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Valuing State-Level Funding for Research: Results for Florida

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This study analyzes the value of agricultural research to Florida by examining the effect of research spending on agricultural productivity, as measured by a total factor productivity index, and profitability, as measured by net farm income. Results suggest that research expenditures do increase agricultural productivity in the state. However, agricultural productivity does not affect net cash income. Further, the economic rents to the productivity gains do not accrue to land values. Instead, the economic value of research innovations accrues more to consumers than to producers. Thus, consumers are the ultimate beneficiaries of agricultural research in Florida, thereby justifying public funding for agricultural research.

Key Words: cointegration, research and development, state expenditures, total factor productivity

JEL Classifications: H40, H72, Q16

In an age of increased scrutiny of state and federal expenditures, some have questioned the public funding of the 10 universities that comprise the State University System in Florida, including the University of Florida (Gainesville, FL), which is its primary Land Grant University. Under its Land Grant mission, the University of Florida produces several outputs, including undergraduate and graduate education, service to communities and special interest groups, and research. Among this collection of outputs, research is typically the most controversial. The controversy is magnified in the case of the Institute of Food and Agricultural Sciences (IFAS) at the University of Florida, the primary mission of which involves research. This article analyzes agricultural profitability resulting from productivity gains attributable to investment in IFAS research and development. Results indicate that spending on IFAS research has directly increased the level of agricultural productivity in the state, but the increased productivity does not directly increase agricultural profitability in the state. Specifically, empirical results suggest that the primary beneficiary of agricultural research in Florida has been the consumer. Such a conclusion has dramatic implications for the types of technologies that the state should invest in through IFAS. In addition, it should be noted that neither productivity nor profitability measures incorporate changes in the effect of agriculture on the environment. This exclusion is significant given the increased emphasis of environmental implications of production agriculture within the agricultural research mission over time.

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Table 1. Productivity Indices for Florida Agriculture 1960–1999

	Output				Input					Total Factor Productivity
	Crops	Livestock	Services	Total	Intermediate	Capital	Land	Labor	Total	
1960	1.8916	0.2662	1.4888	0.7799	0.5067	0.8334	2.3696	2.6459	1.0633	0.7275
1961	2.1044	0.2758	1.4717	0.8448	0.4952	0.8377	2.3871	2.5394	1.0420	0.8041
1962	2.3939	0.2878	1.4880	0.9336	0.5144	0.8427	2.4280	2.5767	1.0685	0.8665
1963	1.9532	0.3037	1.4632	0.8207	0.5249	0.8587	2.4692	2.5128	1.0769	0.7558
1964	1.8962	0.3219	1.5334	0.8176	0.5283	0.8800	2.4885	2.5633	1.0901	0.7439
1965	2.2590	0.3303	1.7003	0.9368	0.5433	0.8995	2.4694	2.7257	1.1252	0.8258
1966	2.4135	0.3548	1.6940	0.9959	0.5737	0.9240	2.4175	2.7030	1.1505	0.8585
1967	2.8486	0.3866	1.6093	1.1299	0.6163	0.9512	2.3441	2.9678	1.2178	0.9202
1968	2.3782	0.4030	1.6772	1.0163	0.6199	0.9895	2.2607	2.7486	1.1928	0.8451
1969	2.7543	0.4228	1.6066	1.1291	0.6592	0.9998	2.1801	2.6483	1.2074	0.9275
1970	2.7232	0.4388	1.5944	1.1315	0.6782	1.0233	2.1167	3.0585	1.2696	0.8839
1971	2.7889	0.4631	1.4906	1.1590	0.6483	1.0256	2.0743	3.0416	1.2375	0.9290
1972	2.9950	0.4655	1.4287	1.2124	0.6621	1.0468	2.0506	2.9284	1.2378	0.9715
1973	3.3850	0.4753	1.5017	1.3256	0.6751	1.0640	2.0398	3.0218	1.2617	1.0419
1974	3.4325	0.5039	1.1937	1.3383	0.7425	1.1169	2.0379	2.4529	1.2590	1.0541
1975	3.6900	0.4540	1.1990	1.4000	0.6655	1.1769	2.0438	2.3357	1.1896	1.1671
1976	3.9055	0.4814	1.2492	1.4521	0.6925	1.1930	2.0547	2.5649	1.2418	1.1597
1977	3.7609	0.4826	1.2291	1.4134	0.6897	1.2144	2.0666	2.5589	1.2423	1.1284
1978	3.9839	0.4696	1.3248	1.4713	0.8392	1.2221	2.0761	2.6050	1.3686	1.0660
1979	3.9901	0.4841	1.2917	1.4808	0.9451	1.2570	2.0811	2.7596	1.4732	0.9968
1980	4.4885	0.5067	1.2125	1.6183	0.9612	1.3104	2.0791	2.5953	1.4716	1.0919
1981	4.2956	0.4769	1.0733	1.5356	0.9070	1.3311	2.0668	2.4591	1.4198	1.0741
1982	4.1121	0.5329	1.1555	1.5321	0.8817	1.3111	2.0404	2.6031	1.4130	1.0835
1983	4.2075	0.5165	1.0306	1.5363	0.9039	1.2828	1.9984	2.4921	1.4040	1.0923
1984	4.0322	0.5002	1.2794	1.4995	0.8689	1.2372	1.9459	2.3375	1.3439	1.1121
1985	4.0175	0.5065	1.3818	1.5076	0.8456	1.1950	1.8897	2.2544	1.3035	1.1556
1986	4.3274	0.5221	1.0904	1.5770	0.8575	1.1423	1.8365	2.2725	1.2951	1.2157
1987	4.3891	0.4848	1.0778	1.5697	0.8979	1.0959	1.7934	2.2916	1.3077	1.1921
1988	4.8693	0.4994	1.0434	1.7043	0.8277	1.0580	1.7655	2.4908	1.2773	1.3252
1989	4.7624	0.5096	1.0452	1.6822	0.8571	1.0389	1.7505	2.3567	1.2752	1.3100
1990	4.5917	0.5041	1.0071	1.6299	0.8727	1.0244	1.7436	2.2236	1.2642	1.2800

