085	1.79196
1970	0.63503	0.56016	1.57091
1971	1.06503	0.80647	2.29675
1972	0.88791	0.59676	1.75519
1973	1.16551	0.72650	2.13678
1974	1.02212	0.61631	1.24344
1975	1.33804	0.79750	1.33589
1976	1.20075	0.65154	1.40551
1977	1.09423	0.53313	1.26888
1978	1.14272	0.51466	1.32377
1979	1.12121	0.50714	1.32137
1980	0.81403	0.38403	0.86849
1981	1.09017	0.51192	1.17937
1982	0.82989	0.41192	0.97491

[a]The numbers here are indices, 1949=1. Variables are defined in Table 5-2.

TABLE B-2. The Estimated Inputs used in Cotton Production[a]

YEAR	Capital TKAP	Labor TWAG	Fertilizer TFER
1949	1.00000	1.00000	1.00000
1950	0.64198	0.63267	0.66872
1951	1.31901	1.17340	1.31122
1952	1.09669	0.94098	1.07776
1953	1.11755	0.94719	1.09127
1954	0.97038	0.83261	0.94157
1955	1.08587	0.92034	1.07402
1956	1.00885	0.84266	1.05169
1957	0.69423	0.67977	0.86245
1958	0.64598	0.61321	0.81337
1959	0.82230	0.79489	1.09590
1960	0.74508	0.76812	1.08128
1961	0.77443	0.73532	1.04273
1962	0.89822	0.83004	1.20867
1963	0.88077	0.78291	1.19299
1964	0.90454	0.78170	1.23330
1965	0.87905	0.71969	1.19066
1966	0.47728	0.37639	0.68539
1967	0.24472	0.18461	0.36845
1968	0.40983	0.32445	0.74681
1969	0.28006	0.23550	0.62905
1970	0.22753	0.20071	0.56286
1971	0.25137	0.19035	0.54209
1972	0.43872	0.29487	0.86725
1973	0.35688	0.22245	0.65428
1974	0.33774	0.20365	0.41087
1975	0.20793	0.12393	0.20760
1976	0.31402	0.17039	0.36757
1977	0.55542	0.27061	0.64407
1978	0.34013	0.15319	0.39402
1979	0.41276	0.18669	0.48644
1980	0.26009	0.12270	0.27749
1981	0.38446	0.18054	0.41592
1982	0.19764	0.09810	0.23218

[a]The numbers here are indices, 1949=1. Variables are defined in Table 5-2.

TABLE B-3. The Estimated Inputs used in Soybeans Production[a]

YEAR	Capital SKAP	Labor SWAG	Fertilizer SFER
1949	1.00000	1.00000	1.0000
1950	1.33630	1.31694	1.3920
1951	1.40374	1.24879	1.3954
1952	1.43793	1.23379	1.4131
1953	1.32677	1.12453	1.2956
1954	1.87834	1.61166	1.8225
1955	1.85940	1.57599	1.8391
1956	2.15502	1.80002	2.2465
1957	1.93707	1.89672	2.4064
1958	2.09502	1.98880	2.6379
1959	1.66968	1.61407	2.2252
1960	1.67457	1.72640	2.4302
1961	2.38651	2.26603	3.2133
1962	2.58075	2.38487	3.4727
1963	2.71506	2.41340	3.6775
1964	3.00477	2.59671	4.0968
1965	3.86741	3.16631	5.2383
1966	3.69599	2.91474	5.3075
1967	3.74093	2.82214	5.6323
1968	3.56893	2.82544	6.5034
1969	3.07843	2.58855	6.9144
1970	2.47715	2.18513	6.1278
1971	3.37221	2.55354	7.2721
1972	4.02390	2.70450	7.9543
1973	6.28024	3.91471	1.5137
1974	4.17822	2.51935	5.0829
1975	5.53226	3.29734	5.5233
1976	3.38054	1.83430	3.9569
1977	6.67946	3.25443	7.7455
1978	6.06706	2.73251	7.0283
1979	6.72542	3.04200	7.9260
1980	3.88095	1.83093	4.1406
1981	4.59054	2.15565	4.9661
1982	3.85661	1.91429	4.5305

[a]The numbers here are indices, 1949=1. Variables are defined in Table 5-2.

