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Department of APPLIED ECONOMICS

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College of Food, Agricultural and Natural Resource Sciences

UNIVERSITY OF MINNESOTA

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Andersen is a Postdoctoral Scholar in the Department of Agricultural and Resource Economics, University of California, Davis and a Research Fellow at the International Science and Technology Practice and Policy (InSTePP) Center at the University of Minnesota; Alston is a Professor in the Department of Agricultural and Resource Economics, University of California, Davis and a member of the Giannini Foundation; and Pardey is a Professor in the Department of Applied Economics, University of Minnesota and Director of InSTePP. *The authors gratefully acknowledge the financial support of the Minnesota Agricultural Experiment Station, the University of California, Agricultural Issues Center, the Institute of Governmental Affairs at UC Davis, and the Giannini Foundation. The authors received constructive input from Catherine Morrison Paul and participants in workshops held at the University of California, Davis, Washington State University, and the 2006 annual meetings of the American Agricultural Economics Association held at Long Beach, California. They are also appreciative of the assistance of John Smylie and the Association of Equipment Manufacturers in making data available.*

ABSTRACT

Measures of productivity growth are often pro-cyclical. This study focuses on measurement errors in capital inputs, associated with unobserved variations in capital utilization rates, as an explanation for the existence of pro-cyclical patterns in measures of agricultural productivity. Recently constructed national and state-specific indexes of inputs, outputs, and productivity in U.S. agriculture for 1949-2002 are used to estimate production functions in growth rate form that include proxy variables for changes in the utilization of durable inputs. The proxy variables include an index of farmers' terms of trade and an index of local seasonal growing conditions. We find that utilization responses by farmers are significant and bias measures of productivity growth in a pro-cyclical pattern. We quantify the bias, adjust the measures of productivity for the estimated utilization responses, and compare the adjusted and conventional measures.

Capital Use Intensity and Productivity Biases

1. Introduction

A common observation is that measures of productivity growth are pro-cyclical, in the sense that measured productivity grows faster on average during periods of economic expansion than during periods of economic contraction (Basu 1996; Basu and Kimball 1997; Wen 2004). Does this observation imply that productivity actually changes in response to the business cycle, or are we simply mismeasuring productivity in a systematic way? The literature on productivity measurement attributes these observed patterns to one or more of four primary sources: i) increasing returns to scale in production; ii) imperfect competition in output markets; iii) exogenous technology shocks; and iv) systematic errors in measuring either inputs or outputs (Basu and Fernald 2000). This study focuses on the last of these, and more specifically on measurement errors related to capital inputs, as an explanation for the existence of pro-cyclical patterns in measures of agricultural productivity.

It is difficult to calculate a time series of capital inputs, and the measures are prone to errors. In the case of U.S. agriculture, to measure the annual quantity of physical assets used in production we have to aggregate assets of different types and ages over time, and this poses many problems for the researcher. Myriad assumptions are required to construct a typical measure of the capital stock; and further (sometimes related) assumptions must be made about the utilization of the stock to derive a measure of capital service flows. It is difficult directly to observe or measure annual variations in the rate of utilization of durable assets, and this difficulty has been widely cited by researchers as a potential source of significant measurement error for capital inputs.

We begin with a detailed examination of the problem of variable capital utilization, and its potential implications for productivity measurement. The hypothesis that unmeasured changes in the utilization of capital can affect productivity measures is then illustrated using a model of production. Next, recently constructed indexes of inputs, outputs, and productivity in U.S. agriculture for 1949-2002 are presented, and the data are used to estimate production functions in growth-rate form that include proxy variables for changes in the utilization of fixed assets. The proxy variables include an index of farmers' terms of trade and an index of local growing conditions. We find that utilization responses by farmers are significant and bias measures of productivity growth in a pro-cyclical pattern. We quantify the bias, adjust the measures of productivity for the estimated utilization responses, and compare the adjusted and conventional measures.

2. Prices as Proxy Variables for Changes in Utilization and Technology

In our models of production we use prices as proxies for unobserved changes in the utilization of capital. A number of alternative rationales have been offered in previous studies as justifications for including output prices or input prices in models of production. Consequently, alternative, potentially competing, explanations may be offered for a finding that prices make statistically significant contributions to production functions.

A related set of issues arise in relation to the inclusion of output prices in cost functions that ordinarily would include quantities of fixed factors and output and prices of variable inputs, but not output prices. One reason for including output prices in cost functions, examined by Pope and Just (1996) and Moschini (2001), is because of a general 'errors in variables' problem that can result in biased parameter estimates when estimating cost functions. These authors were concerned with bias resulting from including actual output as opposed to expected (or planned) output as an independent variable when estimating cost functions. This issue is important in cost functions based on an explicit or implicit assumption of cost minimization.[1] The same issue does not arise in the same way in the estimation of production functions, which is the focus here. On the other hand, pro-cyclical measurement bias in the capital input might be problematic in production function studies, and it might be useful to consider this problem jointly with the problem studied by Just and Pope, and by Moschini.

The induced-innovation hypothesis originally proposed by Hicks (1932) has been used as a justification for including past input prices, output prices, or relative prices in primal models of production in a number of studies, including Fulginiti and Perrin (1993), Paris and Caputo (1995), Mundlak, Larson, and Butzer (1997), and Celikkol and Stefanou (1999).[2] Most of these studies include measures of input prices and output prices as right-hand-side variables. Mundlak (1988) argued that input and output prices are important 'state' variables in agriculture that induce technological change, and should be integrated into primal models of aggregate agricultural production. Commonly, the technology-changing impacts of past output prices are thought to occur with a long lag. Induced innovation entails induced research, the development of new technology, and induced adoption of existing technologies—some of which takes a very long time.

We suggest a third justification for prices to play a role in primal models of production and a new interpretation of the results from previous work that included past prices as explanatory variables in models of production. Specifically, recent or

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[1] For an example and some more discussion of this point, see Jin et al. (2005).

[2] Hicks (1932) proposed that changes in relative factor prices induce entrepreneurs to find new and innovative methods of producing output. Hayami and Ruttan (1970) considered the innovation-inducing role of past output prices in determining the current state of technology in agriculture.

contemporaneous prices can be used to represent the effects of economic expansions and contractions, which are hypothesized to induce changes in the utilization of fixed assets in ways that have more immediate consequences for output and productivity, thus contributing to short-term pro-cyclical patterns in measures of productivity growth, holding technology constant. The previous studies, mentioned above, included prices in production functions to represent induced technical change, whereas we are suggesting a different rationale and one that is more compatible with short-lag responses in time series data.

Transitory changes in output demand and input supply are hypothesized to cause unobserved and unmeasured changes in the utilization of fixed inputs in the short run. We wish to distinguish these short-run responses to contemporary price changes from the longer-run induced innovation responses to more-permanent price changes. In particular, observed increases in output that reflect changes in technology 'induced' by price changes should occur with a longer lag, be more enduring, and be asymmetrical for increases compared with decreases in output.[3] In the case of the utilization-changing effects of prices on production, any changes in observed output should be transient and symmetrical: output may change in either direction and the change will be temporary (no permanent rise in output for a given level of inputs). So there is a spectrum of likely responses to relative price changes:

1. Short-term—intensity of use of durable assets.
2. Medium-term—induced technical change (switching among existing technologies, many embodied in inputs).
3. Long-term—induced innovation (creating new technology options).