Table 1. Continued

	Output				Input					Total Factor
	Crops	Livestock	Services	Total	Intermediate	Capital	Land	Labor	Total	Productivity
1991	4.7998	0.5001	0.9913	1.6808	0.8846	1.0181	1.7400	2.4322	1.2993	1.2844
1992	4.9733	0.5583	1.0426	1.7674	0.8517	1.0063	1.7353	2.6368	1.3021	1.3479
1993	5.2816	0.5718	0.8653	1.8404	0.9619	0.9905	1.7267	2.4611	1.3500	1.3537
1994	5.5425	0.5896	1.0117	1.9354	0.9212	0.9814	1.7147	2.4946	1.3244	1.4513
1995	5.5824	0.5635	1.3957	1.9708	1.0127	0.9766	1.7002	2.4141	1.3686	1.4299
1996	5.5334	0.5678	1.6059	1.9841	0.9657	0.9630	1.6838	2.2499	1.3111	1.5024
1997	5.8133	0.5654	1.5998	2.0549	1.0083	0.9602	1.6661	2.4286	1.3612	1.4989
1998	5.7327	0.5608	1.6939	2.0402	1.0249	0.9535	1.6475	2.4275	1.3681	1.4807
1999	6.2377	0.5816	1.7398	2.1915	0.9986	0.9538	1.6281	2.5719	1.3684	1.5903
Avg. growth	0.0306	0.0200	0.0040	0.0265	0.0174	0.0035	−0.0096	−0.0007	0.0065	0.0201

Source: Ball, Butault, and Nehring.

[a] Output and input quantity indices relative to Alabama.

What Is Productivity?

The most basic definition of productivity involves the quantity of output that can be derived from a fixed quantity of inputs. For example, most would agree that a gain in productivity has occurred if corn yield increased from 70 bushels per acre to 75 bushels per acre given the same set of inputs (i.e., pounds of fertilizer or hours of labor). However, if this increase in corn yield was the result of increased fertilizer use, then the yield increase implied by technological change would be subject to some debate. Similarly, as discussed by Griliches, if the yield increase resulted not from quantity of fertilizer applied, but the quality of fertilizer applied, should the increased yield be attributed to increases in agricultural productivity or increased productivity for fertilizer suppliers? In addition, measurement of productivity is complicated by the use of multiple inputs in production and the production of multiple outputs. To overcome these difficulties, the United States Department of Agriculture develops productivity measures based on aggregate output and input measures.[1]

Ball, Butault, and Nehring develop a detailed productivity index presented in Table 1. The measure developed from these aggregate output and input measures are referred to as index numbers. The index created in this case is called the total factor productivity index (TFP). These results indicate that TFP for agriculture in Florida rose from 0.728 in 1960 to 1.590 in 1999. This represents an average an-

[1] Aggregate agricultural outputs and inputs could be computed based on Divisia quantity indices. Specifically, let Y_t be the aggregate output index, computed as $Y_t = \Sigma_{i=1}^{n} r_{it}y_{it}$, where r_{it} is the revenue share of output y_{it}. Similarly, the aggregate input index can be computed as X_t, $X_t = \Sigma_{j=1}^{m} s_{jt}x_{jt}$, where s_{jt} is the cost share of input x_{jt}. Equating aggregate output with aggregate input yields $Y_t = \gamma_t X_t$. Rearranging slightly yields $Y_t/X_t = \gamma_t$. The rate of technical change can be derived from the log change in both sides, $\ln(Y_t/X_t) - \ln(Y_{t-1}/X_{t-1}) = \ln(\gamma_t/\gamma_{t-1})$. The actual procedure used by Ball, Butault, and Nehring is somewhat more complex. First, the input and output indices are computed using Fisher chained indices. Second, Ball, Butault, and Nehring adjust for quality changes by adjusting input prices to reflect quality changes.

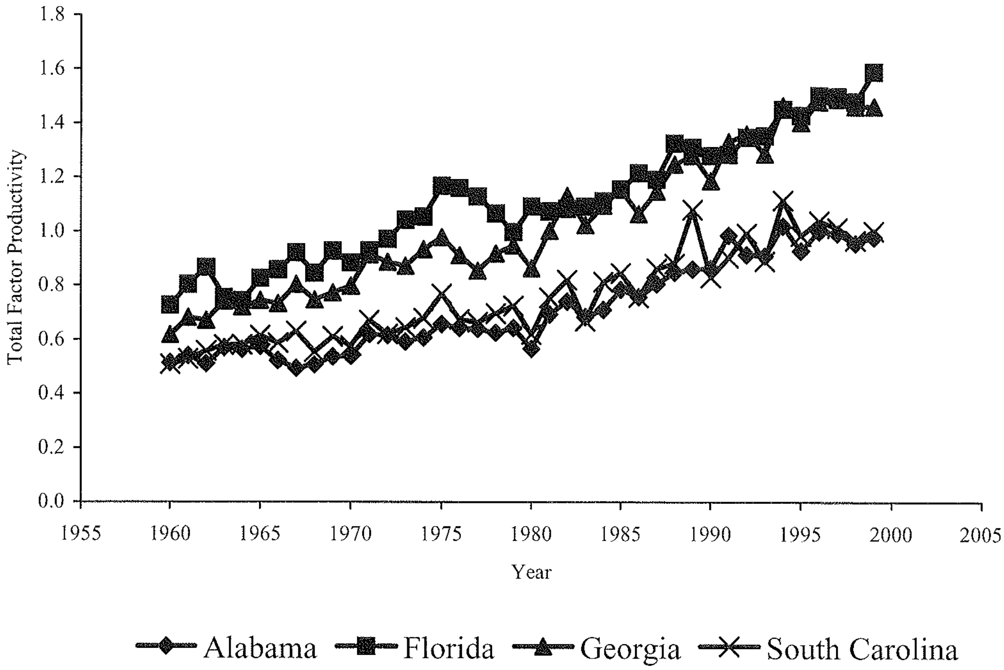

Figure 1. Productivity Growth in Southeast States

nual growth rate of 2.01%. The growth in TFP is primarily the result of increased output. Total farm outputs grew at an annual rate of 2.65% over the sample period, with greater growth in crop outputs (3.06%) as opposed to increased livestock output (2.00%). Total farm inputs remained relatively steady, increasing at only 0.65% per year. However, this stability masks an increase in intermediate inputs of 1.74% per year. The increase is partially offset by declines in land and labor use.

The general picture of Florida agriculture that arises from these results is that of an industry becoming more productive. This productivity results primarily from increased output in the crop sector against relatively stable input use. However, it is important to note that productivity numbers indicate a significant shift in relative input use. Specifically, the quantity of intermediate inputs used has increased relative to the use of capital, land, and labor. A relative decline in labor could be the result of technological innovations that replace labor with machinery. However, producers appear to be substituting intermediate inputs for land and labor. This substitution may be attributed to increased use of agricultural chemicals, such as fertilizers and pesticides. However, without detailed disaggregation of the intermediate inputs index, such conclusions are nebulous.