TABLE B-4. The Estimated Inputs used in Wheat Production[a]

YEAR	Capital WKAP	Labor WWAG	Fertilizer WFER
1949	1.00000	1.00000	1.00000
1950	0.96841	0.95437	1.00876
1951	0.96747	0.86067	0.96176
1952	1.18763	1.01902	1.16715
1953	1.08603	0.92047	1.06049
1954	0.99335	0.85232	0.96386
1955	0.98017	0.83075	0.96947
1956	1.05143	0.87823	1.09608
1957	0.84593	0.82830	1.05091
1958	1.19929	1.13846	1.51007
1959	0.74905	0.72408	0.99828
1960	0.89706	0.92481	1.30185
1961	0.86549	0.82178	1.16533
1962	0.82621	0.76349	1.11178
1963	0.94903	0.84358	1.28545
1964	0.99120	0.85659	1.35145
1965	0.76907	0.62964	1.04169
1966	0.67484	0.53219	0.96910
1967	0.83685	0.63131	1.25996
1968	0.68482	0.54215	1.24792
1969	0.48889	0.41108	1.09809
1970	0.38622	0.34069	0.95542
1971	0.52941	0.40088	1.14167
1972	0.52934	0.35577	1.04639
1973	0.68349	0.42604	1.25306
1974	1.04055	0.62741	1.26586
1975	1.14422	0.68198	1.14238
1976	0.99423	0.53948	1.16377
1977	0.75758	0.36911	0.87850
1978	0.55834	0.25147	0.64681
1979	0.68985	0.31202	0.81300
1980	0.75653	0.35691	0.80714
1981	0.81099	0.38083	0.87734
1982	0.70272	0.34880	0.82553

[a]The numbers here are indices, 1949=1. Variables are defined in Table 5-2.

