PRODUCTIVITY GROWTH IN THE FLORIDA FRESH WINTER VEGETABLE INDUSTRY

Timothy G. Taylor and Gary H. Wilkowske

Abstract

Results indicate that productivity growth has been a prime factor in Florida's ability to retain a competitive position in the United States domestic fresh winter vegetable market. Total factor productivity indexes and productivity growth rates are estimated for the production of four major vegetable crops in one or more of four production areas in Florida. Florida producers have exhibited substantial productivity growth over the 1969-70 to 1981-82 period.

Key words: vegetable, production, productivity, index numbers.

For many years, Florida and the State of Sinaloa, Mexico have been the primary competitors for the United States fresh winter vegetable market. Over the course of the 1970's and into the current decade, each producing region has experienced considerable variation in its market share for the various vegetables supplied, Table 1. These variations have been the result of a variety of factors, both economic and noneconomic in origin.

It is generally argued that Mexican growers enjoy a comparative advantage in producing fresh winter vegetables (Zepp and Simmons). Favorable growing conditions combined with abundant water and relatively inexpensive labor afford Mexican producers production costs lower than those of their Florida counterparts. The recent peso devaluations, while somewhat offset by rapid inflation in Mexico, have perhaps further strengthened this comparative advantage.

In view of such a comparative cost advantage, it is not difficult to foresee a rather dim future for Florida vegetable producers. Indeed, in bilateral negotiations between Florida and Mexican producers in 1969, the Mexican producers *"argued their case from the confident presupposition that their comparative advantage, in climate and low wages, would ultimately give them dominance in the U.S. Market"* (Bredahl et al., p. 18).

In response to this situation, Florida growers, led by the Florida Tomato Exchange (FTE) have twice attempted to obtain some form of protection from the importation of Mexican vegetables by imposing implicit dual size

TABLE 1. FLORIDA AND MEXICAN SHARES OF THE U.S. DOMESTIC FRESH WINTER VEGETABLE MARKET FOR SELECTED VEGETABLES, 1969-70 TO 1981-82

Season	Tomatoes[a]			Squash			Peppers			Cucumbers		
	Florida	Mexico	Other	Florida	Mexico	Other	Florida	Mexico	Other	Florida	Mexico	Other
	Percent											
1969-70	32	56	12	32	21	47	44	33	23	46	39	15
1970-71	41	51	8	35	20	45	40	41	19	36	51	13
1971-72	43	48	9	37	21	42	49	32	19	45	41	14
1972-73	39	48	13	40	22	38	49	33	18	42	44	14
1973-74	43	41	16	36	22	42	47	38	15	42	45	13
1974-75	51	37	12	45	19	36	59	24	17	55	31	14
1975-76	49	38	13	40	22	38	55	26	19	47	41	11
1976-77	39	48	13	41	26	33	36	22	42	42	46	12
1977-78	42	43	15	36	28	36	41	30	29	39	50	11
1978-79	51	39	10	37	31	32	41	30	29	38	45	17
1979-80	55	35	10	47	24	29	41	45	14	35	55	10
1980-81	58	29	13	45	21	34	49	33	18	36	52	12
1981-82	59	28	13	39	40	21	42	39	19	39	44	17

[a]Does not include cherry tomatoes.
Source: U.S. Department of Agriculture, Agricultural Marketing Service, Federal-State Market News, *Marketing Florida Vegetables,* Winter Park, Florida, various issues.

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restrictions for mature green and vine ripe tomatoes and the anti-dumping petition filed by the FTE in 1978. Both attempts were eventually unsuccessful. However, despite these failures, Florida producers have generally retained or increased their market shares in the United States winter vegetable market since the 1969-70 season. In a recent monograph analyzing international trade in fresh winter vegetables, Bredahl et al. (p. 36) maintained that "*technological change, not protection from imports, rejuvenated the Florida industry*."

To support this conclusion, Bredahl et al. analyzed yield data for various vegetable crops in Florida and Mexico over the period 1965-66 to 1981-82. By forming a smoothed 3-year moving average series of yields and examining the movement of the relative price of labor to produce price over the same period, it was concluded that Florida winter tomato and cucumber production had indeed exhibited technical progress.