Given these results, a natural question is "How does the productivity growth in Florida agriculture compare with other states?" Figure 1 presents the TFP index for Alabama, Florida, Georgia, and South Carolina. These states comprise the southeast region in the traditional U.S. Department of Agriculture, Economic Research Service (USDA/ERS) classification scheme. The results in Figure 1 depict the emergence of productivity clubs within the southeastern United States. Specifically, TFP growth is similar for both Florida and Georgia. Productivity in Georgia grows at an annual rate of 2.21% compared with the average growth rate in Florida of 2.01%. Further, TFP in 1999 for Florida is 1.590, which is similar to Georgia's TPF of 1.463. The average annual growth rates in TFP in Alabama and South Carolina over the same time period were 1.65 and 1.73%, respectively. In 1999, TFP in Alabama stood at 0.978, while TFP in South Carolina stood at 1.000.

Ball, Hallahan, and Nehring examine

whether the TFP measures across the 48 continental states have converged over time. Specifically, they estimate whether the growth in TFP for a particular state is inversely proportional with its initial TFP level. This catch-up formulation of convergence was originally formulated by Abramovitz. In general, Ball, Hallahan, and Nehring find that the state-level TFP data supports the catch-up hypothesis. In addition, they find that higher levels of capital also increase the productivity growth. From this result, they conclude that a portion of productivity growth is attributable to better capital, or that productivity growth may be embodied in new capital.

The TFP values presented in Figure 1 are not entirely consistent with the broader results of Ball, Hallahan, and Nehring. Specifically, the productivity of Florida and Georgia are initially higher than those of Alabama and South Carolina, and increase more over the sample. While part of this difference may be explained by capital intensity, as noted by Ball, Hallahan, and Nehring, this study departs from their formulation by explicitly considering the role of investment in research and development through Florida's Agricultural Experiment Station.

The general result of increasing productivity through increased output raises some basic caveats that must be voiced within this type of analysis. First, it is important to note that the TFP is limited to specified and measurable inputs used in production. Of particular importance in this caveat is the treatment of natural resources, such as water used in irrigation. By not explicitly using water, the analysis assumes that water use remains constant over the sample period or that water use is directly proportional to a measured input. Changes in relative water use over the sample period introduce a measurement error into measurement of TFP. Second, as pointed out by Griliches, the TFP index assumes that inputs and outputs are homogenous in quality over the study period. In other words, the important comparison involves the quantity of oranges or tomatoes produced over the time period and not change in quality.

The first caveat is particularly important given the change in the focus of research over the past 15 years toward the development of agricultural methodologies that reduce environmental impacts. Specifically, a significant portion of recent research budgets has focused on the reduction in water applied to crops. These efforts have led to drip irrigation in vegetable production and microjet sprinklers on citrus. In addition, other research has focused on the development of safer pesticides that reduce risks to human health and ecosystems.

What Effect Has IFAS Had on Agricultural Productivity?

Given that agricultural productivity can be measured (perhaps imperfectly), the value of IFAS's research can be estimated through the effect of research spending on TFP in Florida.

Huffman and Evenson provide a useful discussion on the estimation of public investment in research for U.S. agriculture. Their analyses support a trapezoid stock function for transforming annual expenditures toward agricultural research and development into a stock of agricultural knowledge. Within this formulation, the value of additional expenditures increases slowly initially until some plateau, stays constant for some time period, and then begins to decay. Table 2 presents the research stock from 1960 to 1999 defined by this procedure (Huffman, McCunn, and Xu). This research stock increases from \$15.9 million dollars in 1960 to \$55.3 million dollars in 1999.

Both TFP and research spending show strong upward trends over time (Figure 2). The distinct upward trend in both data series raises several problems with estimating the effect of research expenditures on agricultural productivity. Specifically, the common upward trend may lead to spurious regression results (Granger and Newbold). The upward-sloping relationships depicted in Figure 1 are sometimes referred to as nonstationary time series. Mathematically, the best predictor of the next value of each variable is its current value. Statistically, this artifact has several implications, including the fact that one nonstationary time series will appear to be statistically related to another nonstationary time series regardless of

Table 2. Real Investment in Research and Development, Net Cash Income, Real Estate Values, and Total Assets for Florida

Year	Public R & D Stock	Net Cash Income	Real Estate Values	Total Assets
1960	15,885,383	1,630,485	18,833,174	21,993,174
1961	16,122,061	2,042,879	19,353,098	22,582,413
1962	16,356,253	2,084,976	20,180,813	23,629,012
1963	16,597,476	1,930,048	20,755,832	24,210,532
1964	16,887,102	2,167,374	21,511,329	24,826,444
1965	17,228,046	1,926,564	21,276,934	24,843,122
1966	17,580,285	1,856,847	20,260,311	23,998,364
1967	17,954,428	1,882,558	20,553,471	24,528,587
1968	18,346,254	2,027,120	20,007,776	24,042,705
1969	18,746,342	2,254,876	20,833,562	24,984,477
1970	19,198,823	1,871,718	20,804,506	24,913,938
1971	19,693,053	2,284,778	21,184,707	25,559,322
1972	20,232,180	2,837,495	23,430,106	28,496,709
1973	20,827,502	3,196,902	28,713,494	34,573,505
1974	21,487,943	2,580,465	28,931,202	33,690,429
1975	22,268,041	3,328,000	29,327,137	34,190,231
1976	23,181,746	2,989,555	30,930,403	35,901,806
1977	24,133,127	3,100,466	32,853,978	37,665,827
1978	25,213,910	3,412,887	35,456,858	41,076,532
1979	26,418,375	3,157,355	38,874,808	45,174,449
1980	27,737,390	3,005,927	39,919,013	45,906,422
1981	29,180,894	2,942,110	35,115,924	40,476,032
1982	30,740,123	2,936,634	34,376,134	39,738,795
1983	32,376,999	3,288,797	33,274,343	38,345,439
1984	34,127,633	3,212,454	30,370,686	35,862,918
1985	35,889,330	3,214,134	27,531,210	32,099,045
1986	37,642,927	3,282,109	27,564,465	32,135,999
1987	39,398,896	3,629,803	29,182,759	33,885,175
1988	41,161,573	4,163,903	28,179,461	33,084,295
1989	42,870,548	4,148,539	29,105,969	34,123,633
1990	44,544,341	2,952,523	27,411,805	32,488,059
1991	46,135,436	3,383,368	25,465,194	30,422,604
1992	47,639,891	3,646,018	25,494,158	30,262,271
1993	49,066,399	3,187,485	25,057,045	30,185,159
1994	50,428,432	2,979,851	24,685,599	29,745,606
1995	51,695,078	2,546,245	24,664,938	29,300,661
1996	52,864,729	2,558,028	24,475,871	28,976,267
1997	53,928,420	2,755,421	24,507,739	28,856,819
1998	54,890,040	3,094,703	24,043,906	28,207,528
1999	55,321,724	3,132,096	24,874,214	29,156,337