APPENDIX C. PRODUCTIVITY RELATIONSHIPS FOR CROP PRODUCTION

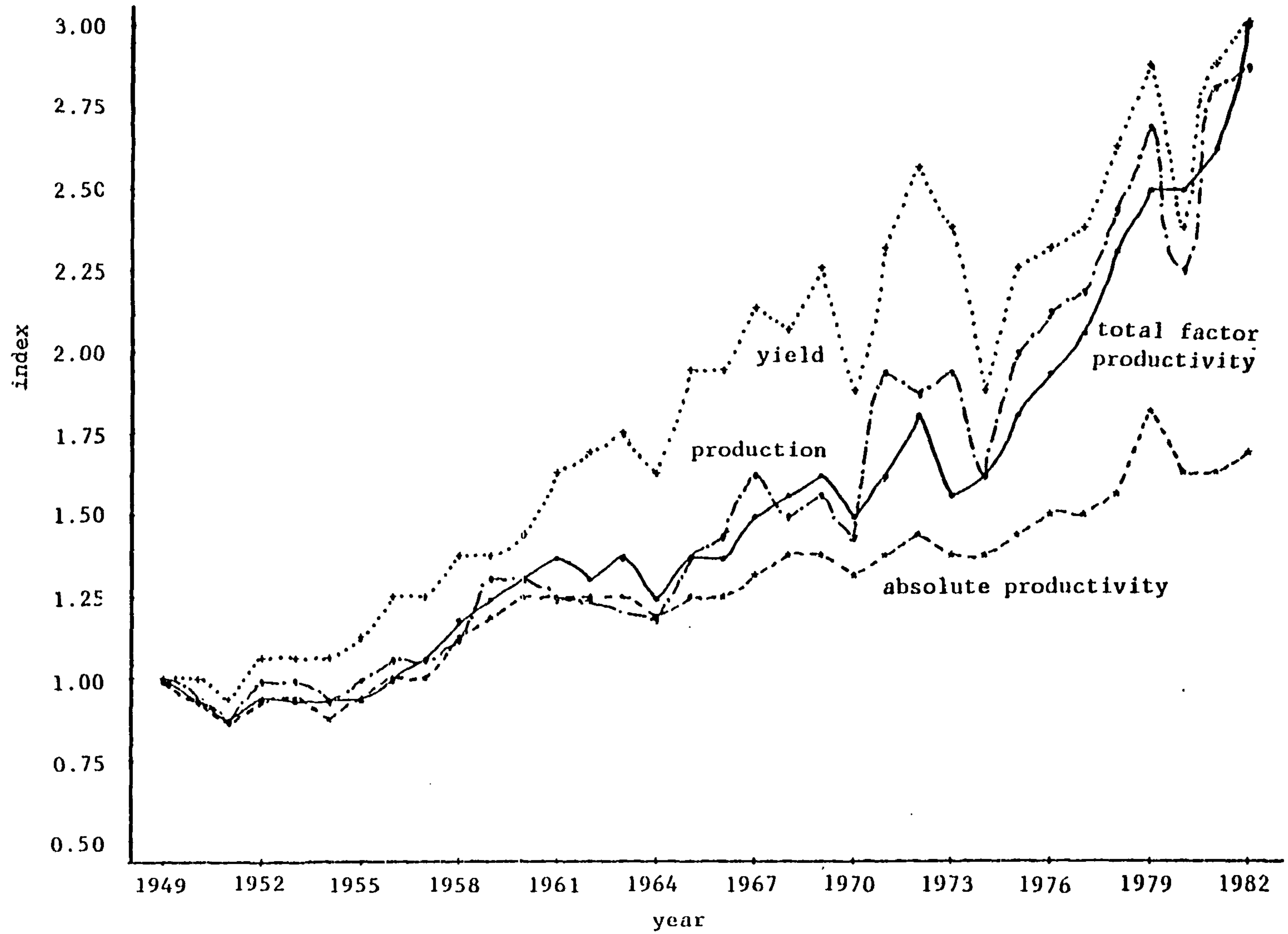

FIGURE C-1. Productivity Relationships for Corn