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[3] For example, an increase in the relative price of self-propelled combine harvesters is unlikely to cause farmers to revert to combines pulled by tractors or horse-drawn reapers. Adoption of self-propelled combines also induces other input changes associated with grain handling and storage (with their commensurate capital stock implications) that imply further adoption-disadoption asymmetries in response to price changes.

A long lag of prices may be necessary to represent the full technology-changing impacts of past prices on current output but current prices (or a short lag of prices) would be more relevant for testing the utilization-changing effects of prices on production.[4] In the application that follows we focus on the utilization-changing effects of demand and supply shocks on productivity and output. This is accomplished with the use of an index of farmers' terms of trade—the ratio of the aggregate prices received for output to the aggregate prices paid for aggregate inputs—which combines incentive effects of both changes in input supply and changes in output demand. The long-term downward trend in this terms-of-trade index reflects long-term productivity growth such that supply of agricultural products has grown faster than demand, but shorter-term movements may nonetheless provide a useful indication of changes in incentives facing farmers and, thus, capital utilization.

3. Variable Asset Utilization and Capital Measurement Errors

Generally, productivity measures are constructed under an assumption that each factor is supplied in unlimited quantities at an exogenous market price, and that all factors of production adjust instantaneously to the quantities desired by producers. The instantaneous adjustment assumption ignores adjustment costs for durable inputs. The assumption that factor supplies are perfectly elastic is probably inappropriate for many sectoral studies, especially for specialized capital items used predominantly in agriculture. If these features of agriculture are ignored, a source of systematic measurement error can be introduced into productivity indexes when they are calculated using standard methods that may be more appropriate to apply to other industries.

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[4] Fulginiti and Perrin (1993), for instance, were interested in these longer-run responses.

An important aspect of measuring capital concerns the actual (or latent) flow of capital services, which is unobservable to the researcher because the data are typically not available.[5] Consider the example of agricultural machinery. Ideally, we would have data on the number of machine hours used each year for each class of machinery, and an hourly rental rate for each class. An index of the quantity of machine services could then be calculated for the different classes of machines with the hourly rental rates as weights. Since such data are not typically if ever available, a measure of the stock of machines is used as a proxy for the quantity of machinery services in the indexing procedure, under the assumption that the flow of machine services is proportional to the stock of machines (with each additional machine providing a fixed number of machine hours per year). If the proportionality assumption is correct, then the observable stock can be used as an accurate proxy for the latent quantity of capital services in the indexing procedure.

Market rigidities, such as adjustment costs for capital inputs, can result in temporary deviations from the equilibrium conditions assumed when constructing a measure of capital using standard approaches. Additionally, economic expansions and contractions may cause unobservable and thereby unmeasured changes in the utilization of existing stocks of capital.[6] This greatly complicates the task of constructing a measure of a flow of services from the stock of capital. If changes in output are recorded with greater accuracy than

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[5] Typically, measures of service flows are based on producer's expectations of the annual return from owning a durable asset (which establishes the price producers are willing to pay for the asset). This gives rise to notions of service life and service profile and thus an expected pattern of intensity of capital use. To the extent the actual intensity of use varies from the (typically static) expectations embodied in our measure we will under- or over-estimate actual service flows.

[6] Perhaps the earliest econometric investigation of the impacts of quasi-fixities in capital and other inputs was the Lau and Yotopoulos (1971) study of Indian agriculture using a restricted profit function. A brief review of the subsequent "temporary equilibrium" literature—largely studied in a dual, dynamic adjustment framework—is provided by Berndt and Fuss (1986) in a volume that includes additional applications by Morrison, Helliwell and Chung, and others. Luh and Stefanou (1991) also studied U.S. agricultural productivity growth using a dual dynamic adjustment model.

changes in capital use, this could lead to the pro-cyclical patterns that are observed in productivity growth measures.

The presence of unmeasured variations in the utilization of durable inputs poses two complications for the measurement of capital and productivity. First, the flow of capital services will be measured with error when typical measurement practices are used. Second, the elasticity of output with respect to an additional unit of capital services will not be constant. The first complication is a result of the fact that we only have information on previously planned usage of assets (based on purchases or counts of units in place), not information on actual (ex post) usage of those assets. The second complication is the result of the changing relative marginal products of different capital classes when certain capital assets are idled or used with varying intensity. Under such conditions, typically constructed rental rates no longer represent the relative marginal products of the different capital classes, and are thus inappropriate to use as weights when constructing an aggregate index of capital service flows to be used to measure productivity.

4. Corrections for the Consequences of Variable Capacity Utilization

Two closely related methods have been suggested for correcting for the consequences of variations in capacity utilization for the measurement of durable inputs and productivity. One common suggestion in the literature is to adjust the service flows of durable inputs using information on other inputs that are deemed easier to measure than capital and whose use changes in concert with the intensity of use of durable inputs. For instance, capital services could be adjusted according to changes in labor or materials inputs. When measured growth in the use of labor or materials is greater than the measured growth in capital services, this could be an indication that standard measurement procedures are underestimating the true growth in capital services. Griliches and Jorgenson (1967), for example, suggested estimating the utilization of physical capital based on the utilization of power. This procedure was originally conceived by Foss (1963) and can be used to adjust measures of capital services directly for utilization changes.

Another method to control for unobservable changes in the use of capital inputs when measuring productivity, suggested by Berndt and Fuss (1986), Morrison (1986), and Slade (1986), is to use a measure of the stock of capital and adjust the factor cost share of capital services by substituting shadow values for market prices. The adjustment procedures are intended to control for the wedge that is created between market prices of capital goods and their shadow values when some (or all) assets are not fully utilized. This is subtly different from the service-flow adjustment approach proposed by Foss (1963), which focused on adjusting the quantity of capital.

While both of these approaches have explicit microeconomic foundations and are widely accepted methods for addressing the utilization problem, each is vulnerable to additional measurement problems, especially in applications to sectoral models of agriculture. This is because the supply of services from capital inputs (and notably the specialized durable inputs most heavily used in agriculture, including many types of agricultural machinery) is neither fixed nor infinitely elastic in the short run, but upward sloping when considering agriculture as a sector.

Figure 1 provides a simple illustration of this concept and the methods that have been suggested in the literature for adjusting the service flows or shadow values of capital services to incorporate unobservable variations in utilization. In Figure 1, K refers to the stock of capital, k is the flow of capital services from the stock, VMP is the value of the marginal product of capital, ρ is the rental rate of capital, and v is the shadow value of an additional unit of capital stock. In long-run equilibrium a given optimal rate of utilization of the stock, U^*, implies a flow of services equal to $k = U^*K$ that is proportional to the stock. For simplicity, we can choose units such that $U^* = 1$ and in long-run equilibrium the quantity measure of capital service flows corresponds to the quantity measure of the stock of capital. This proportional equivalence is embedded as an implicit assumption in much analysis that assumes constant capacity utilization.