Sources: Public R & D stocks are developed from Huffman, McCunn, and Xu. Net cash income is taken from the U.S. Department of Agriculture, Economic Research Service (USDA/ERS) (2004a), while real estate values and total assets are taken from USDA/ERS (2004b).

a scientific linkage. The quintessential example of this relationship is the effect of sunspots on the stock market over short time periods. Specifically, the number of sunspots can be represented as a nonstationary time series over a certain span of years. In addition, most stock indices, such as the Dow Jones Industrial Average, are also nonstationary. Regressing the

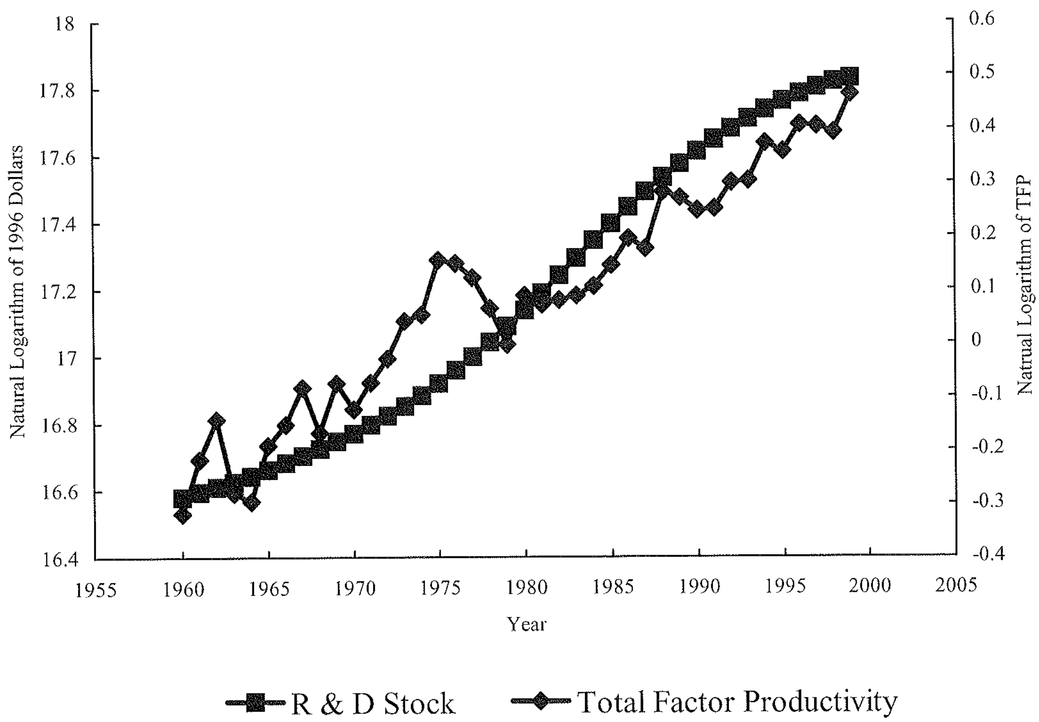

Figure 2. Comparison of IFAS Expenditures on Research and Total Factor Productivity over Time

Dow Jones Industrial Average on sunspot activities will often generate a significant regression. However, the inference that sunspots cause stock-market movements is dubious at best.

To minimize the potential for spurious regression bias in time-series analysis, several empirical approaches have been developed. The first approach involves analyzing the relationship between the growth rates of nonstationary time series. However, as discussed by Engle and Granger, this procedure tends to remove an excess amount of information from the relationship between the time series. As an alternative, they proposed analyzing the time series for cointegration. Cointegration refers to the tendency of nonstationary time series to move together through time. Mathematically, another implication of nonstationary time series is that the variance of such a series expands to infinity over time. This is opposed to stationary time series for which the variance is bounded. Cointegration implies that the variance of the linear relationship between two nonstationary time series is bounded. Thus, the error in a regression equation between two nonstationary time series is stationary. Intuitively, this result implies that the two nonstationary time series never wander too far apart. Econometrically, this relationship is used to infer an equilibrium relationship between the two nonstationary time series. However, such a relationship cannot be used to infer causality. Hence, cointegration typically cannot be used to infer that changes in one nonstationary time series causes changes in another.

The Johansen approach involves estimating a vector error-correction mechanism expressed as

$$(1) \qquad \Delta x_t = \Pi x_{t-1} + \sum_{i=1}^{k} \Gamma_i \Delta x_{t-i} + \Phi D_t + \varepsilon_t$$

where x_t is a vector of endogenous variables, Δx_t denotes the time difference of that vector ($\Delta x_t = x_t - x_{t-1}$), D_t is a vector of exogenous variables, ε_t is a vector of residuals, and Π, Γ_i, and Φ are estimated parameters. If a long-run

Table 3. Augmented Dickey-Fuller and Phillips-Perron Tests for Nonstationarity

	Augmented Dickey-Fuller Test		Phillips-Perron Tests	
Variable	$\hat{\alpha}$	t_α	$\hat{\alpha}$	z_t
Total factor productivity	0.9488	−1.0837	0.9561	−0.8990
Research and development stocks	0.9965	−2.1165	1.0064	0.7114
Net cash income	0.8481	−1.4541	0.8041	−2.4638
Real estate values	0.9064	−1.7125	0.9258	−1.7309
Asset values	0.9023	−1.7423	0.9212	−1.8000

Source: Author's computations using Ouliaris and Philips.

relationship (e.g., cointegrating vector) exits, the Π matrix is singular ($\Pi = \alpha\beta'$). The β vector is the cointegrating vector or long-run equilibrium. Further, the statistical properties of the cointegrating vector are determined by the eigenvalues of the estimated Π matrix. Denoting the ith eigenvalue (in descending order of significance) as λ_i, the test for significance of the cointegrating vector can be written as

$$(2) \qquad 2 \ln Q[H_1(r)|H_1(p)] = -T \sum_{i=r+1}^{p} \ln(1 - \hat{\lambda}_i),$$

which tests the hypothesis that r cointegrating vectors are present, $H_1(r)$, against the hypothesis that p cointegrating vectors are present, $H_1(p)$ (Hamilton p. 645).