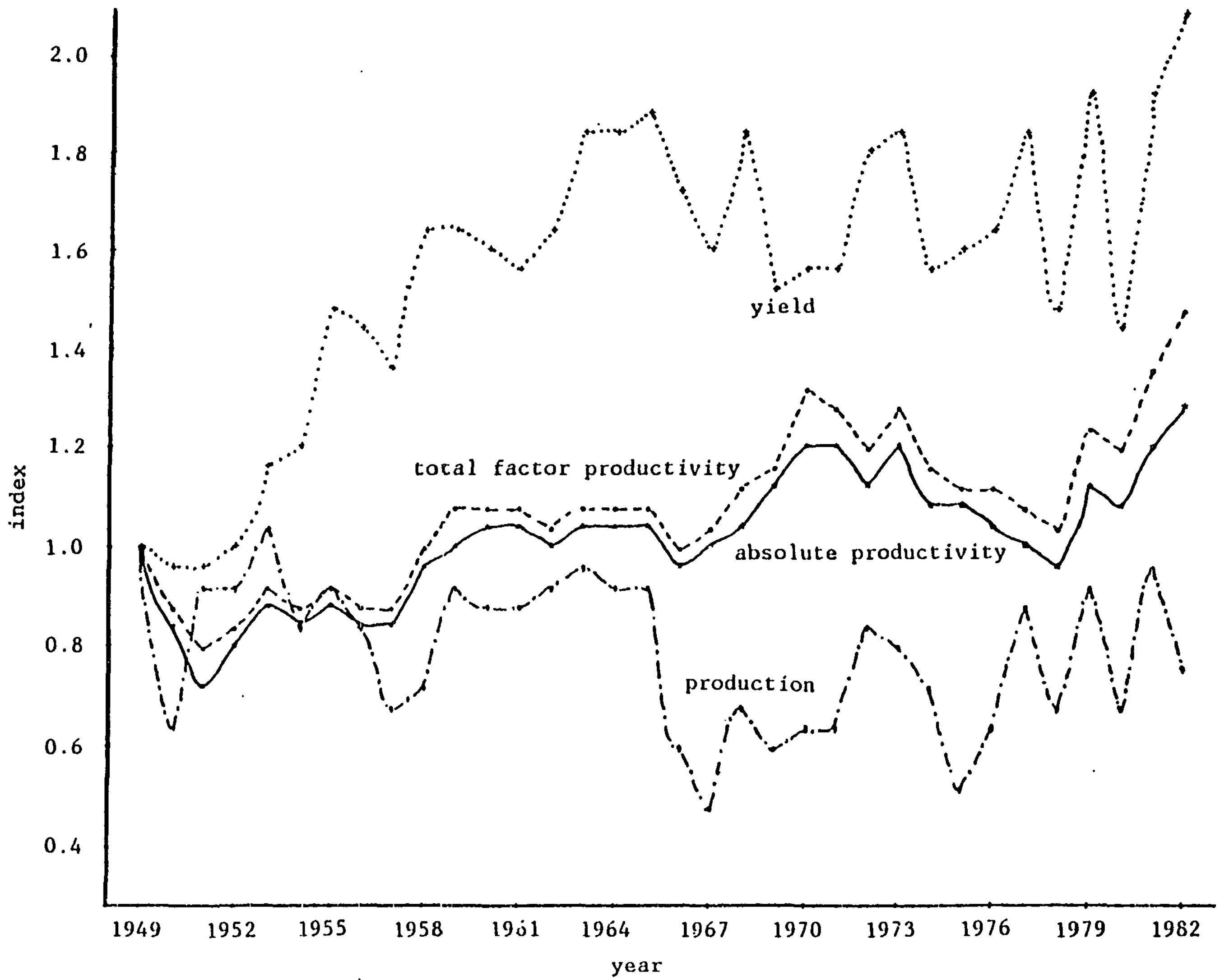

FIGURE C-2. Productivity Relationships for Cotton

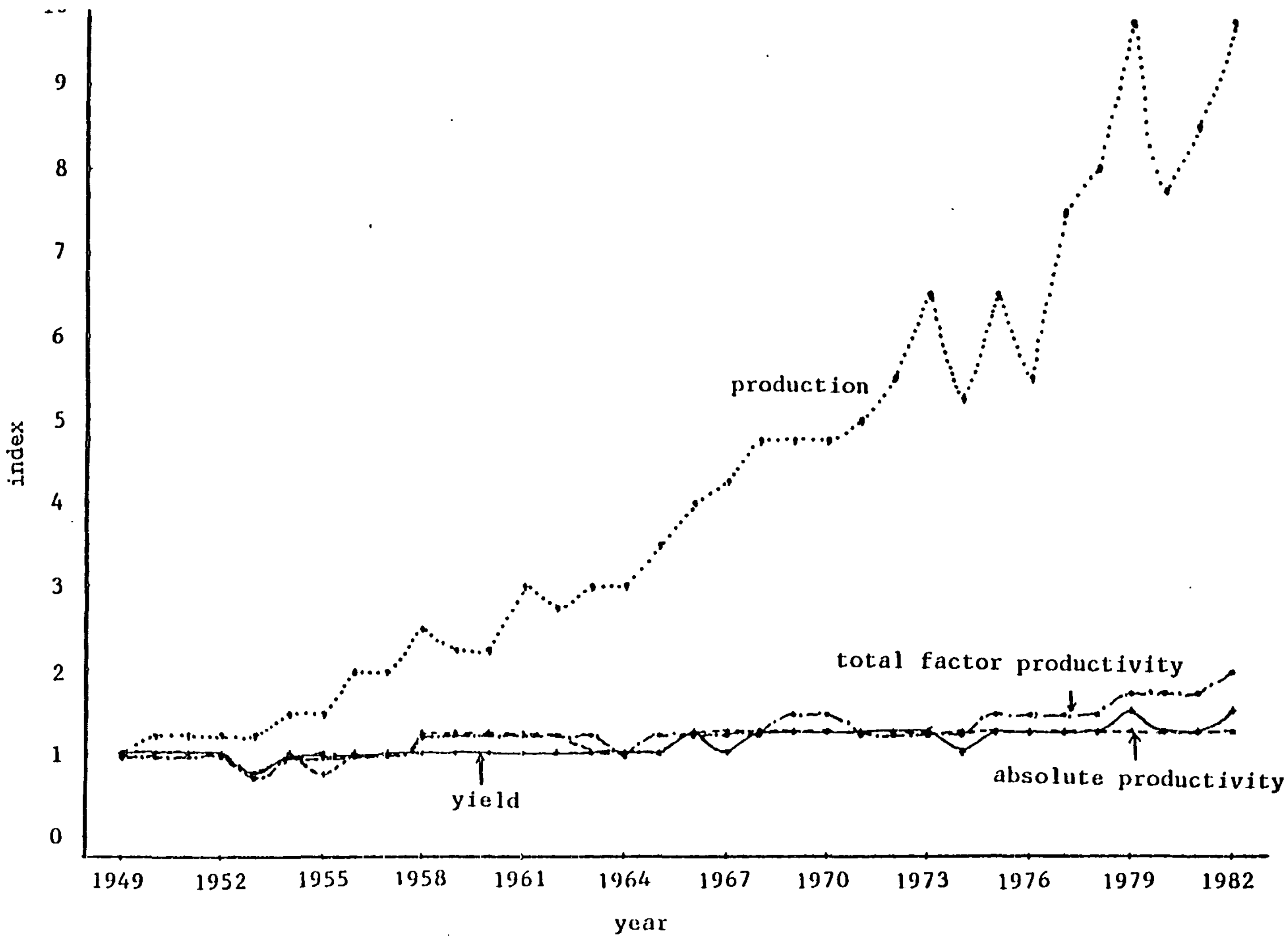

