The Dynamics of Efficiency and Productivity Growth in U. S. Electric Utilities

Supawat Rungsuriyawiboon and Spiro E. Stefanou*

Revised August 2006

Abstract

This study recognizes explicitly the efficiency gain or loss as a source in explaining the growth. A theoretically consistent method to estimate the decomposition of dynamic total factor productivity growth (TFP) in the presence of inefficiency is developed which is constructed from an extension of the dynamic TFP growth, adjusted for deviations from the long-run equilibrium within an adjustment-cost framework. The empirical case study is to U.S. electric utilities, which provides a measure to evaluate how different electric utilities participate in the deregulation of electricity generation. TFP grew by 2.26 percent per annum with growth attributed to the combined scale effects of 0.34 percent, the combined efficiency effects of 0.69 percent, and the technical change effect of 1.22 percent. The dynamic TFP grew by 1.66 percent per annum for electric utilities located within states with the deregulation plan and 3.30 percent per annum for those located outside. Electric utilities located within states with the deregulation plan increased the outputs by improving technical and input allocative efficiencies more than those located outside of states with deregulation plans.

Key words: productivity growth, adjustment costs, dynamic duality, inefficiency, decomposition, deregulation, electricity.

JEL classification: D24, D92, L94

* Chiang Mai University; Pennsylvania State University

An earlier version of this manuscript was presented at the Australian Meeting of the Econometric Society, Melbourne, Australia, July, 2004. Spiro E. Stefanou acknowledges the support of the Marie Curie Transfer of Knowledge Fellowship of the European Community's Sixth Framework Program at the Department of Economics at the University of Crete under contract number MTKD-CT-014288 during Spring 2006.

I. Introduction

The policy analysis of growth in regulated industries depends on understanding the cost structure and how it evolves in the face of quasi-fixed factor adjustment and technical change. As a market-driven economy imposes greater competitive pressure on firm decision makers, decision making necessarily involves balancing the trade off between a) scale and technical efficiency change by exploiting the full productive potential of implemented technologies, and b) technical change by adopting innovations. Sustaining competitiveness over the long run involves attention to productivity growth prospects in both levels; innovations are needed to keep pushing the competitive envelope, and efficiency gains are needed to ensure that implemented technologies can succeed. Accurate analysis of the factors explaining changes in productivity is important to understanding future competitiveness of an industry. Often times, discussion of firm growth typically refers to thinking about a steady state for a very long time.

This paper analyses the contribution of various factors in both levels of productivity growth, i.e. (scale and technical) efficiency change and technological change. Total factor productivity (TFP) growth is defined as the residual growth in outputs not explained by the growth in input use. Early studies in measuring productivity growth used index number techniques to construct a productivity index. The disadvantage of index number techniques is that they require quantity and price information, as well as assumptions concerning the structure of technology and the behavior of producers. In addition, they cannot provide the sources which are attributed to productivity growth. This problem can be addressed by using non-parametric and parametric techniques. These two techniques do not require price information or technological and behavioral assumptions.

Decomposing and measuring the components of productivity growth using the parametric technique has been extensively applied using both primal and dual representations. The primal approach relates the conventional TFP measure to the characteristics of the production technology based on the aggregate production, while the dual approach uses the inverse relationship between the production and cost functions to establish the link between the conventionally measured TFP growth to the shift of aggregate cost function. These two approaches differ only in that the primal approach is developed to disentangle the contribution of factors other than technological progress from shifts in the production function, while the dual approach relates the observed growth to shift of the cost function.

The primal approach to the econometric estimation of productivity growth originated with Solow (1957), who assumed constant returns to scale and technical efficiency, and associated productivity growth with technical change. The conventionally measured productivity growth can be decomposed through the explicit specification of the production structure originates with Griliches (1963, 1964). The primal approach allows decomposition of TFP into a number of components by explicitly using the production function framework. TFP growth is decomposed into components associated with technical change and non-constant scale effects.

The dual approach to the econometric estimation of productivity growth originated with Ohta (1974), who derived the relationships between primal and dual cost measures of scale economies and technical change. Caves, Christensen, and Swanson (1980), Denny, Fuss, and Waverman (1981), and Nadiri and Schankerman (1981) used a flexible cost function and applied the duality theory to improve and refine the measurement of sources of TFP growth.

Nishimizu and Page (1982) originally presented a measurement of productivity growth decomposition in the presence of inefficiency where the efficiency change is presented as a source of productivity growth. Extending the study of Nishimizu and Page (1982), Bauer (1990a) derives detailed primal and dual decompositions of productivity growth in the presence of inefficiency.

Luh and Stefanou (1991) extend the static duality-based measure of TFP growth to a dynamic measure within an adjustment-cost framework. Dynamic TFP growth can be decomposed into a scale-related effect and technical change effect. The scale-related components constitute the proportional growth of the variable factors, quasi-fixed factor levels at the long-run equilibrium, net physical investment, and marginal values of quasi-fixed factor stocks. Bernstein, Mamuneas and Pashades (2004) address productivity growth under factor adjustment as they focus on the technical efficiency impacts of factor improvements in U.S. manufacturing. Formulating technical efficiency and its relation to productivity growth, they find seek to address how the productivity gap relates to the efficiency adjustment cost shares.