In order to examine the statistical relationship between the natural logarithm of TFP and the natural logarithm of research spending, the maximum-likelihood approach developed by Johansen was applied to the two time series. First, I test for nonstationarity using the augmented Dickey-Fuller and the Phillips-Perron tests. These results are presented in Table 3. Both the augmented Dickey-Fuller and Phillips-Perron tests support nonstationarity for the natural logarithm of TFP. However, while the Phillips-Perron test supports nonstationarity in research and development stocks, the augmented Dickey-Fuller test provides less support. Next, given that both series are nonstationary, I then test for the number of cointegrating vectors using Equation (2).[2] These results support the existence of a cointegraing vector (i.e., I reject the hypothesis that $r = 0$ and fail to reject the hypothesis that $r = 1$).

The existence of a cointegrating vector in this framework implies that the linear combination (z_t) of the natural logarithm of TFP and research and the natural logarithm of research and development stocks (RD_t) is stationary, or that a long-run equilibrium exists between these two series.[3] While this cointegrating vector is not uniquely identified, the long-run relationship can be expressed as

$$(3) \qquad z_t = \begin{pmatrix} 1.000 \\ -0.794 \end{pmatrix}' \begin{bmatrix} \ln(TFP_t) \\ \ln(RD_t) \end{bmatrix} + 13.433.$$

Building on Equation (3), the long-run relationship can be expressed as

$$(4) \qquad \ln(TFP_t) - 0.794 \ln(RD_t) + 13.433 = z_t.$$

Manipulating this result further, yields

$$(5) \qquad \frac{dTFP_t}{dRD_t} = 0.794 \frac{TFP_t}{RD_t}.$$

Using the geometric mean of both TFP and research and development stocks, TFP increases 0.0302 with a one million dollar increase in the research and development stock. This number appears small, but it represents 113% of the average annual increase in productivity observed in the state. Thus, we are

[2] The statistics and parameters of the cointegrating relationships presented in this study are computed using JMulti (Krätzig).

[3] In the specification estimated here $E(z_t) \rightarrow \mu$, where $E(\cdot)$ is the expectation operator and μ is a constant. Other specifications are possible (e.g., D_t could contain the constant, season shifts, or a time trend).

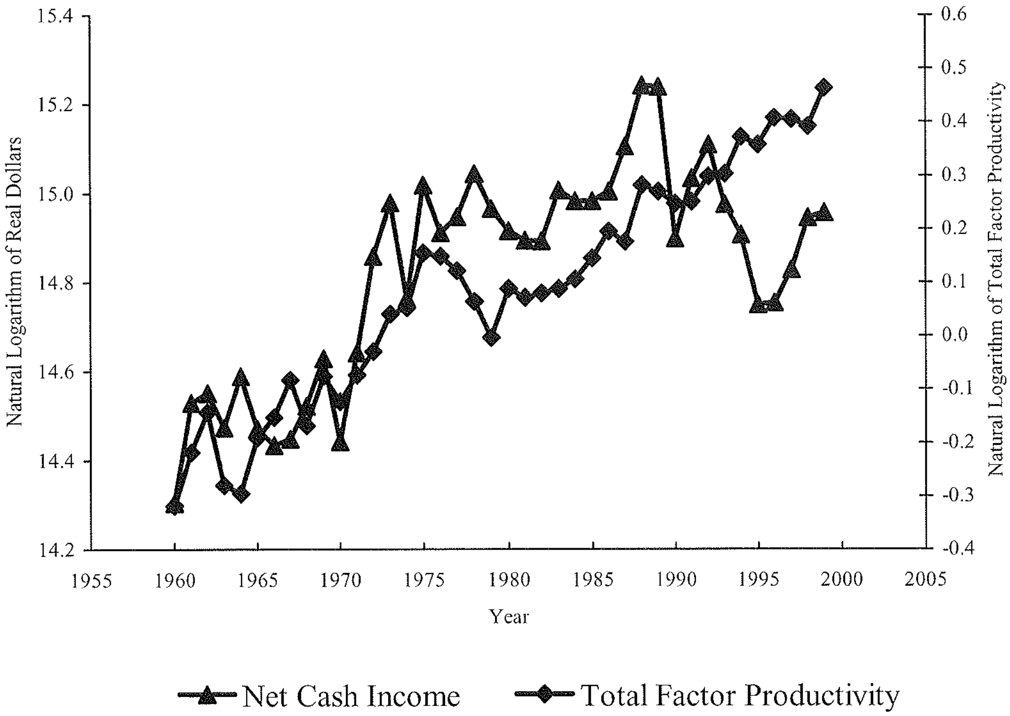

Figure 3. Comparison of Agricultural Income and Total Factor Productivity Growth over Time

left with the conclusion that research expenditures in IFAS have a significant effect on agricultural productivity in the state.

What Effect Does Productivity Have on Profitability

While the positive effect of research expenditures on productivity supports the hypothesis that research expenditures in IFAS are having an effect, an additional linkage is required to support the contention that IFAS research has value to the state. I next establish whether the gains in productivity can be linked to increased profitability in the state's agriculture. To examine this question, I develop a similar cointegrating relationship between TFP and net cash income to agriculture in Florida.

Table 2 presents real net cash income to agriculture in Florida in 1994 dollars. Figure 3 plots this income figure with the TFP index for Florida. Of particular significance is the fact that net cash income, like TFP and research expenditures, appears to be a nonstationary time series. However, the test statistic for cointegration between these series is 10.92, which implies rejection of the cointegration hypothesis at the .05 confidence level. Hence, the evidence rejects a direct relationship between TFP and agricultural profitability in Florida over the sample period.

In order to understand the possible causes of the lack of a long-run equilibrium between agricultural profitability and productivity, I express the change in profit over time as

$$(6) \qquad D(\pi_t) = D(F_t) + D(\Psi_t),$$

where π_t denotes profit in period t, F_t denotes TFP in time t, and Ψ_t denotes the change in relative price ratio in time t.[4] Thus, the direct

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[4] In order to derive this relationship, we start with agricultural profit, defined as $\pi_t = \sum_{i=1}^{n} p_{it}y_{it} - \sum_{j=1}^{m} w_{jt}x_{jt}$, where p_{it} is the price of output i in period t, y_{it} is the level of output i produced and sold in period t, w_{jt} is the price of input j in period t, and x_{jt} is the input j purchased in period t. Differentiating both sides yields $d\pi_t = \sum_{i=1}^{n} dp_{it}y_{it} + \sum_{i=1}^{n} p_{it}dy_{it} - \sum_{j=1}^{m} dw_{jt}x_{jt} -$

relationship between TFP and profitability may be mitigated by changes in relative output and input prices.

