Asset Utilization and Bias in Measures of U.S. Agricultural Productivity

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1. Introduction

A common observation is that measures of productivity growth are pro-cyclical, meaning they are higher (or grow faster) on average during periods of economic expansion than during periods of economic contraction (Basu 1996; Basu and Kimball 1997; Wen 2004). Does productivity actually change 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.

Calculating a time series of capital inputs is difficult and prone to errors. In the case of U.S. agriculture, measuring the annual quantity of physical assets used in production requires aggregating 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 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.

This study begins 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 that include proxy variables for changes in the utilization of fixed assets as independent variables. The proxy variables include the real prices of inputs and outputs as well as 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. The bias is quantified and the measures of productivity are adjusted for the estimated utilization responses and compared to the original measures.

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

What are the justifications for including output or input prices in models of production and why are prices statistically significant when included in production functions? A related set of questions arise in relation to the inclusion of output prices in cost functions that ordinarily would include prices of variable inputs and quantities of fixed factors and output.

One reason for including output prices in cost functions, examined by Just and Pope (1996 and 1998) and Moschini (2001), is because of a general ‘errors in variables’ problem that can result in biased parameter estimates when estimating cost functions. The authors were concerned with bias resulting from including actual output as opposed to expected 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. 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.

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. The induced-innovation hypotheses originally proposed by Hicks 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). Most of these studies include measures of input and output price. 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 the role of prices 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 contemporaneous prices can be used as proxy variables for 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. 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 expectations embodied in our measure we will under- or over-estimate actual service flows.

In the empirical analysis that follows, a ratio of the price of output to the price of inputs is used as a proxy variable for changes in the demand for agricultural outputs and the supply of agricultural inputs. Transitory changes in output demand and input supply are hypothesized to cause 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. 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).

A long lag of prices would be necessary to test the full technology-changing impacts of past prices on current output. Alternatively, current prices (or a short lag of prices – say, one period) are relevant for testing the utilization-changing effects of prices on production. In the empirical analysis 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 prices received for output to the prices paid for variable inputs – which combines incentive effects of both changes in input supply and changes in output demand. The long-term downward trend in this index reflects long-term productivity growth such that supply of agricultural products is growing 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 Productivity Growth

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 a sectoral study of 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.

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 changes in the utilization of existing stocks of capital. 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 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 fixed assets poses two complications for the measurement of capital and productivity. First, the flow of capital services will be measured with error with typical measurement practices. 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.

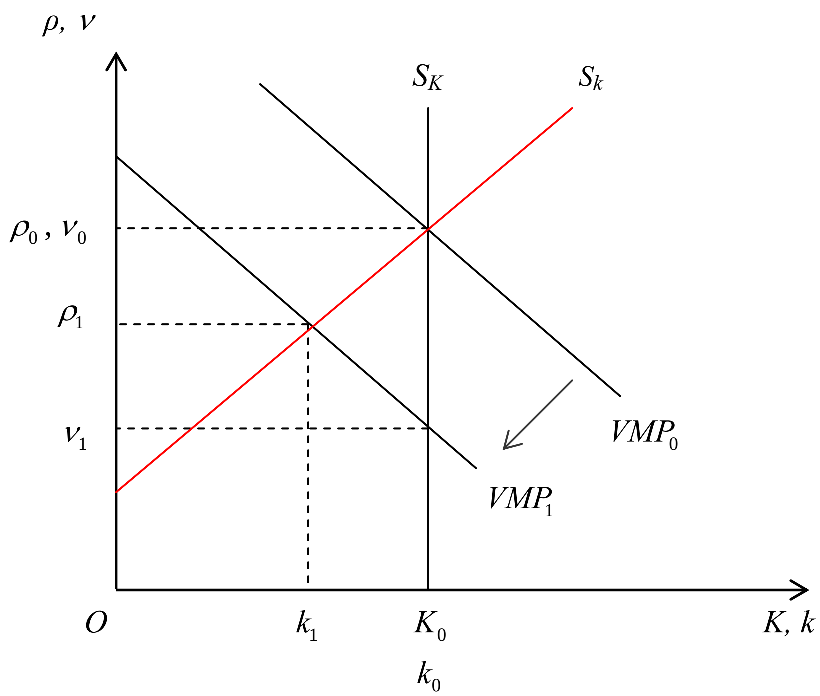
Two closely related methods have been suggested for correcting for the consequences of variations in capacity utilization for the measurement of durable inputs and productivity. One common suggestion in the literature is to adjust the service flows of durable inputs using information on other inputs that are deemed easier to measure than capital. 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 sources. 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 share of capital 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 strong microeconomic foundations and are widely accepted methods for addressing the utilization problem, each is vulnerable to additional measurement problems, especially regarding sectoral models of agriculture. This is because the supply of services from capital inputs 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 the methods that have been suggested in the literature for adjusting the service flows or shadow values of capital inputs to incorporate unobservable variations in utilization.