This study develops a theoretically consistent method to measuring the dynamic TFP growth decomposition in the presence of inefficiency. It extends a dynamic measure of productivity growth adjusted for deviations from the long-run equilibrium within an adjustment cost framework, leading to the recognition of efficiency gain or loss effects to the TFP growth. The dynamic model of productivity growth in the presence of inefficiency is empirically implemented using a panel data set of 72 U.S. electric utilities during the time period of 1986 to 1999. Electricity deregulation and restructuring are now on the policy agenda in many states of the United States. Fabrizio, Rose and Wolfram (2006) focus on the impact of deregulation on technical efficiency for U.S. electric utilities at the plant level with the view to measure the cost reduction of technical efficiency gains and consequently to test for the potential competitive effects of deregulation on technical efficiency. In this study the dynamic measure of TFP growth is used as a measure to examine how the components of electric utilities' productivity growth react to the deregulation of the production of electricity; in particular, to evaluate how different electric utilities will perform that are located within or outside of states with the restructuring plan.

The next section presents the theoretical concept of productivity growth under dynamic adjustment, followed by the mathematical derivations of the dynamic TFP decomposition in the presence of inefficiency. This is followed by a discussion of data construction and key assumptions underlying that construction. The manuscript continues with the empirical results and the conclusions.

II. Productivity Growth under Dynamic Adjustment

Consider the intertemporal model where the firm seeks to minimize the discounted sum of future production costs over an infinite horizon and the firm holds static expectations on the set of real prices and the sequence of production targets[1]

$$J(w,c,K,y,t)=\min_{x,I>0}\int_t^{\infty} e^{-rs}\left[w'x(s)+cK(s)\right]ds \tag{1}$$

subject to $\dot{K}(s)=I(s)-\delta K(s)$, $K(0)=K_0>0$, $K(s)>0$, and

$y(s)=F\left[x(s),K(s),\dot{K}(s),t\right]$, for all $s\in[t,\infty)$,

[1] Price expectations are static in the sense that *relative* prices observed in each base period are assumed to persist indefinitely (Epstein and Denny, 1983). As the base period changes, expectations are altered and previously decisions are no longer optimal. Only that part of the decision corresponding to each base period is actually implemented. As such, this model formulation reflects the behavioral assumption that firms revise price expectations without anticipating revision. In commodity production (historically), input prices tend to move in a less volatile manner than output prices. With this study focusing on the cost minimization framework, output prices are not an issue and the relative importance of relative input price movements is downgraded.

where w is vector of variable input prices; x and K are vectors of variable inputs and quasi-fixed inputs, respectively; c is the vector of rental prices of quasi-fixed inputs; I and $\dot{K}$ are gross and net rates of investment, respectively; r is the constant discount rate ; δ is a constant depreciation rate; $y(s)$ is a sequence of production targets over the planning horizon starting at time t and $F(x(s), K(s), \dot{K}(s), t)$ is the single output production function satisfying the regularity conditions. The inclusion of net investment $\dot{K}$ in the production function reflects the internal cost associated with adjusting quasi-fixed factors in terms of foregone output. The production function, $F(x, K, \dot{K}, t)$, possesses the following properties.

(2-a) $F(x, K, \dot{K}, t)$ is continuous and twice-continuously differentiable.

(2-b) $F(x, K, \dot{K}, t)$ is finite, nonnegative, real valued and single valued for all nonnegative and finite x, K, and $\dot{K}$.

(2-c) $F(x, K, \dot{K}, t)$ is strictly increasing in x and K, and $F(x, K, \dot{K}, t)$ is strictly concave in x.

(2-d) $F(x, K, \dot{K}, t)$ is strictly (decreasing) increasing for increasing (decreasing) in $\dot{K}$ and $F(x, K, \dot{K}, t)$ is strictly concave in $\dot{K}$.

McLaren and Cooper (1980) and Epstein (1981) introduced the intertemporal duality theory which presents the relationship between the underlying technology and value functions. The dynamic duality between the underlying technology and value functions permits the derivation of a system of variable and dynamic demand equations. Epstein (1981) demonstrates that a full dynamic duality can be solved by the appropriate static optimization problem as expressed in the dynamic programming or Hamilton-Jacobi-Bellman equation.

The dynamic programming equation for the problem (1) can be expressed as

$$rJ(w, c, K, y, t) = \min_{x, I, \gamma > 0} \left\{ w'x + cK + (I - \delta K) J_k + \gamma \left(y - F\left(x, K, \dot{K}, t\right) \right) \right\} + J_t , \tag{2}$$

where $\gamma \geq 0$ is the Lagrangian multiplier associated with the production target and is defined as the short-run, instantaneous marginal cost (Stefanou, 1989).

Luh and Stefanou (1991) developed a dynamic measure of productivity growth adjusted for deviations from the long-run equilibrium within an adjustment-cost framework. TFP growth under dynamic adjustment can be explicitly derived by totally differentiating the production function with respect to time. Dynamic TFP growth can be decomposed into a scale-related effect and technical change effect. The scale-related components constitute the proportional growths of the variable factors, quasi-fixed factor levels at the long-run equilibrium, net physical investment, and marginal values of quasi-fixed factor stocks. The technical change effect represents a shift in the production technology.