[Figure 1: *Demand Shock in the Market for Durable Assets*]

Suppose the industry is in long-run equilibrium with a quantity of capital K_0 and a rate of capital service flows of $k_0 = U_0K_0 = K_0$ (for $U_0 = U^* = 1$), given a value of the marginal product of capital of VMP_0, a rental rate of capital equal to ρ_0, and a shadow value of capital equal to v_0 (and thus a ratio of the rental rate of capital to the shadow value of an additional unit of capital stock equal to $\varphi_0 = \rho_0/v_0 = 1$). Now, suppose the value of the marginal product of capital shifts down temporarily to VMP_1. In the short run, the quasi-fixity of capital implies the stock is fixed at K_0 and, through changes in the utilization rate, the supply of services from that stock is upward sloping as indicated by S_k. Hence, when capital is quasi-fixed, a temporary negative demand shock from VMP_0 to VMP_1 reduces the flow of services from k_0 to k_1, and the rental rate from ρ_0 to ρ_1, but these changes are unobserved. As a result, the following three things occur: (i) the ratio of the service flow to the stock no longer equals the long-run equilibrium ratio, U_0; (ii) the ratio of the rental rate of capital to the shadow value of the capital stock no longer equals the long-run equilibrium ratio, φ_0; and (iii) the measured quantity of capital services, k_0, temporarily exceeds the true quantity of capital services, k_1.

The flow of capital services (or, equivalently, the return to capital in equilibrium) is typically estimated as the rental rate of capital multiplied by the productive stock of capital,

$\rho_t K_t$, under the assumption that the flow of services is proportional to the stock of capital and $k_t = K_t$. This is because the actual flow of services is unobservable to the researcher. As noted above, two approaches have been used to approximate the true return to capital services, $\rho_1 k_1$, when the proportion between the stock and flow varies over time. The first, as proposed by Foss (1963), is to make a utilization adjustment to the capital service flow using information on changes in the intensity of use of other inputs. The second approach, which is closely related but, perhaps, more appealing on a theoretical basis, controls for the unobservable change in utilization by using parametric or other methods to estimate the shadow value of an additional unit of capital stock, v_1 and $v_1 K_0$ is used as an approximation of the cost of capital services. However, as shown in Figure 1, in this simple illustration the shadow value, v_1, understates the rental rate of capital, ρ_1, and using $K_0 = k_0$ overstates the true quantity of services, k_1, leaving the potential for additional measurement problems (these errors in price and quantity will be exactly offsetting only if the demand for capital is unit elastic, in which case the total cost of capital services does not change with changes in quantity or price).

5. Primal Versus Dual Approaches

A number of studies have examined the concept of capacity utilization and the implications for productivity measurement using a dynamic, cost-adjustment framework. In particular, see Morrison (1985 and 1986) for examples of studies that use this approach. Luh and Stefanou (1991) used a dynamic model that incorporates adjustment costs for capital inputs to calculate measures of productivity growth for the U.S. agricultural sector. The dynamic, cost-adjustment approach can account for variable capacity utilization with multiple quasi-fixed inputs in a general setting, and can be used to derive improved measures of input use and productivity. This approach allows for the estimation of shadow values for quasi-fixed inputs, which can be substituted for rental rates when calculating a utilization-adjusted measure of primal or dual productivity growth. The cost-adjustment approach is theoretically appealing owing to the strong links between the investment behavior of producers, the utilization of capital assets, and the resulting implications for productivity measurement. From an empirical standpoint, input prices are commonly assumed to be exogenous, and if so, cost function models may avoid simultaneity problems associated with using quantity measures for inputs.

Given its strong behavioral assumptions conceived in the context of an individual firm, a dual approach is probably most relevant when examining firm-level data. One reason why we opted not to use this approach in the present study is that the internal adjustment process is defined using an investment equation for capital inputs that relies on a measure of the rate of change of the quantity of capital, which we claim is measured with error in the case of U.S. agriculture. Also, this approach relies on the assumption that market prices are exogenous.

In addition to these considerations, several compelling reasons led us to opt for a primal approach in the present study. First, this is a study of the U.S. agricultural sector, and a primal approach avoids having to assume ex post cost minimizing behavior in an application using highly aggregated data in which the assumption is questionable. Second, as described above, there is ample precedent in the literature for using a primal approach to estimate relationships between inputs and outputs in models that explicitly incorporate prices, although our reason for including prices differs from those in previous studies. Hence, an alternative interpretation of the prior literature is made possible in this context. Third, the fact that capital utilization rates may vary over time has been examined extensively in a cost-adjustment framework that has yielded insights into productivity measurement, yet little has been done regarding the implications of variable capital utilization for the estimation of production functions and the resulting productivity measures. Finally, recent contributions to both the general economics literature and the agricultural economics literature have suggested that the general advantages of duality-based approaches over the primal approach may have been overstated in the past. Mundlak (1996, 2000), for example, argued the merits of a primal approach to modeling production, stressing that a dual approach uses less of the available information than a primal approach, resulting in statistical inefficiencies.

The intent of this study is to examine the potential errors introduced into capital and productivity measures when assuming capital service flows are proportional to capital stocks. It is a measurement problem related to the quantity of capital, and therefore the problem is approached by first defining a specific form for the measurement error, and then investigating the impacts in a primal setting (i.e., using input quantities not prices). In the primal approach we can relax the assumption that capital service flows are proportional to capital stocks without having to rely on the assumption that prices are competitive or exogenous, or that quantities are chosen to minimize costs.

6. Production Functions Augmented with Variable Capital Utilization

We consider two specifications of a production function, augmented for the variable utilization of durable assets. The first specification is a modified Cobb-Douglas production function in which the quantities of some factors of production are measured with error. The second is a modified Translog production function that represents a generalization of the Cobb-Douglas model.

Start by assuming the existence of an aggregate production function for U.S. agriculture of the Cobb-Douglas form:

$$Q_t = f(\tilde{X}_t, Y_t; \beta) = G_t(Y_t) \times \prod_{i=1}^{n} \tilde{X}_{it}^{\beta_i}\,, \tag{1}$$

where $\tilde{X}_i = (\tilde{X}_1, ..., \tilde{X}_n)$ denotes a vector of conventional inputs like land, labor, capital, and materials; $Y_k = (Y_1, ..., Y_s)$ denotes a vector of variables that determine the current state of technology; and β represents a vector of parameters. Assume we only observe a proxy, X_i for some $\tilde{X}_i$, (for instance a capital stock as a proxy for a capital flow), which is assumed to be related to the true quantity according to a variable rate of utilization, U_i, such that $\tilde{X}_i = X_i \times U_i$. The rate of utilization is a latent unobserved variable. However, we do observe variables, Z_h, that determine the current rate of utilization, $U_i = U_i(Z)$. Taking logarithms (and using lower case italics to denote variables in logarithms) we can write equation (1) as

$$q_t = g_t(y_t) + \sum_{i=1}^{n} \beta_i (x_{it} + u_{it})\,. \tag{2}$$

Now, expressing productivity, g_t, as a linear function of the logged technology-changing variables, y_k, yields

$$g_t = \alpha_0 + \sum_{k=1}^{s} \alpha_k y_{kt} + \varepsilon_{0t}\,, \tag{3}$$

and expressing the utilization rate as a linear function of the utilization-changing variables, z_h, yields,

$$u_{it} = \sum_{h=1}^{m} \lambda_{ih} z_{ht}\,. \tag{4}$$

In these equations the Greek letters α, β, and λ, are used to represent the fixed parameters to be estimated and ε_0 is a random error term, assumed to be distributed independently of the explanatory variables, x_i, z_h, and y_k. Substituting equations (3) and (4) into (2) results in the following augmented Cobb-Douglas production function for estimation:

$$q_t = \alpha_0 + \sum_{k=1}^{s} \alpha_k y_{kt} + \sum_{i=1}^{n} \beta_i x_{it} + \sum_{i=1}^{n} \sum_{h=1}^{m} \beta_i \lambda_{ih} z_{ht} + \varepsilon_{0t} \,. \tag{5}$$