In figure 1, the quasi-fixity of capital implies the stock is fixed in the short run at K_0, and the supply of services from that stock is upward sloping and indicated by S_k. In what follows, k_t is the quantity of capital services, VMP_t is the value of the marginal product of capital, ρ_t is the rental rate of capital, and ν_t is the shadow value of an additional unit of capital stock. The ratio of the quantity of capital services to the stock of capital in long-run equilibrium is denoted $U_0 = k_0 / K_0$, and the ratio of the rental rate of capital to the shadow value of an additional unit of capital stock is denoted $\varphi_0 = \rho_0 / \nu_0$.

Figure 1: Demand Shock with an Upward Sloping Supply of Capital Services



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 level, 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 level, φ_0; (iii) the measured quantity of capital services, k_0, temporarily exceeds the true quantity of capital services, k_1.

The return to capital services 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 stock of capital is proportional to the flow of services. This is because the actual flow of services is unobservable to the researcher. If the stock is in fact proportional to the flow of services each period, the rate of change of the stock will equal the rate of change of the flow; if the rate of utilization changes, however, then the rate of change of the stock will not accurately represent the rate of change of the flow.

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 or rental rate in the hope of obtaining a more accurate measure of the latent value of services, $\rho_1 k_1$. The second approach, which is closely related but 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, ν_1, and $\nu_1 K_0$ is used as an approximation of the return to capital services. However, in this simple illustration, the approximated return, $\nu_1 K_0$ understates the rental rate of capital, ρ_1, and overstates the true quantity of services, k_1, leaving the potential for additional measurement problems. This is not a problem if the demand for capital is unit elastic, in which case total expenditure does not change with changes in quantity or price; otherwise measurement error could persist.

4. A Primal Versus Dual Approach

A number of theoretically appealing 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 for 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 advantages of a cost adjustment approach include strong theoretical linkages 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 so cost function models may avoid simultaneity problems associated with using quantity measures for inputs. A dual approach is probably most relevant when examining highly disaggregated data like firm level data.

One reason why this approach was not used 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 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.

A primal approach is relevant to apply in the present study for a number of reasons. First, this is a study of the U.S. agricultural sector, and a primal approach avoids assuming cost minimizing behavior using highly aggregated data. Second, there is ample precedent in the literature for using a primal approach to estimating relationships between inputs and outputs that incorporates price information as an explicit variable in estimation, although this literature offers a different rationale for the inclusion of prices. 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), 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. In a 1999 publication, Mundlak restated and elaborated further on the benefits of a primal approach to modeling agricultural production.

The focus of this study is the potential errors introduced into capital and productivity measures that result from 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 of the measurement error, and then investigating the impacts in a primal setting (i.e., using input quantities not prices).

The primal approach relaxes the assumption that capital service flows are proportional to capital stocks, and does not rely on the assumption that prices are competitive.

5. Production Functions Augmented with Variable Utilization

We consider two specifications of the production function in this section. The first specification is a modified Cobb-Douglas production function in which the quantities of the factors of production are measured with error. The second specification of the production function is a modified translog production function that incorporates measurement error in the factors of production and represents a generalization of the previous model. Start by assuming the existence of an aggregate production function for U.S. agriculture of the Cobb-Douglas form:

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

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 the $\beta\text{'}s$ represent the 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 level of utilization, U_i, such that $\tilde{X}_i = X_i \times U_i$. The level of utilization is a latent unobserved variable. However, we do observe variables Z_h that determine the current level 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

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

Now, expressing productivity, g_t, as a linear function of the of 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 of the utilization-changing variables, z_h, yields,