III. Derivation of the Dynamic Total Factor Productivity Decomposition in the Presence of Inefficiency

Rungsuriyawiboon and Stefanou (forthcoming) establish a dynamic efficiency model of the cost minimizing firm by integrating the static shadow cost approach and the dynamic duality model of intertemporal decision making. The dynamic efficiency model accounts for four inefficiency components: allocative and technical inefficiencies of net investment demand and variable inputs demand. Given a flexible functional form specification for the value function, $J(\cdot)$, of the dynamic programming equation, the dynamic efficiency model can be applied to panel data of firms to estimate and decompose the cost inefficiency.

Developing the Dynamic Shadow Cost Function

The behavioral value function of the dynamic programming equation for the firms' intertemporal cost minimization behavior in the presence of technical change that corresponds to the shadow prices and quantities can be expressed in the form of a behavioral Hamiton-Jacobi equation,

$$rJ^b\left(w_{nit}^b, c_{it}, K_{it}, y_{it}, t_{it}\right) = \left(w_{nit}^b\right)' x_{nit}^b + c_{it}' K_{it} + \dot{K}_{it}^{b'}\left(J_{k,it}^b\right) + \gamma_n^b\left(y_{it} - F\left(x_{nit}^b, K_{it}, \dot{K}_{it}^b, t_{it}\right)\right) + J_{t,it}^b, \tag{3}$$

where $n = 1,...,N$ index of variable inputs; $i = 1,...,I$ index of firms; $t = 1,...,T$ index of time periods; c is the user cost of capital; K is a quasi-fixed input of capital stock; y is the output; t is time trend; $w^b = (\lambda_1 w_1,...,\lambda_N w_N)$ with $\lambda_n > 0$ representing the behavioral prices of variable inputs; λ_n is the allocative inefficiency parameters for n-th variable input; w_n is the observed n-th variable input price; $J_k^b = \mu J_k^a$ represents the marginal behavioral value of capital where J_k^a represents the observed marginal value of capital and μ is the allocative inefficiency parameter of net investment; $x^b = (1/\tau_x)x$ represents the behavioral variable inputs where $\tau_x \geq 1$ is the inverse of producer-specific scalars providing input-oriented measures of the technical efficiency in variable input use and x is the observed variable input use; $\dot{K}^b = (1/\tau_k)\dot{K}$ represents the behavioral net investment level where $\tau_k \geq 1$ is the inverse of producer-specific scalars providing input-oriented measures of the technical efficiency in net investment and $\dot{K} = dK/dt$ is the level of net investment; $\gamma^b \geq 0$ is the behavioral Lagrangian multiplier defined as the short-run, instantaneous marginal cost; $F\left(x^b, K, \dot{K}^b, t\right)$ is the single output production function satisfying the regularity conditions (*a*) to (*d*); $J_{k,it}^b = \partial J_{it}^b / \partial K$ and $J_{t,it}^b = \partial J_{it}^b / \partial t$.

The behavioral value function of the dynamic programming equation in (3) can be rewritten in terms of $J^b(\lambda w, c, K, y, t)$ as

$$rJ^b(\lambda w, c, K, y, t) = (\lambda w)' x^b + c'K + \dot{K}^{b\prime} J_k^b(\cdot) + \gamma^b\left(y - F\left(x^b, K, \dot{K}^b, t\right)\right) + J_t^b(\cdot). \tag{4}$$

Differentiating (4) with respect to c and (λw), respectively, yields optimal investment demand

$$\dot{K}^b(\cdot) = \left(J_{kc}^b(\cdot)\right)^{-1}\left(rJ_c^b(\cdot) - K - J_{tc}^b(\cdot)\right), \tag{5}$$

and optimal variable input demand

$$x^b(\cdot) = (\lambda)^{-1}\left(rJ_w^b(\cdot) - \dot{K}^{b\prime}(\cdot) J_{kw}^b(\cdot) - J_{tw}^b(\cdot)\right). \tag{6}$$

In the presence of technical inefficiency of net investment and variable inputs, the corresponding observed investment and variable input demands using the input-oriented approach can be written in terms of the optimal investment and variable input demands as

$$\dot{K}^o = \tau_k \dot{K}^b(\cdot) = \tau_k\left(J_{kc}^b(\cdot)\right)^{-1}\left(rJ_c^b(\cdot) - K - J_{tc}^b(\cdot)\right), \tag{7}$$

$$x^o = \tau_x x^b(\cdot) = \tau_x(\lambda)^{-1}\left(rJ_w^b(\cdot) - \left(\dot{K}^{o\prime}/\tau_k\right) J_{kw}^b(\cdot) - J_{tw}^b(\cdot)\right). \tag{8}$$