While the analysis conducted by Bredahl et al. tends to support their hypothesis concerning technical change on Florida's competitive position, their approach has no theoretical basis and must be viewed with some caution. In a sense, if land is considered as a primary factor of production, yield (per acre) actually corresponds to a partial productivity measure (Kendrick, p. 17). Given this interpretation, an upward trend in yield may be indicative of technological progress, but it may also be a manifestation of an increase in the use of other factors of production.

The purpose of this paper is to provide a more rigorous analysis of productivity as related to fresh winter vegetables in Florida. Utilizing the economic theory of index numbers, total factor productivity indexes are obtained for tomato, cucumber, pepper, and squash production in various production areas in Florida over the 1969-70 to 1981-82 period. In addition, annual rates of productivity growth for each crop over the period of analysis are estimated.

TOTAL FACTOR PRODUCTIVITY MEASUREMENT

The concept of total factor productivity (TFP) may be tied to the notion of disembodied technical change. Any action which leads to an increase in total real output per unit of total real input leads to an increase in TFP. Thus, improvements in technical, allocative and organizational efficiency as well as the adoption of technological innovations contribute to growth in productivity. This rather loose notion of the determinants of TFP has led to its sometimes being referred to as a residual measure of the effects of excluded factors of production or unobserved quality changes.

The measurement of TFP can be approached from an econometric standpoint in a continuous time framework or in the context of discrete time using concepts involving aggregation and the economic theory of index numbers. While these two alternatives differ rather substantially as to methodological considerations, they appear to share a common origin in the pioneering work of Solow. Using an aggregate production function with Hick's neutral technical change, Solow associated TFP growth with the time derivative of the production function. Given estimates of the production function, or other dual function, rates of productivity growth may be directly obtained. Recent examples of this approach are found in Caves, Christensen and Swanson, and Langham and Ahmad.

Solow's model also implied that under constant returns to scale, productivity growth could be estimated without estimating the underlying production parameters. Indeed, when Solow's expression for productivity growth is integrated (see Diewert, 1980, p. 443), the resulting measure of TFP is expressible as the ratio of real output to a Divisia (1926) index of total input.[1] By choosing quantity indexes which are discrete approximations to Divisia output and input indexes, an index of TFP may be obtained. Some significant examples of this approach are found in Christensen and Jorgenson (1969, 1970).

For some time, this approach to measuring TFP was considered to be somewhat *ad hoc*. While there were a variety of index number formulations (e.g., Laspeyres, Paasche, Ideal, Tornqvist) which could be considered as discrete approximations to the Divisia index, there existed no apparent theoretical basis to guide the choice among these various discrete approximations. The choice of index number formulae and resulting TFP measures could not be directly tied to the production structure or optimizing behavior.

This situation changed when the seminal paper by Diewert (1976) introduced the notion of exact and superlative index numbers. Given the aggregator (production) function:

$$(1)\ Y_t = f(X_t); \quad t = 0,1,\ldots,T$$

where Y_t is output and X_t is a n-dimensional vector of strictly positive inputs, the quantity

[1] Solow's formulation was cast in the context of a single output production process. Similar reasoning in a multiple output context yields a measure of TFP equal to the ratio of a Divisia index of total output to a Divisia index of total input (Richter, Jorgenson and Griliches).

index $Q(P_0, P_t; X_0, X_t)$ is said to be exact for $f(X_t)$ if the relation:

$$(2)\ Q(P_0, P_t; X_0, X_t) = f(X_t)/f(X_0)$$

holds. Thus, given a specific functional specification for the underlying production function, a specific form for the corresponding quantity index is directly implied.

When the underlying aggregator function is a member of the class of flexible functions, the quantity index in equation (2) is termed superlative. Thus, exact and superlative index numbers may be directly related to a specific form of the production function[2] wherein assumptions concerning the structure of the underlying technology (e.g. elasticities of substitution, scale, etc.) may be quite general.

Perhaps the most commonly used superlative quantity index is the Tornqvist index. Recent examples of its use in productivity measurement are Caves, Christensen and Diewert (1982a) and Heien. The Tornqvist index is exact for the homogeneous translog production function. Thus, it is theoretically consistent with quite general production technologies.