The relationship between output and input prices is sometimes referred to as the cost-price squeeze. A common hypothesis is that input prices rise faster than output prices over time, resulting in reduced profitability in agriculture. Moss uses a cointegration approach similar to the one applied in this article to show that input prices and output prices in agriculture do not form a long-run equilibrium. This finding is consistent with the cost-price squeeze hypothesis and is also consistent with the cointegration results for net cash income and TFP. Specifically, a long-run equilibrium between input and output prices would imply that $D(\Psi_t) = 0$ in Equation (6). By extension, if $D(\Psi_t) = 0$, changes in agricultural profitability would be directly attributable to changes in total factor productivity. More generally, if relative changes in output and input prices do not cancel each other out over time, the net effect of their relative changes needs to be taken into account when analyzing changes in profit over time.

Moss develops the costs-price squeeze in terms of macroeconomic factors. Here, a slightly different approach is used to develop the potential causes of cost-price squeeze in terms of commodity markets. Figure 4 presents the effect of an increase in productivity within a single output market. The increase in productivity shifts the supply function in the commodity market from $S_0(P)$ to $S_1(P)$. This shift results in a reduction of the commodity price from P_0 to P_1 and an increase in the market clearing quantity from Q_0 to Q_1. Graphically, the increase in profitability can be derived as the area $c + d - a$, while the change

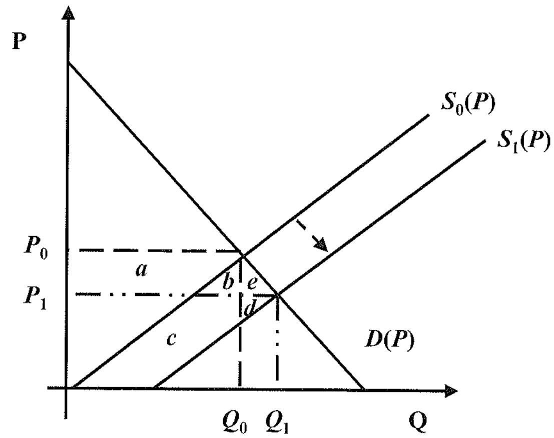

Figure 4. Market Level Effect of Increased Productivity

in consumer surplus can be measured by $a + b + e$ (Just, Hueth, and Schmitz). Standard results for this analysis indicate that, as the demand curve becomes steeper, the quantity effect becomes smaller relative to the price effect and the net change in profit resulting from the outward shift in supply declines. However, the change in consumer surplus due to increased productivity in agriculture is always positive.

As described by Alston, Norton, and Pardey, the simple single market model of consumer surplus presented in Figure 4 is complicated by horizontal market relationships. Specifically, most of the crops produced in one region (i.e., Florida) are also produced in other regions (i.e., California or other countries). The existence of other production regions tends to reduce the elasticity of demand for an individual region. In the limit, if a region is a relatively small producer, its effect or residual demand curve[5] may be perfectly elastic. Further, the introduction of additional production regions raises the possibility of technological spillover where, for example, technologies de-

$\Sigma_{j=1}^{m} x_{jt} dw_{jt}$. Rewriting this expression using logarithmic differentiation yields $D(\pi_t) = \Sigma_{i=1}^{n} r_{it} D(p_{it}) + \Sigma_{i=1}^{n} r_{it} D(y_{it}) - \Sigma_{j=1}^{m} s_{jt} D(w_{jt}) - \Sigma_{j=1}^{m} s_{jt} D(x_{jt})$, where $D(z) = d\ \ln(z)$. This expression can be rearranged to yield $D(\pi_i) = [\Sigma_{i=1}^{n} r_{it} D(y_{it}) - \Sigma_{j=1}^{m} s_{jt} D(x_{jt})] + [\Sigma_{i=1}^{n} r_{it} D(p_{it}) - \Sigma_{j=1}^{m} s_{jt} D(w_{wt})]$. The first term on the left-hand side of this expression is simply the change in TFP as previously discussed, while the second term on the left-hand side is the relative change in input and output prices.

[5] The residual demand curve is defined as the market demand curve for a commodity less the supply curve for all other potential producers of the commodity. It is the demand curve facing a particular producer or group of producers. This curve is sometimes used to assess the opportunity of a single firm or group of firms to extract monopolistic rents (Baker and Bresnahan, Scheffman and Spiller).

veloped for citrus produced in Florida can be used by producers in California. The more elastic the region's residual demand curve and the more specific its production technology, the more likely TFP growth will generate increased profitability in that region.

Because aggregate agricultural demand tends to be fairly inelastic, we expect that price reductions due to technological change will be larger than the increase in quantity. As a result, while producers are typically made better off by technological change, most of the benefits accrue to consumers. This result is consistent with the cost-price squeeze hypothesis analyzed by Moss. However, the consistency of this storyline at the state level is dependent on the market share of that state and the potential spillover effects of technology developed by that state's agricultural experiment station. In the case of Florida, I would argue that its unique climate yields a demand curve that is not perfectly elastic. Specifically, the elasticity of demand for many of its crops are subject to competitive pressures from imports (i.e., oranges from Brazil and tomatoes from Mexico), but have limited domestic competition within its market window. Thus, a large portion of the rents being generated by agricultural research in Florida are accruing to consumers. However, it is also possible that a portion of the rents are being dissipated through spillover effects that increase the competitiveness of other producers (i.e., the adoption of microjet technologies or improved citrus rootstocks in Brazil).

Effect of Productivity Growth on Land Values

An alternative explanation of the failure of productivity growth to increase agricultural profitability is that any excess profit is captured in land values. Under this hypothesis, increased profits due to productivity growth are bid into the most fixed factor of production. Thus, as agricultural productivity increases, land values increase. The increase in land values increases the opportunity cost by a sufficient amount to remove profit gains in future time periods.

To test this hypothesis, a cointegrating relationship between farmland values and TFP is estimated. Graphically, real farmland values follow a nonstationary path similar to TFP (Figure 5). The likelihood ratio test for a single cointegrating relationship between farmland values and TFP is 10.33, which can be rejected at any conventional confidence level. Thus, the data do not support the hypothesis that increased productivity simply accrues to land values.