The dynamic programming equation for the firms' intertemporal cost minimization behavior corresponding to the actual prices and quantities can be expressed as

$$rJ^a = w'x + c'K + \dot{K}'J_k^a + \gamma^a\left(y - F\left(x^b, K, \dot{K}^b, t\right)\right) + J_t^a, \tag{9}$$

where input-oriented efficiency measurement is maintained. Considering the actual quantities as the optimal levels, optimized actual quantities are $\dot{K}^o = \tau_k \dot{K}^b(\cdot)$ and $x^o = \tau_x x^b(\cdot)$. The optimized actual dynamic programming equation can be expressed as

$$rJ^a = w'x^o + c'K + \dot{K}^{o\prime} J_k^a + J_t^a, \tag{10}$$

By assuming a shift in the behavioral value function is the same proportion as the actual value function so that $J_t^a = J_t^b(\cdot)$, the optimized actual value function can be rewritten in the terms of the behavioral value function as follows

$$rJ^a = w'(\tau_x/\lambda)\left(rJ_w^b(\cdot) - \dot{K}^{b'}(\cdot)J_{kw}^b(\cdot) - J_{tw}^b(\cdot)\right) + c'K + \left(\tau_k \dot{K}^b(\cdot)\right)\left(J_k^b(\cdot)/\mu\right) + J_t^b(\cdot). \tag{11}$$

Differentiating (10) with respect to c and w, respectively, optimized actual investment demand yields

$$\dot{K}^o = \left(J_{kc}^a\right)^{-1}\left(rJ_c^a - K - J_{tc}^a\right), \tag{12}$$

and optimized actual variable input demand yields

$$x^o = rJ_w^a - \dot{K}^{o'}J_{kw}^a - J_{tw}^a. \tag{13}$$

Differentiating (11) with respect to c and w, respectively, and substituting into (12) and (13) yields the system equation of the dynamic efficiency model which consists of the optimized actual investment demand and the optimized actual variable input demand in terms of the behavioral value function.

Defining Total Factor Productivity Growth

In the case of the single output, single quasi-fixed input, and n variable inputs, the measurement of productivity growth under dynamic adjustment associated with the production technology, $F\left(x^b, K, \dot{K}^b, t\right)$, is derived by totally differentiating $y = F\left(x^b, K, \dot{K}^b, t\right)$ with respect to time which yields

$$\frac{dy}{dt} = \sum_n^N F_{x_n^b}\frac{dx_n^b}{dt} + F_k\frac{dK}{dt} + F_{\dot{K}^b}\frac{d\dot{K}^b}{dt} + \frac{dF}{dt} \tag{14}$$

Dividing through by output $y(t)$ and letting "^" indicate the percentage rate of growth over time, equation (14) becomes

$$\hat{y} = \sum_{n}^{N} \frac{F_{x_n^b} x_n^b}{y} \hat{x}_n^b + \frac{F_k K}{y} \hat{K} + \frac{F_{\dot{K}^b} \dot{K}^b}{y} \hat{\dot{K}}^b + \frac{1}{y} \frac{dF}{dt} \tag{15}$$

By assuming an interior solution for the long-run cost minimization in (9), substituting the first order conditions of the actual value function of the dynamic programming equation (9) leads to

$$\hat{y} = \sum_{n}^{N} \frac{(\tau_x w_n) x_n^{b*}}{y\gamma^{a*}} \hat{x}_n^{b*} + \frac{F_k K}{y} \hat{K} + \frac{(\tau_k J_k^a) \dot{K}^{b*}}{y\gamma^{a*}} \hat{\dot{K}}^{b*} + \hat{A} \tag{16}$$

where $\hat{A} = \frac{1}{y}\frac{dF}{dt}$, reflecting the shifting in the production function due to technical change. From the relationship between the optimized actual and behavioral values which relate $x^{b*} = (1/\tau_x) x^{o*}$ and $\dot{K}^{b*} = (1/\tau_k)\dot{K}^{o*}$, equation (16) can be rewritten as[2]

$$\hat{y} = \sum_{n}^{N} \frac{w_n x_n^{o*}}{y\gamma^{a*}} \hat{x}_n^{o*} + \frac{F_k K}{y} \hat{K} + \frac{J_k^a \dot{K}^{o*}}{y\gamma^{a*}} \hat{\dot{K}}^{o*} + \hat{A} \tag{17}$$

The marginal productivity of capital stock F_k is derived by totally differentiating the optimized version of equation (9) with respect to K to yield

$$rJ_k^a = c + \dot{K}^{o*} J_{kk}^a - \gamma^{a*} F_k + J_{tk}^a$$

$$F_k = \frac{c - rJ_k^a + \dot{K}^{o*} J_{kk}^a + J_{tk}^a}{\gamma^{a*}} \tag{18}$$

[2] The relative changes of the actual variable inputs, the actual net investment, and the marginal actual value of capital are equivalent to the relative changes of the behavioral variable inputs, the behavioral net investment demands, and the marginal behavioral value of capital so that $\hat{x}^{o*} = \hat{x}^{b*}$, $\hat{\dot{K}}^{o*} = \hat{\dot{K}}^{b*}$, and $\hat{J}_k^a = \hat{J}_k^b$