To demonstrate this,[3] assume that the production function for each crop analyzed is given by $Y_t = f(X_t)$, where:

$$(3)\ f(x_t) = \alpha_o + \sum_{i=1}^{n} \alpha_i \ln X_{it} + 1/2 \sum_i \sum_j \gamma_{ij} \ln X_{it} \ln X_{jt},\quad t = 1, \ldots, T;$$

$$\gamma_{ij} = \gamma_{ji},\ i \neq j;\ \Sigma\alpha_i = 1;\ \sum_i \gamma_{ij} = 0,\quad j = 1, \ldots, n$$

and X_{it} denote inputs ($i = 1,\ldots,n$) while Y_t denotes output. Producers are furthermore assumed to maximize current profits in each period given output price, P_t, and input prices $W_t = (W_{1t},\ldots,W_{nt})$.

To obtain the TFP index between the base period, say $t = 0$, and the t^{th} period, assume that $X^* = (X^*_{1o},\ldots,X^*_{no})$ and Y^*_0 denotes the solution to the base period profit maximization problem:

$$(4)\ \underset{X,\,Y}{\text{MAX}} \left\{ P_0Y_0 - W_0 \bullet X_0 \,\middle|\, f(X_0) = Y_0 \right\},$$

where $W_0 \bullet X_0 = \Sigma W_{i0}X_{i0}$ and $f(X_0)$ is the translog production function defined in equation (3). If productivity growth occurs in a neutral manner (i.e. a radial expansion of the isoquant), the expression

$$(5)\ Y_t = (1 + \tau_t)\, f(X_t)$$

may be obtained, where again $f(X_t)$ is defined as in equation (3). In this equation, the term $(1 + \tau_t)$ corresponds to the increase ($\tau_t>0$) or decrease ($\tau_t<0$) in TFP between the base period and period t.

During period t, the profit maximization problem reflecting productivity growth can be written as:

$$(6)\ \underset{X,Y}{\text{MAX}} \left\{ P_tY_t - W_t \bullet X_t \,\middle|\, (1 + \tau_t)\, f(X_t) = Y_t \right\}.$$

Denoting the optimal output and input levels by Y^*_t and $X^*_t = (X^*_{1t},\ldots,X^*_{nt})$, respectively, and combining these results with those obtained from equation (4) yields:

$$(7)\ Y^*_t/Y^*_0 = (1 + \tau_t)\, f(X^*_t)/f(X^*_0).$$

Rearranging this expression yields a measure of TFP relative to the base period:

$$(8)\quad (1 + \tau_t) = \frac{Y^*_t}{Y^*_0} \div \frac{f(X^*_t)}{f(X^*_0)}.$$

Finally, since by assumption $f(X_t)$ corresponds to a linear homogeneous translog production function and the Tornqvist quantity index is exact for the expression $f(X^*_t)/f(X^*_0)$, equation (8) may be rewritten as:

$$(9)\ (1 + \tau_t) = \frac{Y^*_t/Y^*_0}{\prod_{i=1}^{n} \left(\dfrac{X^*_{it}}{X^*_{io}}\right)^{1/2\,(S_{io} + S_{it})}},$$

where S_{it} denotes the cost share of the i^{th} input.

Development of the TFP index in equation (9) was first offered by Diewert (1976) in order to more rigorously justify the measures of TFP used by Christensen and Jorgenson (1970). Thus, if producers follow profit maximizing behavior and technology is characterized by a linear homogeneous translog production function, equation (9) provides an exact discrete measure of TFP. This, it should be emphasized, is in contrast to considering this expression as a discrete approximation to a Divisia index.

Perhaps not surprisingly, the TFP measure in equation (9) can be obtained from several different, but related, sets of assumptions. Diewert

[2] Exact and superlative price indexes are defined in similar fashion by appealing to the dual unit cost function.
[3] This derivation draws heavily on Diewert (1976).

(1980, p. 489-491) demonstrated that the right-hand side of equation (9) can be obtained from a "time modified" linearly homogeneous translog production function. In this case, the above TFP measure is tied to a strong form of Hick's neutral technical change.