The Effect of Research and Development on Farm Income

Finally, I expand the original specification to consider the possibility of cointegration between TFP, net cash income, and research and development stock. This specification allows for Florida's investment in research and development to affect farm income through channels other than those measured in the productivity variable. The results of the Johansen statistic for this specification presented in Table 4 indicate that two long-run relationships exist between the three variables

$$(7)\qquad \begin{bmatrix} \ln(TFP_t) \\ \ln(NCI_t) \end{bmatrix} = \begin{bmatrix} 0.768 \\ 0.716 \end{bmatrix} \ln(RD_t) + \begin{bmatrix} -12.994 \\ 2.267 \end{bmatrix}$$

where NCI_t denotes the real net cash income to agriculture. Thus, these results suggest that state investment in research and development does affect farm income, but not through productivity.

Supporting this conclusion, the test for Granger causality for research and development stock causing TFP and net cash income is 6.23, which is statistically significant at any conventional level of significance. However, the Granger causality test for TFP causing research and development stocks and net cash income is 1.90, which is not statistically different from zero for any conventional confidence level. Thus, TFP does not cause changes in net cash income. Similarly, the Granger causality test for net cash income causing research and development stocks and TFP is 1.83, which is not statistically significant at any conventional confidence level. Hence, net

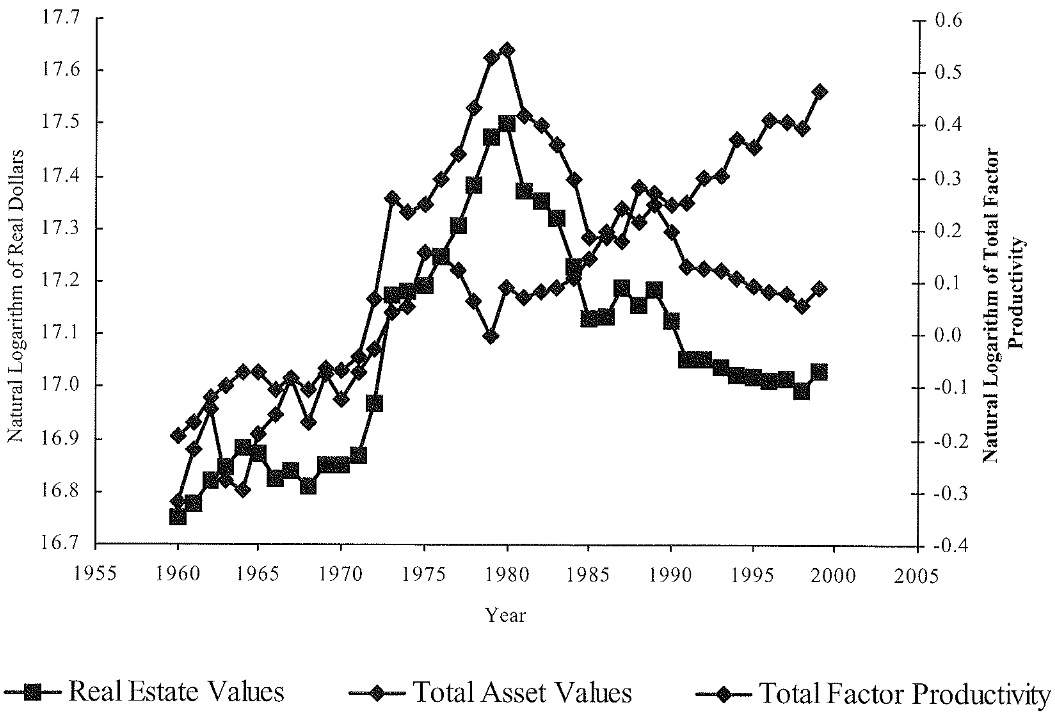

Figure 5. Comparisons of Farmland and Total Agricultural Asset Values with TFP

Table 4. Johansen Tests for Cointegration

Number of Cointegrating Vectors	$LR\ (r)$	$P[LR(r)]$
Total Factor Productivity and Research and Development Stocks		
$r = 0$	50.68	0.000
$r = 1$	5.53	0.238
Total Factor Productivity and Net Cash Income		
$r = 0$	10.92	0.557
$r = 1$	3.79	0.457
Total Factor Productivity and Real Estate Values		
$r = 0$	10.33	0.613
$r = 1$	2.38	0.703
Total Factor Productivity and Total Asset Values		
$r = 0$	10.54	0.594
$r = 1$	2.48	0.686
Total Factor Productivity, Net Cash Income, and Research and Development Stocks		
$r = 0$	67.11	0.000
$r = 1$	20.16	0.050
$r = 2$	5.17	0.275

Source: Author's computations using JMulti (Kätzig).

cash income does not cause changes in research and development stocks or TFP.

Unfortunately, these tests may be fragile. Converting the vector error-correction model into a vector autoregression specification and computing the reverse characteristic polynomials for the dynamic specification yields two numbers inside the unit circle. Obviously, cointegrating relationships are not truly stationary, or the variance of the linear relationship between endogenous variables may not be bounded. Thus, these long-run equilibria may be suspect.

Conclusions and Implications

This study analyzes the value of agricultural research to Florida by examining the effect of research spending on agricultural productivity as measured by a total factor productivity index. The effect of productivity on farm income in the state is examined. Statistical results suggest that research expenditures by IFAS do increase agricultural productivity in the state. However, extending the framework to examine the effect of increased productivity on agricultural profitability fails to support the hypothesis that increases in productivity imply increased agricultural profitability.

Three possible explanations for the failure of increased productivity to produce increased profits are developed. The first explanation involves the relative elasticity of demand for agricultural outputs. Specifically, inelastic demand for agricultural outputs could cause the price declines associated with increased productivity to more than offset increased output levels. Statistical evidence for this hypothesis can be found in the literature (Moss). The relative effect of demand elasticity must be viewed within the context of multiple markets. Most of the commodities produced in Florida can be produced in other regions inside and outside the United States. This availability of output from other regions increases the effective elasticity of demand facing Florida's producers, which increases the potential profitability of productivity change in Florida. A second possible explanation of the lack of effect of productivity on profitability is technological spillover. While the existence of multiple markets for agricultural output increases the elasticity of demand, the ability of other regions to learn from the new technologies developed by a state's agricultural experiment station decreases the residual demand for a particular state. In fact, the catch-up hypothesis formulated by Ball, Hallahan, and Nehring provides support for such a spillover effect at the state level. However, in the case of Florida, this spillover effect in the United States is limited by the uniqueness of Florida's climate. A third possibility for the failure of productivity to affect agricultural profitability is that future profits due to increases in agricultural profitability are immediately captured by land values. This possibility is examined by analyzing the relationship between farmland values and productivity over time. Results indicate that farmland values do not respond to TFP over time. Thus, we conclude that farmland values do not capture the premium generated by productivity growth.