The second specification is a modified Translog production function that incorporates measurement error and represents a generalization of the Cobb-Douglas model:

$$q_t = g_t(y_t) + \sum_{i=1}^{n} \beta_i (x_{it} + u_{it}) + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} (x_{it} + u_{it})(x_{jt} + u_{jt}) \,. \tag{6}$$

Substituting equations (3) and (4) into (6) results in the following augmented Translog production function for estimation:

$$\begin{aligned} q_t = \alpha_0 + \sum_{k=1}^{s} \alpha_k y_{kt} + \sum_{i=1}^{n} \beta_i x_{it} + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} x_{it} x_{jt} + \ldots \\ \sum_{i=1}^{n} \sum_{h=1}^{m} \lambda_{ih} z_{ht} \left(\beta_i + \sum_{j=1}^{n} \gamma_{ij} x_{jt} + \frac{1}{2} \sum_{j=1}^{n} \gamma_{ij} \sum_{h=1}^{m} \lambda_{jh} z_{ht} \right) + \varepsilon_{0t} \,. \end{aligned} \tag{7}$$

Two simplifying assumptions were made prior to estimating equations (5) and (7). First, we consider only measurement errors associated with variable utilization of capital. While unobservable utilization changes may be important for other inputs such as land and labor, we envisage the problem is less pronounced with these inputs given our construction of these variables.[7] Second, the utilization term is assumed to follow a specific form.

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[7] Specifically, we measured labor in terms of hours on farms (rather than counts of operators and others), adjusting for significant changes in the part-time farming patterns of farmers. The land variable is an estimate of the quantity of land in farms, accounting for policy induced set-aside acres in agriculture and changes in the mix of pasture- and range-land and irrigated and non-irrigated crop land.

Details on the utilization term and a list of the specific production functions to be estimated are provided in the next section.

7. Empirical Analysis

The main data used in this study are state-specific Fisher Ideal indexes of inputs, outputs, and multifactor productivity (MFP) in U.S. agriculture in the 48 contiguous states for the period 1949-2002.[8] As an illustration, the corresponding national indexes of inputs, outputs, and productivity are presented in Figures 2 and 3.

[Figure 2: *Indexes of the Quantity of Capital, Labor, Land, and Materials, 1949-2002*]
[Figure 3: *Indexes of the Quantity of Output, Input, and MFP, 1949-2002*]

We use the following variables, which are all state-specific except for the annual time trend.

1. Output, q: the logarithm of the index of the quantity of agricultural output.
2. Inputs, x_i: the logarithms of indexes of the quantities of quality-adjusted land, x_1, labor, x_2, capital, x_3, and materials, x_4.
3. An annual time trend, $y_{1:}$ 1949 = 1.
4. Seasonal growing conditions, y_2: the logarithm of the index of pasture and range conditions expressed in deviations from the mean of the logarithm of the index.[9]
5. Terms of trade, z_1: the logarithm of the ratio of the index of the price of aggregate output to the index of the price of aggregate input.

When specified in logarithms the state-level indexes of output are non-stationary, which might result in spurious parameter estimates.[10] However, when the same measures

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[8] These data, the Andersen, Pardey, Craig, and Alston (APCA) series, represent a revised and updated version of data published by Acquaye, Alston, and Pardey (2003) and originally developed and used by Craig and Pardey (1996). More complete descriptions can be found in Pardey, Andersen, and Craig (2007).

[9] In all of the regressions the growing conditions index enters as a technology shifter, but in some of the regressions it also enters as a utilization-changing variable. This is done to separate the direct effects of weather from the indirect effects of changes in the utilization of capital resulting from changes in weather. For example, a drought will have direct impacts on current output, but it may also have indirect effects if farmers choose to leave machinery idle.

are first differenced and thus specified as rates of growth, they are stationary; therefore, we have specified the estimating equations in rates of growth as well as in undifferenced logarithmic form. Descriptive statistics for all of the variables used in the analysis are presented in Table 1 for the period 1949-2002.

[Table 1: *Descriptive Statistics for Variables in the Regression Analysis*]

The analysis proceeds using a two-step procedure, where the first step involves constructing appropriate proxy variables to represent utilization, and the second step involves estimating various production functions augmented with the utilization variables. As previously mentioned the index of farmers' terms of trade—the ratio of the aggregate price of output to the aggregate price of variable inputs—combines incentive effects of both changes in input supply and changes in output demand. Cyclical movements in this measure may provide a useful indication of short-term changes in incentives facing farmers, and hence in the utilization of capital.

In the regression analysis the terms of trade measures for each state, z_1, are trend-filtered and lagged one period, thereby representing cyclical movements in farmers' expectations about terms of trade. To obtain these measures, we began by regressing each of the state-specific terms-of-trade measures on the annual time trend, y_{1t}. OLS estimates of equation (8) were obtained for each state,

$$z_{1t} = \delta_0 + \delta_1 y_{1t} + \varepsilon_t , \tag{8}$$

and the residuals, $\hat{\varepsilon}_t$, from the regressions were retained. A 'pre-determined' or 'expected' terms of trade measure was then defined as the residuals from these regressions lagged one period, $\hat{z}_{1t} = \hat{\varepsilon}_{t-1}$. This procedure is based on the widely used 'naïve' expectations model

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[10] Dickey-Fuller tests of a unit root were used to verify that most of the state-level indexes of output are non-stationary when expressed in logarithms, but stationary after first differencing (logarithmic differences).

and our hypothesis that changes in capital utilization are linked to short-run cyclical movements in farmers' terms of trade (not long-run trends in this measure).

Next, capital utilization is assumed to depend on economic and environmental circumstances, and is therefore specified as a function of the terms of trade measure, $\hat{z}_{1t}$, and the index of growing conditions expressed in deviations from the state-specific long-run mean, y_{2t}.

$$u_t = \lambda_{31}\hat{z}_{1t} + \lambda_{32}y_{2t} \tag{9}$$

When the utilization term (in logarithms) is equal to zero, this implies that farmers are using a constant proportion of the stock of capital in production each period, the proportionality assumption holds, and capital services are measured without error.

We estimate production functions with the variables in logarithms and rates of change (first differences in logarithms). In each case a base model is estimated, representing a conventional Cobb-Douglas or Translog production function, as well as an augmented version with variable utilization. The base (conventional) models are nested in the utilization models as shown in Table 2, which lists the different specifications.

[Table 2: *Specifications of the Production Functions in the Empirical Analysis*]

The following estimation results were obtained using STATA software. For the purpose of this analysis the data set consists of observations for 48 states over the years 1950-02, resulting in a sample of 2,544 observations (2,496 observations in rates of change) of the variables. Regression estimates for equations A to D in Table 2 were obtained using Fixed-Effects (FE) panel data methods or Non Linear Least Squares (NLLS), where applicable.