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

The $\alpha's$, $\beta's$ and the $\lambda's$ are the fixed parameters to be estimated, and ε_0 is a random error term, assumed to be distributed independently of the x_i's, z_h's, and the y_k's. Substituting equations (3) and (4) into (2) results in the following equation 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 previous model:

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

Equation (6) is a second-order Taylor series approximation in logarithms. Substituting equations (3) and (4) into (6) results in the following equation for estimation:

$$q_t = \alpha_0 + \sum_{k=1}^{s} \alpha_k y_{kt} + \sum_{i=1}^{n} \beta_i x_{it} + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} x_{it} x_{jt} + \ldots$$

$$\sum_{i=1}^{n} \sum_{h=1}^{m} \lambda_{ih} z_{ht} \left(\beta_i + \sum_{j=1}^{n} \gamma_{ij} x_{jt} + \frac{1}{2} \sum_{j=1}^{n} \gamma_{ij} \sum_{h=1}^{m} \lambda_{jh} z_{ht} \right) + \varepsilon_{0t} . \tag{7}$$

A few simplifying assumptions were necessary to econometrically estimate equations (5) and (7). The first assumption is that capital input is the only factor of production measured with error. While unobservable utilization changes may be important for other inputs such as land and labor, we assume the problem is less pronounced with these inputs. The second assumption concerns the specification of the utilization term, which is assumed to follow a specific form. The utilization term and a list of the specific production functions estimated in the empirical analysis that follows is provided in the next section.

6. Empirical Analysis

The data used in the following analysis consist of state-specific measures of inputs and outputs in U.S. agriculture for the period 1949-2002. The data represent a revised and updated version of data published by Aquaye, Alston, and Pardey (2002). The update and revisions were sponsored by the Minnesota Agricultural Experiment Station and the International Science and Technology Practice and Policy Center (InSTePP) at the University of Minnesota, the University of California at Davis, and the Giannini Foundation of agricultural economics. We will refer to this as the UMN data for the remainder of the study. Detailed production data on U.S. agriculture will soon be available through InSTePP, including the Fisher Ideal indexes used in this analysis. In this study we present the indexes of inputs, outputs, and productivity at the national level in U.S. agriculture. These are presented in figures 2 and 3.