Given static price expectations, $dw^b = dc = 0$, and constant output targets over time, $dy = 0$, the rate of change in the shadow value of capital is derived by total differentiating the optimized actual value function $J_k^a(w^b, c, K, y, t)$ leading to[3]

$$\dot{J}_k^a = \frac{dJ_k^a}{dt} = \dot{K}^{o*} J_{kk}^a + J_{tk}^a \tag{19}$$

Substituting equation (19) in (18), the marginal productivity of capital stock is written as

$$F_k = \frac{c - rJ_k^a + \dot{K}^{o*} J_{kk}^a + J_{tk}^a}{\gamma^{a*}} = \frac{c - rJ_k^a + \frac{dJ_k^a}{dt}}{\gamma^{a*}} \tag{20}$$

The equation (20) can be interpreted as the value of the marginal product of capital stock, $\gamma^{a*} F_k$, equals the change in the instantaneous marginal factor cost flow, c, plus the capital gain (or loss) associated with the acquisition of the additional unit of capital input, $\frac{dJ_k^a}{dt}$, less the opportunity cost of an additional unit of capital, rJ_k^a.

Substituting (20) into (17) yields

$$\hat{y} = \sum_n^N \frac{w_n x_n^{o*}}{y\gamma^{a*}} \hat{x}_n^{o*} + \frac{(c - rJ_k^a)K}{y\gamma^{a*}} \hat{K} + \frac{J_k^a \dot{K}^{o*}}{y\gamma^{a*}} \hat{J}_k^a + \frac{J_k^a \dot{K}^{o*}}{y\gamma^{a*}} \hat{\dot{K}}^{o*} + \hat{A} \tag{21}$$

The terms for the change of technical and allocative inefficiencies from actual variable input demand, actual net investment demand, actual variable inputs prices and the marginal actual value of capital are defined in Table 1.

Rearranging equation (21) to account for the change of technical inefficiencies of variable inputs and net investment defined in Table 1 yields

---

[3] Totally differentiating $J_k^a(w^b, c, K, y, t)$ leads to $dJ_k^a = J_{kw^b}^a dw^b + J_{kc}^a dc + J_{kk}^a dK + J_{ky}^a dy + J_{kt}^a dt$. Given static price expectations $dw^b = dc = 0$ and $dy = 0$. Dividing dJ_k^a through by $d(t)$ yields $\dot{J}_k^a = \frac{dJ_k^a}{dt} = \dot{K}^{o*} J_{kk}^a + J_{tk}^a$.

$$\hat{y} = \sum_{n}^{N} \frac{\left(w_n x_n^{b*} + \zeta_{xn}\right)}{y\gamma^{a*}} \hat{x}_n^{o*} + \frac{\left(c - rJ_k^a\right)K}{y\gamma^{a*}} \hat{K} + \frac{\left(J_k^a \dot{K}^{b*} + \zeta_k\right)}{y\gamma^{a*}} \hat{J}_k^a + \frac{\left(J_k^a \dot{K}^{b*} + \zeta_k\right)}{y\gamma^{a*}} \hat{\dot{K}}^{o*} + \hat{A}. \tag{22}$$

Equation (22) can be written as

$$\begin{aligned} \hat{y} = & \sum_{n}^{N} \frac{w_n x_n^{b*}}{y\gamma^{a*}} \hat{x}_n^{b*} + \sum_{n}^{N} \frac{\zeta_{xn}}{y\gamma^{a*}} \hat{x}_n^{o*} + \frac{\left(c - rJ_k^a\right)K}{y\gamma^{a*}} \hat{K} + \frac{J_k^a \dot{K}^{b*}}{y\gamma^{a*}} \hat{J}_k^b + \frac{\zeta_k}{y\gamma^{a*}} \hat{J}_k^a \\ & + \frac{J_k^a \dot{K}^{b*}}{y\gamma^{a*}} \hat{\dot{K}}^{b*} + \frac{\zeta_k}{y\gamma^{a*}} \hat{\dot{K}}^{o*} + \hat{A}. \end{aligned} \tag{23}$$

Rearranging equation (23) to account for the change of allocative inefficiencies of variable inputs and net investment defined in Table 1 yield

$$\begin{aligned} \hat{y} = & \sum_{n}^{N} \frac{\left(w_n^b x_n^{b*} + \zeta_{\lambda n}\right)}{y\gamma^{a*}} \hat{x}_n^{b*} + \sum_{n}^{N} \frac{\zeta_{xn}}{y\gamma^{a*}} \hat{x}_n^{o*} + \frac{\left(c - rJ_k^a\right)K}{y\gamma^{a*}} \hat{K} + \frac{\left(J_k^b \dot{K}^{b*} + \zeta_\mu\right)}{y\gamma^{a*}} \hat{J}_k^b \\ & + \frac{\zeta_k}{y\gamma^{a*}} \hat{J}_k^a + \frac{\left(J_k^b \dot{K}^{b*} + \zeta_\mu\right)}{y\gamma^{a*}} \hat{\dot{K}}^{b*} + \frac{\zeta_k}{y\gamma^{a*}} \hat{\dot{K}}^{o*} + \hat{A}. \end{aligned} \tag{24}$$