Caves et al. (1982b) demonstrated that under the assumption of constant returns to scale, equation (9) can be interpreted as the geometric mean of two Malmquist input (output)[4] based productivity indexes. This formulation, which is based on distance functions, avoids input output separability assumptions. Further, Caves et al. (1982b) generalized equation (9) to include technologies with non-constant returns to scale.

EMPIRICAL RESULTS

Total factor productivity indexes were computed for tomato, squash, pepper, and cucumber production in one or more of four major production areas in Florida over the 1969-70 to 1981-82 period. Estimation of equation (9) requires data on output, inputs and their cost shares for each crop.

Productivity was measured on a per acre basis. Thus, output was measured as yield per harvested acre. Inputs were also measured on a per acre basis. Specific inputs utilized in the analysis included seed/transplants, fertilizer, agricultural chemicals, energy,[5] cultural labor, harvest labor, capital services, and a miscellaneous category. All data were obtained from Brooke, Taylor, and Taylor and Wilkowske.

To obtain "physical" input measures, per acre expenditure data on the various input categories were deflated by a corresponding prices paid index.[6] Thus, inputs utilized in the analysis correspond to constant (1977 = 100) dollar input series. The capital input measure is a proxy for the service flow of capital and includes depreciation, repairs and maintenance, and machine hire. The miscellaneous category includes plastic mulch as well as hand tools and office supplies.

The computed TFP indexes for the nine crop-area combinations considered in this analysis are presented in Table 2. The TFP indexes generally appear to yield inferences consistent with those obtained by Bredahl et al. In all three production areas, the TFP indexes for tomato production exhibited an upward trend. One of the three squash producing areas also exhibited noticeable increases in productivity. It is difficult to ascertain any significant increase in TFP for squash production in the Dade County or Immokalee areas. There is no clear trend in the TFP indexes for pepper production. This appears consistent with the findings of Bredahl et al. Finally, cucumber production was characterized by a moderate increase in productivity over the 1969-70 to 1981-82 period.

As noted by Kendrick, it is not the absolute levels of TFP indexes that are important, but rather the changes in the productivity indexes over time. While the indexes in Table 2 allow some basic inferences about trends in TFP for each crop, more specific statements require further analysis.

A major complication in obtaining more precise estimates of productivity growth is that output is measured as yield per acre. Thus, factors such as adverse weather can cause considerable variation in output and hence the TFP indexes. Such factors are very possibly a major determinant behind the rather noticeable fluctuations in the productivity index series in Table 2.

TABLE 2. ESTIMATED TOTAL FACTOR PRODUCTIVITY INDEXES FOR SELECTED FLORIDA VEGETABLE CROPS BY PRODUCTION AREA, 1969-70 TO 1981-82

Season	Tomatoes			Squash			Peppers		Cucumbers
	Ruskin	Dade	Immokalee	Palm Beach	Dade	Immokalee	Palm Beach	Immokalee	Immokalee
1969-70	0.8619	0.6870	0.5669	0.8312	1.0147	0.3782	0.3798	0.4202	0.3603
1970-71	0.8268	0.8057	0.7236	1.0185	0.9899	0.7036	0.6743	0.5860	0.6652
1971-72	1.0376	0.7361	0.7486	1.0574	1.0543	0.7738	0.5677	0.7149	0.7144
1972-73	0.8755	0.7121	0.7179	0.9444	1.1055	0.6335	0.7362	0.7792	0.5562
1973-74	1.0911	0.7542	0.8729	1.0521	1.1104	0.8088	1.0975	0.8749	0.7111
1974-75	1.0435	1.0464	1.0965	0.9799	1.1474	0.7304	0.9348	1.0137	0.8962
1975-76	1.2689	0.8992	1.1413	1.1882	1.0836	0.9184	0.9508	0.9772	0.8204
1976-77	1.1848	0.4734	0.9558	1.0315	1.2497	0.8933	0.9889	0.8290	0.9040
1977-78	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1978-79	1.2466	0.8442	1.1266	1.3296	1.2420	0.7044	1.0770	1.0420	1.1231
1979-80	1.6170	0.8405	1.0084	1.3716	1.1723	0.7346	1.0706	0.8915	0.8858
1980-81	1.5220	1.0021	1.1233	1.6197	1.1874	0.7462	0.8121	0.7153	0.9864
1981-82	1.6116	1.2465	1.3550	1.6139	1.2331	0.7796	0.8084	0.7140	1.0649

[4] In general, Malmquist input based and output based productivity indexes differ by a factor dependent on returns to scale. Under constant returns to scale both productivity measures are identical.