FIGURE C-3. Productivity Relationships for Soybeans

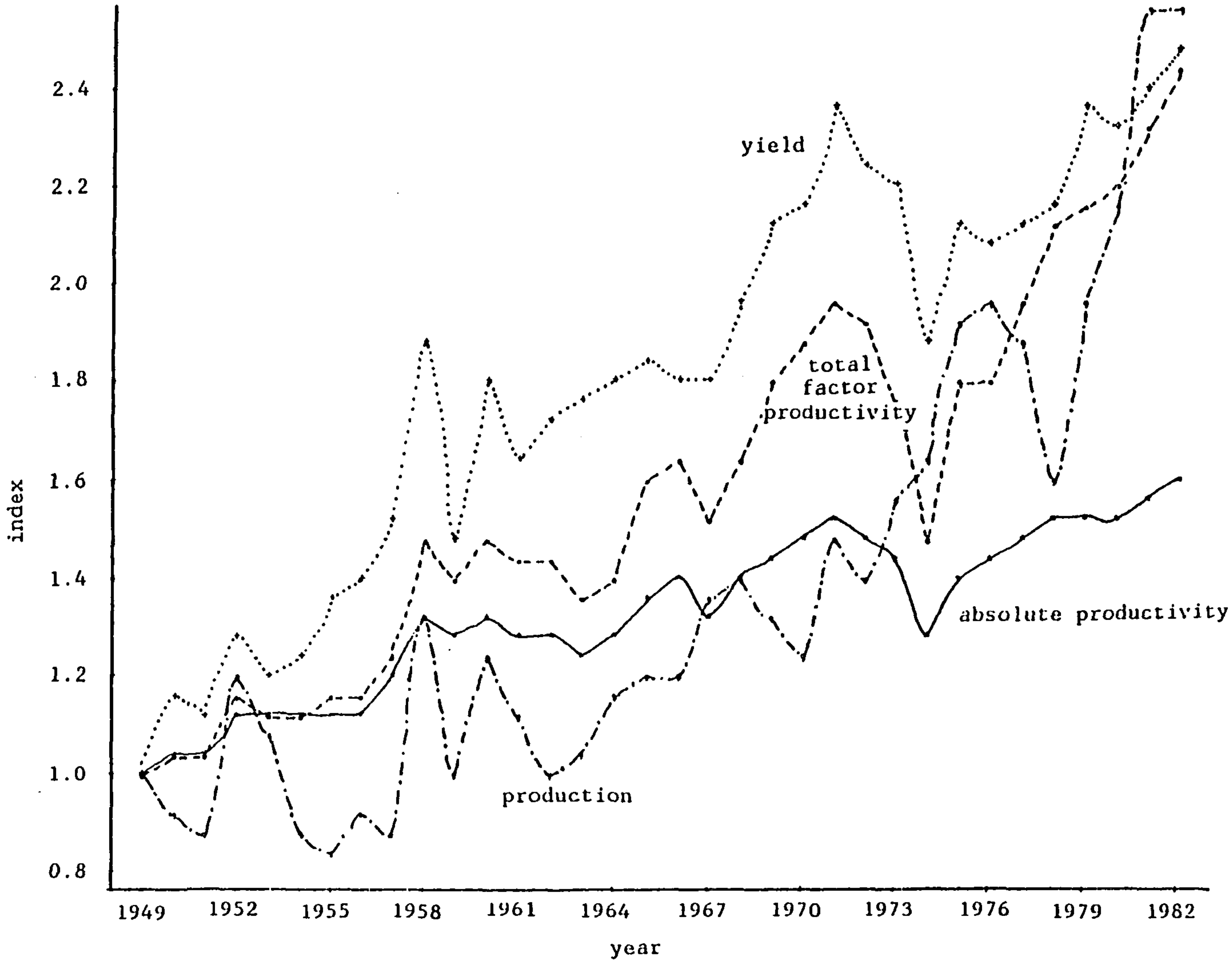

FIGURE C-4. Productivity Relationships for Wheat