Figure 2: Indexes of the Quantity of Capital, Labor, Land, and Materials

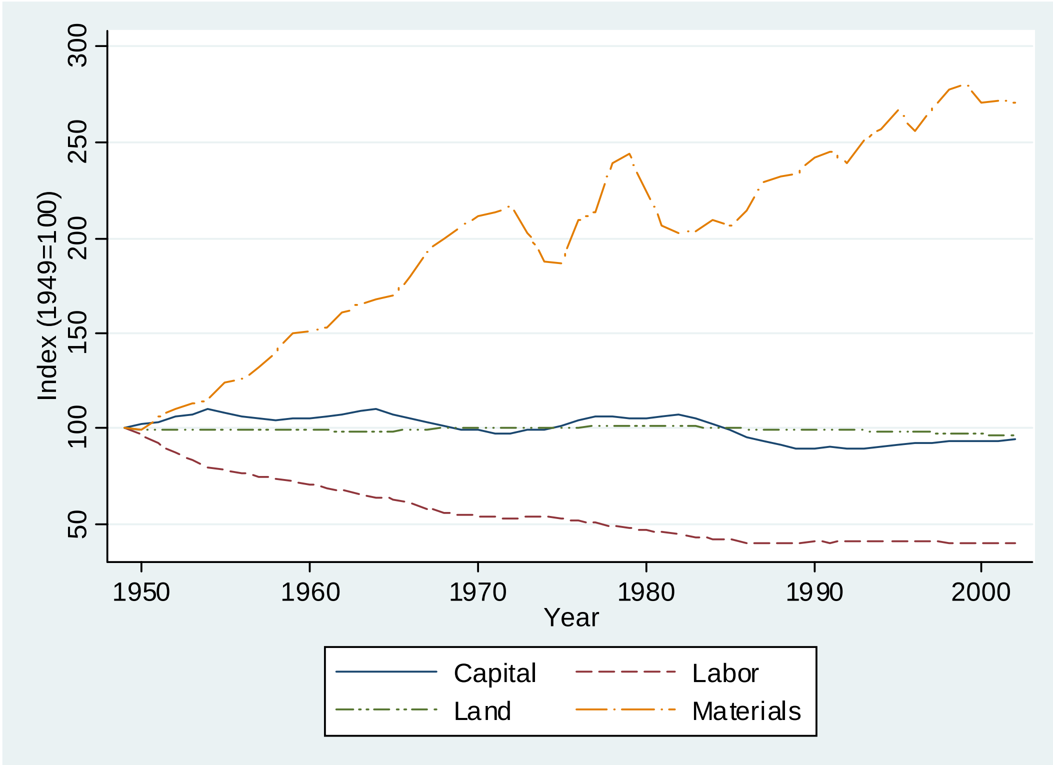
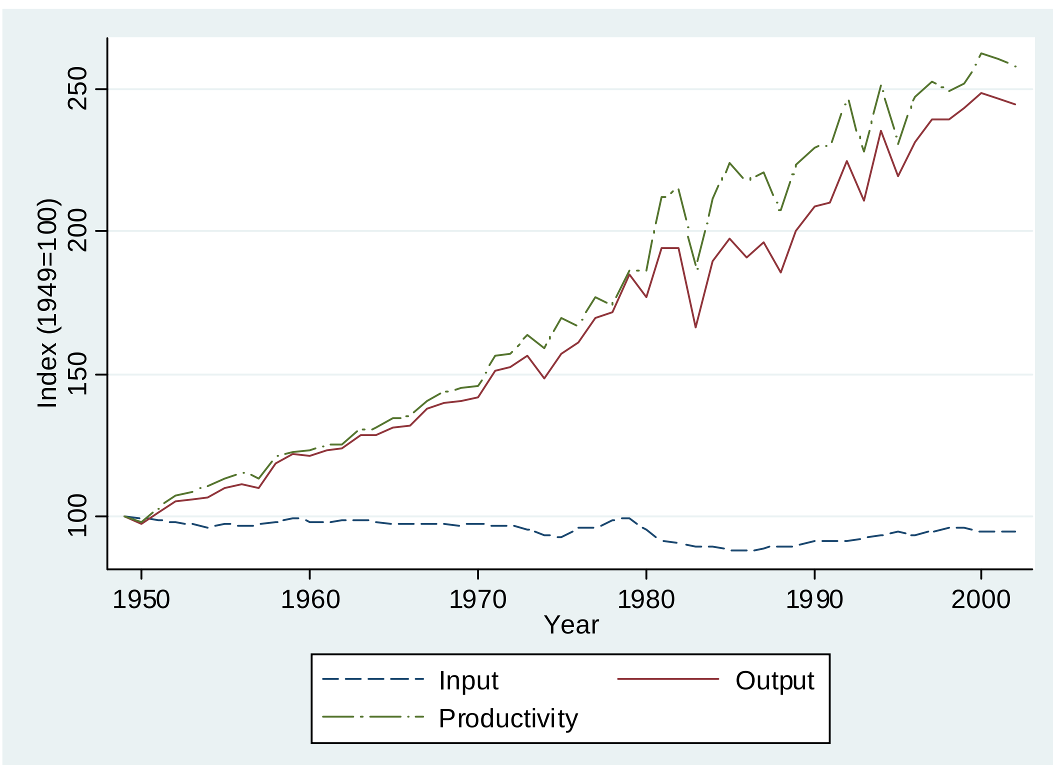


Figure 3: Indexes of the Quantity of Output, Input, and Productivity



In the empirical analysis 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 quantity 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. Note that the index appears as an intercept shifter in all of the regressions, and also appears as a utilization-changing variable in some of the regressions.
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.

The analysis proceeds using a two-step procedure, where the first step involves constructing appropriate proxy variables representing utilization, and the second step involves estimating various production functions augmented with the utilization proxies. As previously mentioned the index of farmers' terms of trade – the ratio of the price of output to the 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 and the 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).

In the analysis that follows, the utilization is assumed to be proportional to economic and environmental circumstances, and is therefore specified as is a function of the terms of trade measure, $\hat{z}_{1t}$, and the index of growing conditions expressed in deviations from the state-specific 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.