Estimation results from the Cobb-Douglas models are shown in Table 3, where a total of 28 parameter estimates are presented, of which 22 are significant at the 1 percent level, 1 at the 10 percent level, and 5 are insignificant.[11] Most of the estimated production elasticities seem too small for land and labor and too large for materials input, suggesting the presence of bias. The fact that conventionally measured capital, labor and land inputs were shrinking (as well as the quality-adjusted measures used here), while output was rapidly expanding in U.S agriculture during most of 1950-02, makes estimating a production function for this period challenging. This fact is reflected in the mostly small (probably downwards biased) and often statistically insignificant values for the estimated production elasticities for land and labor in the regression results.

[Table 3: *Cobb-Douglas Models: Fixed-effects (within) Estimates*]

The results for the Translog specifications are presented in Table 4, which contains a total of 70 parameter estimates, 24 of which are significant at the 1 percent level, 13 at the 5 percent level, 8 at the 10 percent level, and 25 are insignificant. The added flexibility of the Translog specification comes hand-in-hand with imposing less (and potentially too little) structure on the production technology, which can result in unreasonable parameter estimates (such as negative production elasticities). In the case of the base model Translog production function, the results are mostly consistent with prior expectations about agricultural production. The production elasticities from this model are all positive and statistically significant, except for labor. The estimate of returns to scale is 0.93, which is statistically significantly less than one but close nonetheless.

[Table 4: *Translog Models: Fixed-effects (FE) and Non-linear Least Squares Estimates (NLLS)*]

Table 5 shows the estimates of annual MFP growth from the different model specifications. All of the estimates of productivity growth rates are statistically significantly

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[11] The 28 parameters do not include the estimates of the R^2 and returns to scale included at the bottom of the table.

different from zero at the 1 percent level of significance. The parametric estimates in Table 5 are all smaller than the (non-parametric) estimate of the average annual growth in U.S MFP from 1950-2002 equal to 1.69 percent, which was calculated as the sample average of the annual rates of change of the index of productivity among all states and years. We surmise that part of the reason why the parametric estimates are smaller is that some additional specification error exists (such as omitted variables) that is biasing the measures downward. Previous studies that have used a primal approach to obtain parametric estimates also found comparatively small rates of productivity growth in U.S. agriculture, such as Capalbo and Denny (1986) and Jorgenson (1990).

[Table 5: *Annual MFP Growth in U.S. Agriculture 1951-2002*]

We are now in a position to answer a few important questions. Are the estimates of productivity growth pro-cyclical? Did changes in the intensity of use of capital contribute to pro-cyclical patterns in these measures? The elasticities in Table 6 represent the percentage increase in productivity growth that would result from a one percent increase in the given variable, holding all other factors constant, calculated at the sample means of the variables.

[Table 6: *Elasticity of Productivity with Respect to Expected Terms of Trade and Growing Conditions*]

The regression results for the different specifications indicate that the terms of trade and growing conditions variables have a significant and positive effect on productivity growth. These results support the hypothesis that measured productivity growth is pro-cyclical, and that unobserved changes in the utilization of capital in response to short-run fluctuations in farmers' terms of trade and growing conditions have contributed to these patterns. Furthermore, the results using the full sample are similar in magnitude across models (except the undifferenced Translog model), indicating that a ten percent increase in farmers' terms of trade would cause between a 1.1 and 1.4 percent increase in measured productivity. Similarly, a ten percent increase in the index of growing conditions above the long-run average would cause a 1 percent increase in measured productivity. As indicated in the descriptive statistics in Table 1, year-to-year proportional changes in the measure of terms of trade ranged between -0.50 and 0.53, and year-to-year proportional changes in the measure of growing conditions ranged between -2.28 and 2.26, sufficient to contribute significantly to year-to-year changes in measured productivity.

Cyclical measurement errors in indexes of input quantities of the types identified in this study will have consequences for studies that use the indexes as data. Any of the given annual estimates may be significantly biased. Cyclical errors should have a smaller impact on (non-parametric) estimates of productivity growth based on index numbers because the errors tend to average out over a sufficiently long sample. In other words, estimates of long-run productivity growth based on averages are not so susceptible to cyclical utilization bias, but could be biased nonetheless. The implications may be more serious for parametric studies of production that can be sensitive to measurement errors in the variables. Specifically, cyclical measurement error in the independent variables will cause attenuation to the null (or zero) in parameter estimates in a regression analysis; the parameter estimates will be biased. Therefore, in the next section we propose a simple procedure to expunge the utilization bias from measures of productivity growth for use in parametric studies of production and productivity.

8. Filtered Measures of Productivity Growth

Our measure of productivity is defined as a function of the variables that affect technology, in this case a simple time trend, y_{1t} and weather conditions, represented by the index of growing conditions, y_{2t}; however, we have shown that through their influence on capital utilization, other variables influence measures of productivity, such as the index of farmer's expected terms of trade, $\hat{z}_{1t}$ and, again, the index of growing conditions, y_{2t}. In this section we estimate filtered measures of productivity growth using these variables and compare the filtered measures with estimates calculated conventionally as the simple rate of change of the index of productivity.

Letting s denote states, the first step in procedure for calculating our filtered measures is to regress the state-level measures of productivity growth, Δg_{st}, on the measures of expected farmers' terms of trade, $\Delta \hat{z}_{1st}$, and growing conditions, Δy_{2st}, expressed as rates of growth, resulting in the following equation:

$$\Delta g_{st} = \alpha_0 + \alpha_1 \Delta \hat{z}_{1st} + \alpha_2 \Delta y_{2st} + \upsilon_s + \varepsilon_{st} . \tag{10}$$

A fixed-effects (within) regression procedure was used for estimation.[12] The residuals, $\hat{\varepsilon}_{st}$, represent the portion of productivity growth unexplained by changes in terms of trade and growing conditions. A utilization-filtered measure of annual productivity growth, Δg^{*}_{st}, was then calculated for each state using the following equation:

$$\Delta g^{*}_{st} = \Delta g_{st} - \hat{\alpha}_1 \Delta \hat{z}_{1st} - \hat{\alpha}_2 \Delta y_{2st} = \hat{\alpha}_0 + \hat{\upsilon}_s + \hat{\varepsilon}_{st} . \tag{12}$$

The results from equation (12) are filtered measures of productivity growth with reduced measurement error that generally are less volatile than the standard estimates. Among all

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[12] Equation (11) requires an additional constraint to econometrically estimate α_0 and υ_s, and we used the constraint that the average of the state-specific effects is equal to zero, $\overline{\upsilon_s} = 0$.

states and time periods the estimate of U.S. average annual productivity growth increased from 1.69 percent to 1.77 percent as a result of the filtering; on average a negative bias because standard procedures resulted in an overstatement of capital utilization. The standard deviation of the filtered productivity series is statistically significantly smaller than the original unadjusted series. The standard deviation of the original measure of productivity growth for all states and time periods is 0.0815, and the adjusted measure is 0.0747. An *F*-test of the hypothesis that the ratio of the standard deviations equals one was rejected at the one percent level of significance.