Equation (24) can be written as

$$\begin{aligned} \hat{y} = & \sum_{n}^{N} \frac{w_n^b x_n^{b*}}{y\gamma^{a*}} \hat{x}_n^{b*} + \sum_{n}^{N} \frac{\zeta_{\lambda n}}{y\gamma^{a*}} \hat{x}_n^{b*} + \sum_{n}^{N} \frac{\zeta_{xn}}{y\gamma^{a*}} \hat{x}_n^{o*} + \frac{\left(c - rJ_k^a\right)K}{y\gamma^{a*}} \hat{K} + \frac{\zeta_k}{y\gamma^{a*}} \hat{\dot{K}}^{o*} \\ & + \frac{\zeta_\mu}{y\gamma^{a*}} \hat{\dot{K}}^{b*} + \frac{J_k^b \dot{K}^{b*}}{y\gamma^{a*}} \hat{\dot{K}}^{b*} + \frac{J_k^b \dot{K}^{b*}}{y\gamma^{a*}} \hat{J}_k^b + \frac{\zeta_\mu}{y\gamma^{a*}} \hat{J}_k^b + \frac{\zeta_k}{y\gamma^{a*}} \hat{J}_k^a + \hat{A}. \end{aligned} \tag{25}$$

Multiplying and dividing the right hand side of (25) by the total long-run shadow cost, rJ^a, lead to

$$\hat{y} = \frac{rJ^a}{y\gamma^{a*}} \left[\begin{aligned} & \sum_{n}^{N} \frac{w_n^b x_n^{b*}}{rJ^a} \hat{x}_n^{b*} + \sum_{n}^{N} \frac{\zeta_{\lambda n}}{rJ^a} \hat{x}_n^{b*} + \sum_{n}^{N} \frac{\zeta_{xn}}{rJ^a} \hat{x}_n^{o*} + \frac{\left(c - rJ_k^a\right)K}{rJ^a} \hat{K} + \frac{J_k^b \dot{K}^{b*}}{rJ^a} \hat{J}_k^b \\ & + \frac{\zeta_\mu}{rJ^a} \hat{J}_k^b + \frac{\zeta_k}{rJ^a} \hat{J}_k^a + \frac{J_k^b \dot{K}^{b*}}{rJ^a} \hat{\dot{K}}^{b*} + \frac{\zeta_\mu}{rJ^a} \hat{\dot{K}}^{b*} + \frac{\zeta_k}{rJ^a} \hat{\dot{K}}^{o*} \end{aligned} \right] + \hat{A}, \tag{26}$$

where $\left(rJ^a / y\gamma^{a*}\right)$ denotes as the ratio of the long-run average total cost to short-run marginal cost. The terms of dynamic productivity decomposition in the presence of inefficiency are defined in Table 2.

The total growth in output over time can be expressed as

$$\hat{y} = \frac{rJ^a}{y\gamma^{a*}}\left[\left(\hat{F}_v + \hat{F}_{vx} + \hat{F}_{v\lambda}\right) + \left(\hat{F}_I + \hat{F}_{Ik} + \hat{F}_{I\mu}\right) + \left(\hat{F}_J + \hat{F}_{Jk} + \hat{F}_{J\mu}\right) + \hat{F}_{qs}\right] + \hat{A} \tag{27}$$

TFP growth $\left(T\hat{F}P\right)$ is defined as the residual growth in outputs not explained by the growth in actual variable input use, actual net physical investment, marginal actual value of capital and quasi-fixed factor stocks

$$T\hat{F}P = \hat{y} - \left(\left(\hat{F}_v + \hat{F}_{vx} + \hat{F}_{v\lambda}\right) + \left(\hat{F}_I + \hat{F}_{Ik} + \hat{F}_{I\mu}\right) + \left(\hat{F}_J + \hat{F}_{Jk} + \hat{F}_{J\mu}\right) + \hat{F}_{qs}\right) \tag{28}$$

From equation (28), TFP growth can be alternatively defined as

$$T\hat{F}P = \left(\frac{rJ^a}{y\gamma^{a*}} - 1\right)\left[\left(\hat{F}_v + \hat{F}_{vx} + \hat{F}_{v\lambda}\right) + \left(\hat{F}_I + \hat{F}_{Ik} + \hat{F}_{I\mu}\right) + \left(\hat{F}_J + \hat{F}_{Jk} + \hat{F}_{J\mu}\right) + \hat{F}_{qs}\right] + \hat{A} \tag{29}$$

The ratio of $\left(rJ^a / y\gamma^{a*}\right)$, which is equal to

$$\frac{rJ^a}{y\gamma^{a*}} = \frac{wx^{o*} + cK + \dot{K}^{o*}J_k^a + J_t^a}{y(t)\left(\gamma^{a*} + \dot{K}^{o*}J_{ky}^a + J_{ty}^a\right)} \tag{30}$$

is the inverse of the cost elasticity in an intertemporal cost minimization problem, evaluated at the cost-minimizing position. Therefore, $\left(rJ^a / y\gamma^{a*}\right)$ is a measure of scale elasticity in the presence of sluggish adjustment behavior. Consequently, from equation (29), TFP growth is decomposed into scale related effects, disequilibrium effects, efficiency gain/loss effects, and technical change.