In the empirical analysis the measure of productivity is defined as a function of the variables that affect technology, in this case a simple time trend, y_{1t}, as well as the index of growing conditions in deviations form, y_{2t}:

$$g_t = \alpha_0 + \alpha_1 y_{1t} + \alpha_2 y_{2t} + \varepsilon_{0t} . \tag{10}$$

In all of the regressions the growing conditions index enters as an intercept-shifter, and in some of the regressions it also enters as a utilization-changing variable.

An additional important note about the analysis in this study is that most of the state-level indexes of output are non-stationary when specified in levels or logarithms, which might result in spurious parameter estimates.[1] However, the indexes of output are stationary when specified as rates of growth; therefore, we have specified the estimating equations in rates of growth as well as in logarithms. Thus, we estimate first- and second-order Taylor series expansions of the production function in logs and rates of change of the variables. In each case a base model is estimated representing a conventional Cobb-Douglas or translog production function (expressed in logs and rates of growth of the variables). The base (conventional) models are nested in the utilization models as shown in table 1.

Table 1 lists the different specifications of the production functions in the empirical analysis. The specifications are denoted A-D. The regression results for the different equations are presented in tables A.1 and A.2 in the Appendix, and refer to the specifications listed in table 1. 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 in logs and 2,496 observations in rates of change of the variables. Regression estimates for equations A - D were obtained using Fixed-effects (FE) panel data methods or Non Linear Least Squares (NLLS), where applicable.

[1] 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).

Table 1: Specifications of the Production Functions in the Empirical Analysis

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

$$q_t = \alpha_0 + \sum_{k=1}^{s} \alpha_k y_{kt} + \sum_{i=1}^{n} \beta_i x_{it} + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} x_{it} x_{jt}$$

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.

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 figures in table 2 are elasticities that represent the percentage increase in productivity growth that results from a one percent increase in the given variable, holding all other factors constant.

Table 2: Elasticity of Productivity of Expected Terms of Trade and Growing Conditions

Estimated Productivity Elasticities

	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)

***denotes estimates are statistically significantly different from zero at the 1 percent level of significance.

** denotes estimates are statistically significantly different from zero at the 5 percent level of significance.

These results support the hypothesis that measured productivity growth is pro-cyclical, and that unobserved changes in the utilization of capital have contributed to these patterns. Furthermore, the results using the full sample are similar in magnitude across models (except the translog model in logs), 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 growth.[2]

The regression results for the different specifications also indicate that growing conditions have a significant, persuasive, and positive effect on productivity growth. Table 2 also shows the elasticities of productivity with respect to growing conditions. Recall that the index of growing conditions is expressed in deviations from the mean, which measures conditions above or below the long-run average. Therefore, the figures in table 2 can be interpreted as the percentage increase in productivity given a one percent increase in the deviation of the index of growing conditions.[3] The results in table 2 are mostly significant at the one percent level and indicate that a ten percent increase in the index of growing conditions above the long-run average results in approximately a one percent increase in measured productivity growth.

As previously mentioned the translog specification of the production function represents a generalization of the Cobb-Douglas model that incorporates quadratic as well as linear terms. 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

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[2] The distribution of the terms of trade measure is approximately symmetric and centered on zero, with a standard deviation equal to 0.09 and a range between negative 0.5 and positive 0.54.

[3] The distribution of the measure of growing conditions is approximately symmetric and centered on zero, with a standard deviation equal to 0.31, and a range between negative 2.6 and positive 2.6.

elasticities). Translog production functions often produce results that are inconsistent with theoretical expectations. In the case of the base model translog production function the results are mostly consistent with prior expectations about agricultural production. The production elasticities are all positive and significant except for labor. The estimate of returns to scale is 0.93, which is statistically significantly less than one but close nonetheless. Table 3 lists all of the estimated production elasticities from the different specifications.