The state-specific estimates of filtered productivity growth were also compared with the unfiltered versions, indicating pervasive bias in the state-specific estimates. In Table 7 we present the averages of filtered and unfiltered annual rates of productivity growth, 1950-2002, as well as the percentage difference between the estimates in terms of averages and the standard deviations of the annual series.

[Table 7: *State-Specific MFP Growth and Bias*]

The presence of a positive bias in the estimates of annual average MFP growth indicates an underestimation of capital inputs, and the presence of a negative bias indicates an overestimation of capital inputs. Similarly, the presence of a positive bias in the standard deviations implies a higher volatility in the unfiltered series compared with the filtered series. The state-specific estimates of annual average bias in MFP growth range from negative 26.7 percent in New Hampshire to positive 39.7 percent in Texas. The state-specific estimates of bias in the standard deviation of MFP growth range from negative 32.8 percent in Maryland to positive 21.4 percent in New York.

Our results indicate that standard measurement practices slightly overstate the actual quantity of capital inputs used in U.S. agriculture during the period 1950-2002, which might be the result of farmers leaving some machinery idle, or not utilizing all of their storage capacity, resulting in underestimation of productivity growth. In certain states and during certain time periods the estimated bias in MFP growth is large, and ignoring this bias could result in substantial errors in interpreting rates of MFP growth among different states and time periods. Econometric models of production and productivity are especially susceptible to this bias.

9. Conclusion

U.S. agricultural output more than doubled during the years 1950-2002, reflecting increased use of materials inputs along with changes in technology, combined with reductions in the use of capital, land and labor inputs. The overall growth in output is essentially entirely attributable to productivity growth, since the aggregate index of inputs did not grow appreciably.

Like other studies of other sectors, we have shown that U.S. agricultural productivity growth was procyclical throughout the second half of the 20th century. This study has focused on one of the reasons for these observed productivity patterns— measurement error in the capital variable when estimates of the capital stock (assuming constant utilization rates) are used to represent the flows of services from the capital stock. A model of agricultural production was presented that incorporated the variable utilization of capital assets. Conventional production functions were augmented to account for the variable utilization of capital assets. The hypothesis tested here is that the assumption of constant utilization rates gives rise to year-to-year, or cyclical errors in estimates of the quantity of capital and productivity, contributing to pro-cyclical productivity patterns that tend to average out in longer-term measures.

The hypothesis that cyclical movements in demand for agricultural outputs and inputs affect measures of agricultural productivity was tested empirically. The results indicate that a portion of the pro-cyclical patterns observed in measures of productivity growth can be attributed to errors in measuring durable inputs like physical capital. In many of the regression results the finding was for significant and positive utilization effects related to changes in farmers' terms of trade as well as changes in growing conditions. The utilization responses were used to filter measures of productivity growth. We found that filtering the estimated utilization responses out of the estimates of productivity growth statistically significantly changed the measures.

The most important finding in this study is that unobservable cyclical movements in the utilization of durable assets have the potential to introduce significant bias in studies of production, especially in parametric studies that are sensitive to measurement error in the input quantities. It is quite possible that the utilization problem analyzed in this study may be more pronounced in capital-intensive sectors of the economy such as construction, manufacturing, and mining.

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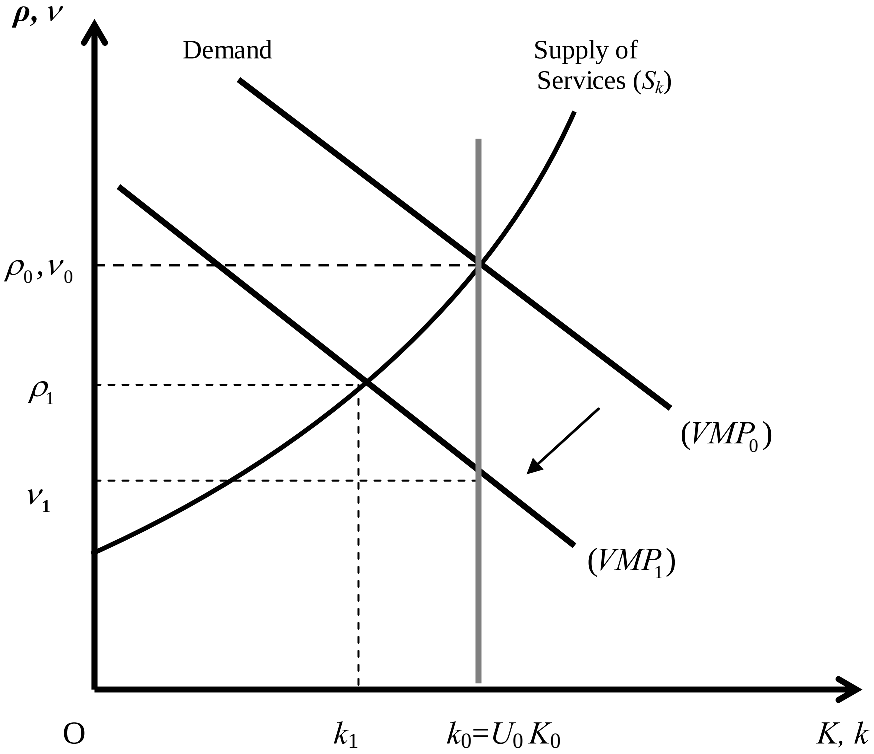
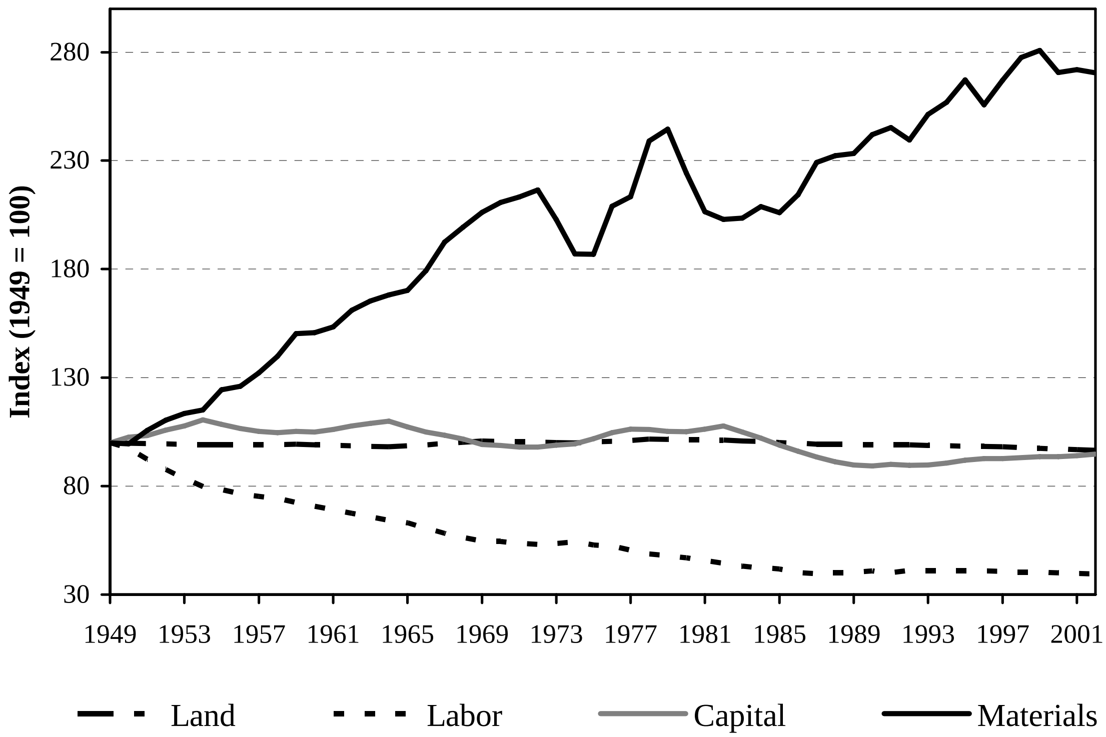
Figure 1: *Demand Shock in Market for Durable Assets*