Estimation Approach

The system equation of the dynamic efficiency model consisting of the optimized actual net investment demand and the optimized actual variable input demand in terms of the behavioral value function can be estimated after appending a linear disturbance vector with mean vector zero and variance-covariance matrix Σ into the system equation. Following Cornwell, Schmidt, and Sickles (1990), the producer and input specific estimates of allocative and technical efficiencies of net investment and of variable inputs are specified as producer specific and time-varying specific parameters to implement the dynamic efficiency model in the panel data context. Given a quadratic functional form to specify a behavioral value function of the dynamic programming equation, the system equation of the dynamic efficiency model is estimated in two steps. In the first step, the optimized actual net investment demand is estimated by using the maximum likelihood (ML) estimation. In the second step, the system of optimized actual variable input demand equations is estimated by using the Generalized Method of Moment (GMM) estimation given all parameter values that were obtained in the first stage. The details of estimation approach of the dynamic efficiency model are presented in Rungsuriyawiboon and Stefanou (forthcoming). Decomposition of the dynamic TFP growth is calculated by using the estimated coefficients obtained from the estimation of the dynamic efficiency model.

IV. Application to U.S. Electric Utilities

A panel data set of 72 U.S. major investor-owned electric utilities using fossil-fuel fired steam electric power generation during the time period of 1986 to 1999 is used in this study. Electric utilities are divided into two groups according to the status of state electric industry restructuring activity. Electric utilities have all plants located in states which enacted enabling legislation or issued a regulatory order to implement retail access and electric utilities have all plants located in states without the deregulation plan. The primary sources of data are obtained from the Energy Information Administration (EIA), the Federal Energy Regulatory Commission (FERC) and the Bureau of Labor Statistics (BLS). Variables used in the estimation consist of output, prices and quantities of fuels, the aggregate of labor and maintenance, and capital stocks.

Output variable is represented by net steam electric power generation in megawatt-hour. The price of fuel aggregate is a Tornqvist price index of fuels (i.e. coal, oil, gas) which is calculated as a weighted geometric average of the price relatives with weights given by the simple average of the value shares in period t and $t+1$. The fuel quantities can be calculated by dividing the fuel expenses by the Tornqvist price of fuel aggregate. The aggregate price of labor and maintenance is a cost-share weighted price for labor and maintenance. The price of labor is a company-wide average wage rate. The price of maintenance and other supplies is a price index of electrical supplies from the Bureau of Labor Statistics. The weight is calculated from the labor cost share of nonfuel variable costs for those utilities with entirely steam power production. Quantities of labor and maintenance equal the aggregate costs of labor and maintenance divided by a cost-share weighted price for labor and maintenance. The capital stock is measured by using estimates of capital costs as discussed in Considine (2000). The price of capital is the yield of the firm's latest issue of long term debt adjusted for appreciation and depreciation of the capital good using the Christensen and Jorgenson (1970) cost of capital formula.

Once the system equation of the dynamic efficiency model consisting of the optimized actual net investment demand and the optimized actual variable input demand in terms of the behavioral value function is estimated[4], the parameter estimates of the dynamic efficiency model are used to calculate the decomposition of dynamic TFP growth. The next section presents

---

[4] The estimated coefficients of the dynamic efficiency model are presented in Rungsuriyawiboon and Stefanou (forthcoming). An additional assumption that firms are perfectly technical efficient in net investment demand, $\tau_k = 1$, is assumed to implement the estimation. While this assumption permits estimation of the system, it is also not as restrictive in this context as may first appear. Technical inefficiency of net investment, τ_k, is represented by the physical operation of generating plants. Thermal conversion efficiency is used to measure the performance of generating plants. The report of EIA showed that the standard deviation of an average plant efficiency of steam electric power generating plants measured by thermal conversion efficiency is very low for each plant. Sensitivity analysis on the technical efficiency parameter of net investment was performed and the likelihood and R^2 for each estimated equation are quite stable within this range and suggest no statistically significant change between the model with $\tau_k = 1$ and τ_k equal to any other value less than unity.

overall time period results, followed by comparison of the results for groups of electric utilities according to the status of state electric industry restructuring activity.

Overall Time Period Results

The proportional growth of output and the scale- and efficiency-related components constituting this growth over the time period of 1987-1999 are presented in Table 3. The average value of scale elasticities over the period 1987-1999 is 1.371, which indicates increasing-returns to scale in the production of the electricity industry. Over the period 1987-1999, the electricity output grew by 3.72 percent.

The scale-related components constituting the growth in electricity output involve the growth in the behavioral variable inputs demand, $\hat{F}_v$, the growth in the quasi-fixed factors at the long-run equilibrium, $\hat{F}_{qs}$, the growth in the behavioral net physical investment demand, $\hat{F}_I$, and the growth in the endogenously determined marginal behavioral values of quasi-fixed factor stocks, $\hat{F}_J$. The proportional growth rates for the steady-state quasi-fixed factor and marginal behavioral values of quasi-fixed factor stocks grew at an average annual rate of 0.51 and 1.69 percent, respectively. The average growth rates for the behavioral variable inputs and the behavioral net physical investment are negative, indicating that the behavioral variable inputs and the behavioral net physical investment were reduced by 0.63 and 0.69 percent per annum, respectively.