[5] Energy includes all expenditures on fuel, oil, and grease utilized for farm machinery and trucks used in production. Fuel or electricity expenses for irrigation are also included.

[6] Prices paid indices corresponding to the input categories were obtained from annual issues of USDA *Agricultural Prices.*

To estimate what might be termed the normal rate of productivity increase, such weather related output variations must be taken into account. To incorporate such factors into the analysis and obtain an estimate of the annual rate of productivity increase, a regression analysis was performed. For each crop-area combination, an equation of the form:

$$(10)\ \ln P_{it} = \alpha_{0i} + \alpha_{1i} T + \alpha_{2i} D_i + U_{it}$$

was estimated, where P_{it} is the estimated TFP index for the i^{th} crop-area combination, T is a trend variable, D_i is a weather dummy and U_{it} is the disturbance term.

The binary weather variable is defined to take a value of one if the yield of the i^{th} crop was adversely affected by weather and zero otherwise. The appropriate specification of such a variable is obviously a difficult matter. Indeed, just how adverse weather conditions must be to have seriously affected yields is difficult to ascertain. In order to define this variable, yield data for each crop were analyzed.[7] Any year which exhibited a substantial decline in yield was investigated. If this decline could be related to adverse weather,[8] the binary weather variable was set to one.

Though the specification of equation (10) is rather simple, it does allow some significant inferences about TFP growth. Assuming that binary weather variable adequately accounts for weather related yield declines, the parameters $\alpha_{1i} = \frac{\partial \ln P_{it}}{\partial T}$ yield direct estimates of the average annual rate of productivity growth for each crop over the period of analysis. Furthermore, the statistical significance of these growth rates may be analyzed on the basis of simple t-tests.

Parameter estimates of equation (10) for each crop-area combination are presented in Table 3. Inspection of the parameter estimates and standard errors corresponding to the trend variables indicate that the production of each crop analyzed has exhibited statistically significant rates of productivity growth. Furthermore, given the rather small sample size, the estimated standard errors are extremely small, indicating considerable precision in the estimated growth rates.

Tomato production in the Ruskin, Dade, and Immokalee production areas had estimated annual rates of productivity growth of 5.6, 3.4, and 4.8 percent, respectively. The higher rates of productivity growth in the Ruskin and Immokalee production areas are perhaps attributable to staked tomato cultivation as opposed to the predominately ground culture tomatoes typically produced in the Dade County area.

Squash production in Palm Beach County and Immokalee production areas had estimated growth rates in TFP of 4.6 and 5.8 percent. Production in the Dade County area exhibited a rather moderate rate of productivity growth, averaging about 1.6 percent annually.

The estimated annual growth rates in productivity for pepper production are somewhat surprising. It may be recalled that Bredahl et al., and the TFP indexes in Table 2, seem to indicate very little productivity growth in pepper production. However, pepper production in the Immokalee area was estimated to have an annual rate of TFP growth of 6.6 percent,

TABLE 3. ESTIMATED REGRESSION EQUATIONS FOR THE AVERAGE ANNUAL RATE OF INCREASE IN TOTAL FACTOR PRODUCTIVITY FOR SELECTED FLORIDA VEGETABLES, 1969-70 TO 1981-82