Expanding on the bivariate relationships, the study then examines the possibility of a long-run relationship between TFP, research and development expenditures, and farm income. The results suggest that there are two long-run relationships between these three variables. Further, causality tests suggest that increased research and development expenditures cause both TFP and farm income to increase. These results support the contention that research and development expenditures increase farm income at the state level, but this effect is not fully explained by our measure of productivity. This statistical formulation appears fragile at best.

Finally, we return to the original question: "How is state-level funding for research valued?" The results of these analyses indicate that agricultural research does have a direct value to the state of Florida. Agricultural research increases the productivity of agriculture over time. The results also suggest, however, that the economic value of these innovations accrues more to consumers than to producers. Thus, consumers are the ultimate beneficiaries of agricultural research in Florida. This result agrees with most of the literature on productivity growth. The result is also consistent with the funding of agricultural research from the public sector as opposed to private funding. If the value of agricultural research accrued primarily to the producer, one could make a strong argument that producers should pay directly for agricultural research.

The results of this study also indicate how the agricultural research agenda could be structured to capture relatively more of the gains to productivity within the sector. In developing the relationship between changes in profit, productivity, and relative prices, it is demonstrated that producers profit more from productivity gains when demand is more elastic. In other words, the gains to productivity dissipated into consumer surplus are smaller in markets with more elastic demand curves. This distinction is of particular importance to Florida because of the relative diversity of agriculture within the state and the dominance of higher valued crops such as vegetables, citrus, and ornamental crops. Some evidence suggests that the demands for these higher valued crops are more elastic than for other commodities (Huang and Lin).[6] Thus, research funding that emphasizes increases in productivity could be focused toward these crops. In addition, the results suggest that agricultural research should focus at least a portion of research expenditures away from efforts targeted to increasing productivity and toward efforts that increase the relative price by increasing the relative quality of agricultural output.

Finally, it should be emphasized that measurement of agricultural productivity is based on observable inputs and outputs and the assumption that these inputs and outputs are homogenous over time. This point is especially important given the significance of environmental implications of agricultural production. The measures of productivity developed by the USDA do not account for changes in water use over time. Similarly, a significant portion of the research over time has involved minimizing the environmental consequences of agricultural chemical use instead of increasing relative productivity. Hence, agriculture in general is affected by the exclusion of factors of production and basic changes in the factors included in the index over time.

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References

Abramovitz, M. "Catching Up, Forging Ahead, and Falling Behind." *Journal of Economic History* 46(1986):385–406.

Alston, J.M., G.W. Norton, and P.G. Pardey. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. New York: CAB International, 1998.

Baker, J.B., and T.F. Bresnahan. "The Gains from Merger or Collusion in Product-Differentiated Industries." *Journal of Industrial Economics* 33,4(1985):427–44.

[6] Huang and Lin estimate an almost ideal demand system and household survey data to estimate the demand elasticities for a variety of commodities, including fruit, which have an estimated demand elasticity of −0.719; juice, which has an estimated demand elasticity of −1.0109; and vegetables, which have an estimated demand elasticity of −0.7238. These elasticities compare with an estimated demand elasticity for bread of −0.3537 and cereal of −0.5489.

Ball, V.E., J.P. Butault, and R.F. Nehring. "United States Agriculture, 1960–96: A Multilateral Comparison of Total Factor Productivity." *Agricultural Productivity: Measurement and Sources of Growth*. V.E. Ball and G.W. Norton, eds., pp. 251–76. Boston: Kluwer Academic Publishers, 2002.

Ball, V.E., C. Hallahan, and R. Nehring. "Convergence of Productivity: An Analysis of the Catch-Up Hypothesis within a Panel of States." *American Journal of Agricultural Economics* 86,5(2004):1315–21.

Engle, R.F., and Granger, C.W.J. "Cointegration and Error Correction: Representation, Estimation and Testing." *Econometrica* 55,2(1987):251–76.

Granger, C.W.J., and P. Newbold. "Spurious Regressions in Econometrics." *Journal of Econometrics* 26,2(1974):1045–66.

Griliches, Z. "Measuring Inputs in Agriculture: A Critical Survey." *Journal of Farm Economics* 42,5(1960):1411–26.

Hamilton, J.D. *Time Series Analysis*. Princeton, NJ: Princeton University Press, 1994.

Huang, K.S., and B.H. Lin. "Estimation of Food Demand and Nutrient Elasticity from Household Survey Data." Washington, DC: U.S. Department of Agriculture, Economic Research Service, Technical Bulletin 1887, 2000.

Huffman, W.E., and R.E. Evenson. "New Econometric Evidence on Agricultural Total Factor Productivity Determinants: Impact of Funding Sources." Working Paper 03029, Department of Economics Working Paper Series, Iowa State University, Ames, IA, December 2003.

Huffman, W.E., A. McCunn, and J. Xu. "Public Agricultural Research Expenditures with an Agricultural Productivity Emphasis: Data for 48 States, 1927–95." Iowa State University Department of Economics Staff Paper, Ames, IA, 2001.

Johansen, S. "Statistical Analysis of Cointegrating Vectors." *Journal of Economic Dynamics and Control* 12,2/3(1988):231–54.

Just, R.E., D.L. Hueth, and A. Schmitz. *The Welfare Economics of Public Policy*. Northampton, MA: Edward Elgar Publishing, 2004.

Krätzig, M. "The Software JMulti." *Applied Time Series Econometrics*. H. Lütkepohl and M. Krätzig, eds. New York: Cambridge University Press, 2004.

Moss, C.B. "The Cost Price Squeeze in Agriculture: An Application of Cointegration." *Review of Agricultural Economics* 14,2(1992):209–17.

Ouliaris, S., and P.C.B. Philips. *COINT 2.0a: Gauss Procedures for Cointegrated Regressions.* 1997.

Scheffman, D.T., and P.T. Spiller. "Geographic Market Definition under the U.S. Department of Justice Merger Guidelines." *Journal of Law and Economics* 30,1(1987):123–47.

U.S. Department of Agriculture—Economic Research Service [USDA/ERS]. *Farm Income Data.* Internet site: http://www.ers.usda.gov/farmincome/ (Accessed March 17, 2004a).

U.S. Department of Agriculture—Economic Research Service [USDA/ERS]. *Farm Balance Sheet Data.* Internet site: http://www.ers.usda.gov/data/farmbalancesheet/ (Accessed March 17, 2004b).