Table 3: Production Elasticities for Land, Labor, Capital, and Materials

	Production Elasticities			
	Land	Labor	Capital	Materials
Cobb-Douglas models				
Base Models				
Logs	0.385***	-0.005	0.228***	0.391***
Growth rates	0.030	0.063*	0.222***	0.213***
Utilization Models				
Logs	0.384***	-0.025	0.239***	0.396***
Growth rates	0.065	0.034	0.239***	0.220***
Translog models				
Base Models				
Logs	0.317***	0.008	0.232***	0.370***
Growth rates	-0.032	0.067	0.198***	0.220***
Utilization Models				
Logs	-0.095	0.370**	-0.846***	1.043***
Growth rates	0.125	0.033	0.171***	0.214***

All figures are point estimates evaluated at the means of the variables, RTS = retuns to scale.
***denotes estimates are statistically significantly different from zero at the 1 percent level of significance.
** denotes estimates are statistically significantly different from zero at the 5 percent level of significance.
* denotes estimates are statistically significantly different from zero at the 10 percent level of significance.

In most of the results the estimated production elasticities seem low for land and labor and high for materials input, suggesting the presence of bias. The fact that conventionally measured 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.

The final task remaining is to examine the estimates of productivity growth from the different models, adjust the measures of productivity growth for the estimated utilization responses, and compare the adjusted figures with the unadjusted figures. Table 4 shows the estimates of annual productivity growth from the different model specifications. All of the estimated figures are statistically significantly different from zero at the 1 percent level of significance.

Table 4: Annual Productivity Growth in U.S. Agriculture 1950-2002

	Logs		Growth rates	
	Base	Utilization	Base	Utilization
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

The sample average of measured productivity growth for all 48 states and 52 time periods is equal to 1.69 percent.[4] The parametric estimates in table 4 are all substantially lower than the (non-parametric) estimate calculated as the sample average of the rate of change of the index of productivity. We think part of the reason why the parametric estimates are lower is that some additional specification error exists (such as omitted variables) that is biasing the measures downward. The cyclical measurement errors considered in this study will bias parametric studies of production because they amount to measurement error in the

[4] Annual productivity growth is calculated as the natural logarithm of the ratio of index of productivity in period's *t* and *t*-1.

independent variables, which causes downward bias in parameter estimates in a regression analysis. However, the cyclical errors should have a small or negligible 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 substantially biased by the cyclical errors, but any of the given annual estimates may be significantly biased, and this has important implications for parametric studies of production. Therefore, we propose a simple procedure to expunge the utilization bias from measures of productivity growth for use in parametric studies of production and productivity.

The procedure begins by regressing the state-level measures of productivity growth on the estimates of expected terms of trade and growing conditions. The residuals, $\hat{\varepsilon}_t$, from the regressions are retained, representing the portion of productivity growth unexplained by changes in terms of trade and growing conditions. An adjusted measure of annual productivity growth, g_t^*, is calculated by adding the residuals to the (unbiased) sample averages of productivity growth, $\overline{g}$, for each state, $g_t^* = \overline{g} + \hat{\varepsilon}_t$. The result is an adjusted measure of productivity growth with reduced measurement error that is slightly less volatile than the standard estimates. The means of the adjusted and unadjusted productivity series are the same by design; however, the standard deviation of the adjusted productivity series is statistically significantly smaller than the original series. The standard deviation of the original measure of productivity growth is 0.0815 and the adjusted measure is 0.0698. 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 national estimates of adjusted and unadjusted productivity growth are presented in figure 4.

Figure 4: The Original and Utilization-Adjusted Measures of Productivity Growth in U.S. Agriculture for the Years 1951-2002