Crop	Production area	Independent variables			R^2
		Intercept	Trend	Weather dummy	
Tomatoes	Manatee-Ruskin	-0.23813	0.05559	-0.26219	.90
		(0.0477)[a]	(0.0061)	(0.0854)	
Tomatoes	Dade County	-0.37435	0.03363	-0.74243	.78
		(0.0726)	(0.0092)	(0.1285)	
Tomatoes	Immokalee-Lee	-0.38995	0.04810	-0.2257	.83
		(0.0767)	(0.0093)	(0.1305)	
Squash	Palm Beach	-0.10292	0.04638	-0.27582	.57
		(0.1057)	(0.0135)	(0.1310)	
Squash	Dade County	0.00733	0.01673	-0.15791	.78
		(0.0246)	(0.0031)	(0.0440)	
Squash	Immokalee-Lee	-0.54503	0.05844	-0.43893	.90
		(0.0481)	(0.0070)	(0.0539)	
Peppers	Immokalee-Lee	-0.61392	0.06610	-0.54826	.65
		(0.1077)	(0.0159)	(0.1646)	
Peppers	Palm Beach	-0.69286	0.08323	-0.55797	.68
		(0.1217)	(0.0179)	(0.1860)	
Cucumbers	Immokalee-Lee	-0.52067	0.04770	-0.54782	.87
		(0.0812)	(0.0099)	(0.1393)	

[a] Estimated standard errors in parentheses.

[7] One of the reviewers pointed out that weather may also be extremely good resulting in abnormally high yields as well. Examination of the data did not indicate any such occurrences over the 1969-70 to 1981-82 period.

[8] The primary sources used to document weather related yield decreases were annual issues of the USDA, Florida *Vegetable Summary*.

while productivity growth in the Palm Beach area averaged 8.3 percent annually. A possible explanation for these rather unexpected results is weather. The TFP indexes in Table 2 for the latter 2 to 3 years apparently reflect yield declines due to adverse weather in the form of freezing temperatures and excessive rainfall.

Finally, cucumber production exhibited significant growth in productivity. Over the 1969-70 to 1981-82 seasons, the annual rate of productivity growth was estimated to be about 4.8 percent.

CONCLUSIONS

The results of this analysis indicate that substantial productivity growth has been realized in the production of fresh winter vegetables in Florida over the 1969-70 to 1981-82 period. Although the analysis does not permit the effects of individual factors on productivity growth to be isolated, some general factors which are likely to have been significant in productivity increases can be identified.

In tomato production, the introduction of full bed plastic mulch culture has been a significant factor in measured productivity increases by enabling more uniform supply of soil nutrients and water. It has also reduced fertilizer leaching in the sandy soils typical to Florida. Productivity increases can also be attributed to the development of cultivars with improved bacterial and viral disease resistance.

The productivity gains exhibited in pepper production may also be attributed to the introduction of plastic mulch culture and the introduction of improved cultivars with resistance to bacterial and viral disease. Additional factors contributing to productivity growth are the introduction of containerized transplants and plug mix seeding, and increased use of integrated pest management.

The potential sources of productivity gains in squash and cucumber production are somewhat more difficult to identify. In squash production, the introduction of new high yielding cultivars and improved cultivation practices have been a major factor in productivity increases. In addition, multiple cropping practices (e.g. following tomatoes with cucumbers or squash) for both of these vine crops have, in all probability, contributed to measured increases in TFP.

The empirical results of this analysis do not allow one to state that productivity increases have been the sole factor in Florida producers' ability to retain a competitive position in the United States fresh winter vegetable market. Indeed, there is a veritable plethora of factors which serve to determine the market shares of producing regions. The estimated rates of productivity increase do, however, lend considerably more plausibility to the rather qualitative results upon which Bredahl et al. formed their hypothesis. The estimated rates of productivity increase exhibited by Florida producers over the 1969-70 to 1981-82 are substantial. Thus, it is apparent that productivity growth, at the very least, has been a major determinant of Florida's competitive position in the United States domestic fresh winter vegetable market.

It is difficult to determine whether or not the substantial rates of productivity growth observed over the 1969-70 to 1981-82 period will continue. Indeed, given the many factors which contribute to productivity growth, any such projections would be little more than mere guesses. The results of this analysis do, however, suggest that if such rates of productivity increase are to be maintained, the continued scientific development of improved cultivars, fumigants, and herbicides will be required. These later factors are especially critical as environmental concerns place more constraints on the potential toxic effects of such chemicals.

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