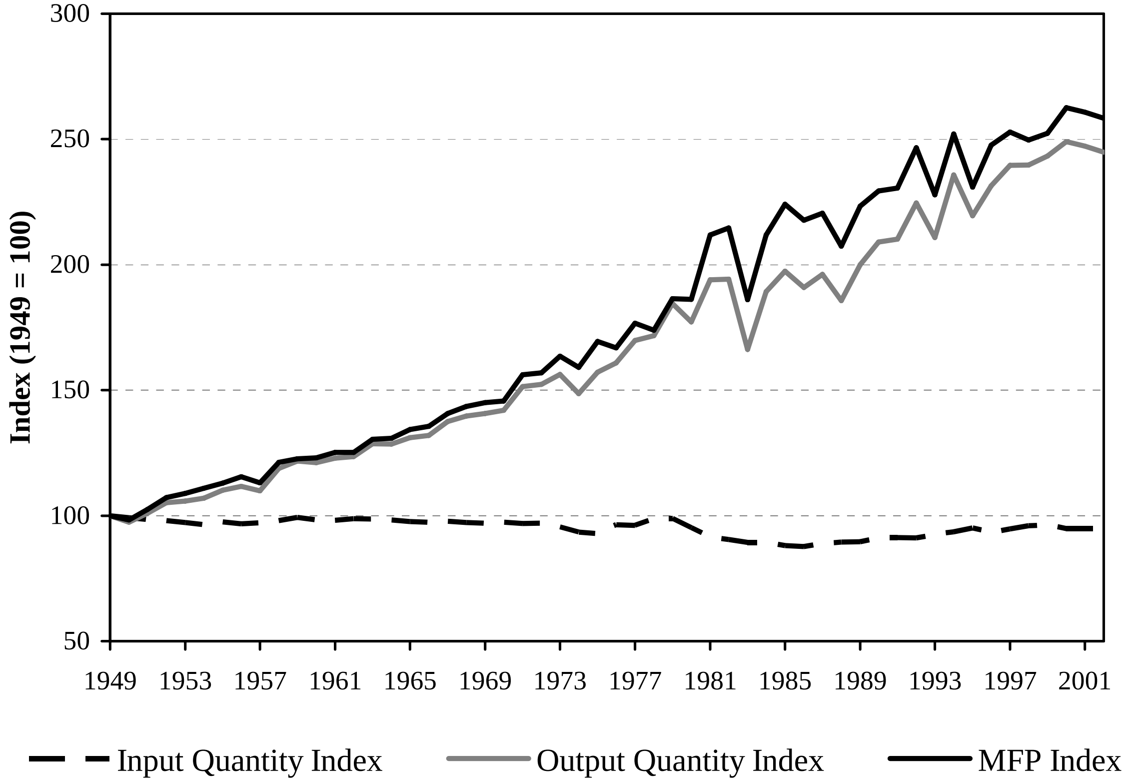
Source: Authors.

Figure 2: *Indexes of the Quantity of Capital, Labor, Land, and Materials, 1949-2002*



Source: Authors.

Figure 3: *Indexes of the Quantity of Input, Output, and Productivity, 1949-2002*



Source: Authors.

Table 1: *Descriptive Statistics*

	Mean	Minimum	Maximum	Standard Deviation
Natural Logs				
Output	4.999	4.130	6.200	0.406
Labor	3.941	2.810	4.620	0.427
Land	4.455	3.240	4.890	0.306
Capital	4.572	3.535	5.423	0.290
Materials	5.125	3.660	6.322	0.506
Growing conditions	4.284	2.080	4.670	0.231
Terms of trade	-0.001	-0.417	0.527	0.099
Rate of Growth (percent per year)				
Output	0.014	-0.530	0.490	0.082
Labor	-0.018	-0.200	0.230	0.036
Land	-0.005	-0.070	0.050	0.015
Capital	-0.002	-0.121	0.090	0.026
Materials	0.016	-0.293	0.311	0.060
Growing conditions	-0.005	-2.280	2.260	0.304
Terms of trade	0.000	-0.496	0.530	0.086

Note: The estimates in logarithms include 2,544 observations. The estimates in growth rates include 2,496 observations.

Table 2: *Specifications of the Production Functions in the Empirical Analysis*

Equation Type and Specification

A. Conventional Cobb-Douglas

$$q_t = \alpha_0 + \alpha_1 y_{1t} + \alpha_2 y_{2t} + \sum_{i=1}^{n} \beta_i x_{it}$$

B. Utilization Augmented Cobb-Douglas

$$q_t = \alpha_0 + \alpha_1 y_{1t} + \alpha_2 y_{2t} + \sum_{i=1}^{n} \beta_i x_{it} + \beta_3 (\lambda_{31} \hat{z}_{1t} + \lambda_{32} y_{2t})$$

C. Conventional Translog

$$q_t = \alpha_0 + \alpha_1 y_{1t} + \alpha_2 y_{2t} + \sum_{i=1}^{n} \beta_i x_{it} + \beta_3 (\lambda_{31} \hat{z}_{1t} + \lambda_{32} y_{2t})$$

D. Utilization Augmented Translog

$$q_t = \alpha_0 + \sum_{k=1}^{s} \alpha_k y_{kt} + \sum_{i=1}^{n} \beta_i x_{it} + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} x_{it} x_{jt} + (\lambda_{31} \hat{z}_{1t} + \lambda_{32} y_{2t}) \left[\beta_3 + \sum_{j=1}^{4} \gamma_{3j} x_{jt} + \frac{1}{2} \gamma_{33} \lambda_{31} \hat{z}_{1t} \right]$$

Note: Two equations were estimated for each specification, one in logarithms and the other in rates of change of the variables.

Table 3: *Cobb-Douglas Models: Fixed-effects (within) Estimates*

		Logs		Growth rates	
		Base	Utilization	Base	Utilization
Production Elasticities					
Land	β_1	0.385	0.384	0.030	0.065
		(0.023)	(0.023)	(0.104)	(0.104)
Labor	β_2	-0.005	-0.025	0.063	0.034
		(0.017)	(0.017)	(0.037)	(0.037)
Capital	β_3	0.228	0.239	0.222	0.239
		(0.023)	(0.023)	(0.065)	(0.064)
Materials	β_4	0.391	0.396	0.213	0.220
		(0.015)	(0.015)	(0.024)	(0.024)
Trend	α_1	0.012	0.012		
		(0.000)	(0.000)		
Growing Conditions	α_2	0.084	0.090	0.103	0.104
		(0.012)	(0.011)	(0.007)	(0.007)
(TOT) Elasticity	$\lambda_{31}\beta_3$		0.129		0.116
			(0.023)		(0.019)
Constant	α_0	-23.876	-23.207	0.013	0.013
		(0.754)	(0.767)	(0.002)	(0.002)
RTS	$\sum_{i=1}^{4}\beta_i$	0.999	0.994	0.528	0.528
R^2		0.866	0.868	0.176	0.176

Note: Standard errors in parentheses. TOT = Terms of trade. RTS = Returns to scale.