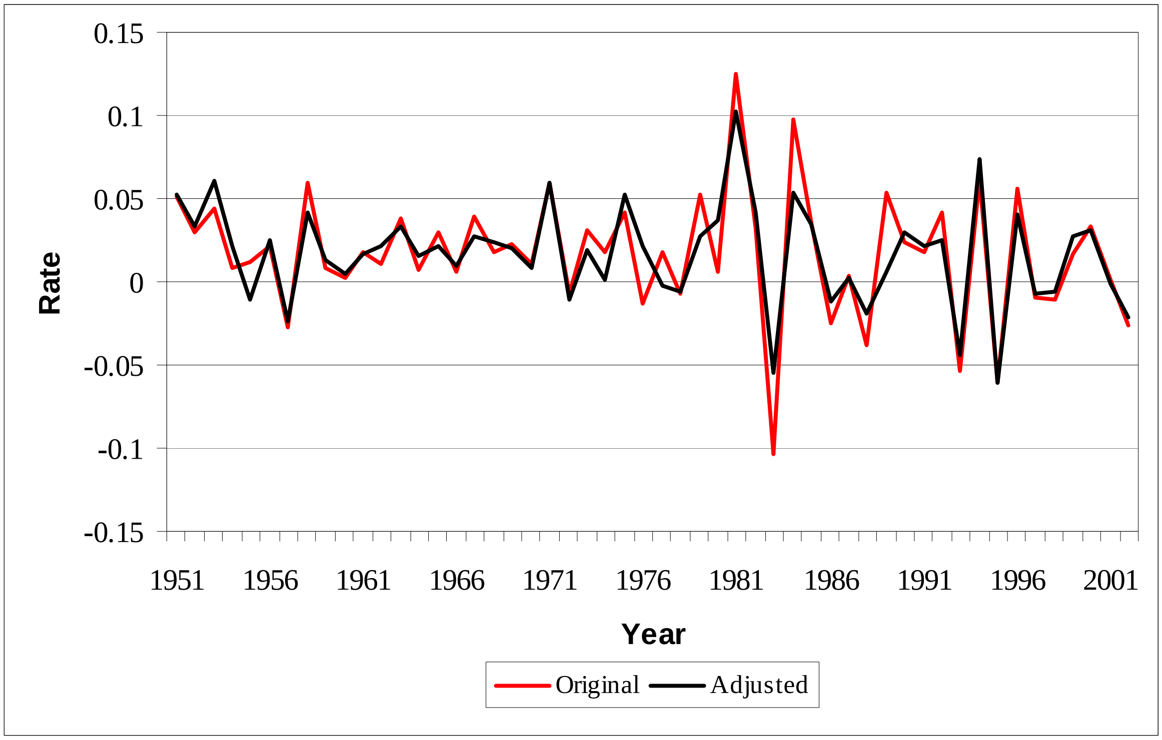

Figure 4 shows that the measures of productivity growth are substantially different during certain periods. In some years the adjusted measure is less than half of the original measure. The state-level estimates indicate similar results, illustrating the significance of the adjustment procedure when using these measures in parametric studies of production and productivity.

7. Conclusion

U.S. agricultural output approximately doubled during the years 1950-2002, reflecting increased use of materials and capital inputs along with changes in technology, combined with reductions in the use of 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. This residual productivity growth, after accounting for changes in quantities of aggregate inputs, reflects the influence of technical change and measurement error.

The parametric analysis in this study suggests productivity grew at approximately 1.2 – 1.6 percent annually. The estimate of 1.2 – 1.6 percent annual productivity growth still leaves a significant 'measure of ignorance' about the sources of economic growth in U.S. agriculture compared with other sectors of the economy where productivity measures are consistently lower (Jorgenson 1995).

This study has focused on measurement error in the capital variable when estimates of the capital stock (assuming constant utilization rates) are taken to be a proxy for the flow 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 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 adjust measures of productivity. We found that adjusting productivity for the estimated utilization responses 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. It is important to keep in mind that cyclical errors in measuring capital inputs can result in significant bias, especially in parametric studies that are sensitive to measurement error in the independent variables. 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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Appendix

Table A.1: Regression Estimates

Cobb-Douglas Models		Fixed-effects (within) estimates			
		Logs (NT=2544)		Growth rates (NT=2496)	
		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

Standard errors in parentheses; TOT = Terms of Trade; RTS = Returns to Scale

***denotes estimates are statistically significantly different from zero at the 1 percent level of significance.

** denotes estimates are statistically significantly different from zero at the 5 percent level of significance.

* denotes estimates are statistically significantly different from zero at the 10 percent level of significance.

Table A.2: Regression Estimates

Trans-log Production Function: Fixed-effects estimates (FE) for base models and Non-linear Least Squares (NLLS) estimates for utilization models

Parameters			Logs (NT=2544)		Growth rates (NT=2496)	
			Base (FE)	Utilization (NLLS)	Base (FE)	Utilization (NLLS)
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

Standard errors in parentheses; RTS = Returns to Scale

***denotes estimates are statistically significantly different from zero at the 1 percent level of significance.

** denotes estimates are statistically significantly different from zero at the 5 percent level of significance.

* denotes estimates are statistically significantly different from zero at the 10 percent level of significance.