Table 4: *Translog Models: Fixed-effects (FE) and Non-linear Least Squares Estimates (NLLS)*

		Logs		Growth rates	
		Base (FE)	Utilization (NLLS)	Base (FE)	Utilization (NLLS)
Parameters					
Land	β_1	-0.878	-1.290	-0.137	-0.002
		(0.373)	(0.459)	(0.150)	(0.139)
Labor	β_2	0.121	0.627	0.086	0.049
		(0.310)	(0.326)	(0.051)	(0.050)
Capital	β_3	-0.933	-2.018	0.168	0.136
		(0.462)	(0.543)	(0.074)	(0.043)
Materials	β_4	0.191	0.824	0.223	0.223
		(0.273)	(0.295)	(0.029)	(0.028)
Cross-Product Terms					
Land/Labor	γ_{12}	0.220	0.259	2.494	1.367
		(0.119)	(0.143)	(2.550)	(2.419)
Land/Capital	γ_{13}	0.253	0.264	-0.356	-3.229
		(0.130)	(0.112)	(3.654)	(1.427)
Land/Materials	γ_{14}	-0.281	-0.253	4.945	3.955
		(0.100)	(0.120)	(1.844)	(1.731)
Labor/Capital	γ_{23}	-0.036	-0.222	-3.058	-0.233
		(0.107)	(0.097)	(1.663)	(0.367)
Labor/Materials	γ_{24}	-0.066	-0.025	-1.248	-0.784
		(0.060)	(0.073)	(0.654)	(0.643)
Capital/Materials	γ_{34}	-0.381	-0.424	-1.986	0.806
		(0.094)	(0.086)	(0.970)	(0.323)
Land/Land	γ_{11}	0.069	0.060	-6.339	-15.007
		(0.105)	(0.260)	(3.944)	(6.81)
Labor/Labor	γ_{22}	-0.075	-0.068	-0.247	-0.204
		(0.045)	(0.097)	(0.522)	(0.998)
Capital/Capital	γ_{33}	0.233	0.666	-1.625	-0.235
		(0.106)	(0.188)	(1.435)	(0.213)
Materials/Materials	γ_{44}	0.334	0.658	-0.085	-0.033
		(0.035)	(0.067)	(0.227)	(0.437)
Intercept Terms					
Trend	α_1	0.012	0.012		
		(0.000)	(0.000)		
Growing Conditions	α_2	0.099	0.022	0.102	0.142
		(0.015)	(0.028)	(0.005)	(0.015)
Utilization Terms					
Terms of Trade	λ_{31}		-0.058		0.839
			(0.110)		(0.264)
Growing Conditions	λ_{32}		0.371		-0.237
			(0.118)		(0.105)
Constant	α_0	-17.157	-14.815	0.015	0.015
		(1.332)	(1.890)	(0.002)	(0.002)
RTS		0.927	0.471	0.453	0.543
R^2		0.818	0.819	0.183	0.209

Note: Standard errors in parentheses. RTS = Return to scale.

Table 5: *Annual MFP Growth in U.S. Agriculture 1951-2002*

	Logs		Growth rates	
	Base	Utilization	Base	Utilization
		------------- *percent per year* -------------		
Cobb-Douglas models	1.22	1.19	1.30	1.26
Translog models	1.18	1.17	1.51	1.55

Note: All estimates are significantly different from zero at the 1 percent level of significance.

Table 6: *Elasticity of Productivity of Expected Terms of Trade and Growing Conditions*

	Cobb-Douglas models		Translog models	
	Logs	Growth rates	Logs	Growth rates
Terms of Trade	0.129	0.116	0.043	0.143
	(0.023)	(0.019)	(0.093)	(0.045)
Growing Conditions	0.090	0.104	-0.292	0.102
	(0.011)	(0.007)	(0.121)	(0.014)

Note: Standard errors in parentheses.

Table 7: *State-Specific MFP Growth and Bias*

	Annual Averages, 1950-2002		Bias	
State	Filtered	Unfiltered	Averages	St. Dev.
		--------- percent per year ----------		
Alabama	2.64	2.45	-7.46	16.05
Arizona	1.57	1.48	-5.86	1.58
Arkansas	3.23	2.88	-11.40	19.80
California	1.98	1.85	-6.52	-16.24
Colorado	1.83	1.57	-15.47	7.43
Connecticut	1.34	1.46	8.15	-18.99
Delaware	2.20	2.33	5.94	23.13
Florida	1.63	1.79	9.50	2.96
Georgia	2.84	2.71	-4.61	24.69
Idaho	2.11	2.15	1.76	-0.17
Illinois	1.77	1.53	-14.57	16.30
Indiana	1.73	1.56	-10.71	18.96
Iowa	1.77	1.68	-5.35	11.95
Kansas	1.65	1.63	-1.29	7.43
Kentucky	1.11	0.86	-24.77	15.54
Louisiana	2.37	2.08	-13.13	7.58
Maine	1.60	1.67	4.29	-6.47
Maryland	2.03	1.99	-2.24	32.79
Massachusetts	1.18	1.38	15.48	-11.94
Michigan	2.01	1.80	-11.13	13.50
Minnesota	2.08	1.99	-4.83	4.55
Mississippi	3.03	2.96	-2.22	11.20
Missouri	1.35	1.17	-14.55	19.03
Montana	0.85	1.04	20.11	20.86
Nebraska	1.81	1.89	4.55	10.29
Nevada	0.97	0.93	-3.91	-7.81
New Hampshire	1.12	1.46	26.69	3.24
New Jersey	0.91	1.03	12.44	-1.14
New Mexico	2.14	1.74	-20.38	7.89
New York	1.31	1.31	-0.13	-21.35
North Carolina	2.52	2.47	-1.83	10.93
North Dakota	2.05	2.13	3.82	10.10
Ohio	1.63	1.40	-15.16	15.23
Oklahoma	1.86	1.33	-33.50	-0.47
Oregon	1.67	1.58	-5.57	-18.58
Pennsylvania	2.03	1.89	-7.12	15.12
Rhode Island	1.34	1.47	9.21	-12.71
South Carolina	2.47	2.29	-7.42	19.66
South Dakota	1.79	1.76	-1.54	6.93
Tennessee	1.50	1.29	-15.14	15.74
Texas	1.92	1.29	-39.72	21.25
Utah	1.56	1.51	-3.24	-13.20
Vermont	1.44	1.44	-0.06	-12.67
Virginia	1.43	1.35	-5.72	21.98
Washington	1.85	1.87	1.07	11.97
West Virginia	1.53	1.44	-5.62	4.07
Wisconsin	1.48	1.40	-5.82	6.38
Wyoming	0.82	0.83	2.18	-5.54
U.S.	1.77	1.69	-4.72	8.97

Note: Bias is calculated as the natural log of the unfiltered series minus the natural log of the filtered series.