The efficiency-related components constituting the growth in electricity output involve the technical efficiency effect from the change of variable inputs use, $\hat{F}_{vx}$, the allocative efficiency effect from the change of variable inputs use, $\hat{F}_{v\lambda}$, the allocative efficiency effect from the change of net investment use, $\hat{F}_{I\mu}$, and the allocative efficiency effect from the change of marginal value of capital, $\hat{F}_{J\mu}$. The proportional growth rates, caused by the technical efficiency effect from the change of variable inputs use, and by the allocative efficiency effects from the changes of variable inputs use, net investment use, and marginal value of capital, grew at an average annual rate of 0.11, 0.98, 0.69 and 0.02 percent, respectively. The technical efficiency effect from the change of variable inputs use and the allocative efficiency effects from the changes of variable inputs use and net investment use decreased from the period 1992-1995 to 1996-1999, while the allocative efficiency effect from the change of marginal value of capital increased between these two periods.

The long-run measures of the TFP growth over the period 1987-1999 are presented in Table 4. The dynamic measure of TFP growth can be decomposed into scale- and efficiency-related effects and the technical change effect. The TFP grew at 2.26 percent per annum and indicated low TFP growth prior to the year 1996. The combined effect of scale, quality-adjusted input growth, and long-run disequilibrium input use indicates the losses in the beginning of the sample period and then the gains thereafter. The average annual growth rate of the combined scale effect grew by 0.34 percent. The combined efficiency effect of variable input and net investment use and the change of marginal value of capital indicate a gain for the entire sample period. The proportional growth rate for the combined efficiency effect grew at an average annual rate of 0.69 percent. The combined efficiency effect indicates a significant increase during the period of 1992-1995 and then decreases to 0.42 during the period 1996-1999. This suggests the presence of an anticipation effect on the part of firms facing deregulation. Anticipation of deregulation gave firms the incentive to increase the outputs by improving technical and input allocative efficiencies. After the firms realized a small gain due to the deregulation in the short run, the firms began to operate less efficiently. This is demonstrated by a decrease of the combined efficiency effect during the period of 1996-1999. Technical change grew at an average annual rate of 1.22 percent. There was technological progress over the entire sample period with technological regress during the 1992-1995 periods as they were anticipating deregulation.

Comparison of the Results for Groups of Electric Utilities

Table 5 presents the quantitative decomposition of the long-run TFP growth by the group of electric utilities affected by the deregulation plan over the period 1987-1999. The dynamic TFP grew at 1.66 percent per annum by electric utilities located within states with the deregulation plan and 3.30 percent per annum by those located outside. The dynamic TFP growth of electric utilities located within states with the deregulation plan is attributed to the technological progress of 0.73 percent, the combined scale effect of 0.16 percent, and the combined efficiency effect of 0.76 percent. In contrast, while the dynamic TFP growth of those located outside of states with the deregulation plan is attributed to the technological progress of 2.08 percent, the combined scale effect of 0.64 percent, and the combined efficiency effect of 0.57 percent.

The estimated results indicate that electric utilities located within states with the deregulation plan have average annual growth of the technical change and of the combined scale effect lower than those located outside but they have average annual growth of the combined efficiency effect greater than those located outside. This result implies that electric utilities located within states with the deregulation plan increased the outputs by improving technical and input allocative efficiencies more than those located outside of states with deregulation plans. TFP growth of electric utilities located outside states with the deregulation plan is attributed to the technical change contribution and the modest contribution of the combined scale and efficiency effects. In contrast, TFP growth of those firms located within states with the deregulation plan resulted from the modest contribution of the technical change and the combined efficiency effects and the small gain of the combined scale effect.

Figure 1 illustrates plots of the dynamic TFP growth for all firms and for the group of electric utilities affected by the deregulation plan over the period 1987-1999. The plot of the dynamic TFP growth for all firms is similar to that of the electric utilities located within states with the deregulation plan. Electric utilities located outside of states with the deregulation plan present TFP growth over the period 1987-1999. There was a significant progress in TFP growth in 1993 and with minor regress in 1990 and 1994. Electric utilities located within states with the deregulation plan presents a significant regress in TFP in 1990 and modest regress during the period of 1994-1995. However, there is TFP growth after the deregulation period.

The TFP regress can be explained by the anticipation of the effect of the deregulation. In 1992, Congress passed the Energy Policy Act to open up the wholesale market in the production of electricity. The Federal Energy Regulatory Commission (FERC) issued Orders 888 and 889 in April of 1996 to force utilities with transmission networks to deliver power to third parties at nondiscriminatory cost-based rates. These policies to open markets led to new competitors in generation and marketing. Electric utilities located within states with the deregulation plan reacted to these regulatory changes in advance which led to the significant regress of TFP in 1990. The more modest regress of TFP growth during the period of 1994-1995 indicates an anticipation of the changes arising in 1992. The plot of technical change over time by electric utilities located outside states with the deregulation plan is rather smooth and indicates technological progress over the time period, while those located within states with the deregulation plan indicate technological regress during the 1990-1995 periods. The plots of the combined scale and efficiency effects are quite smooth and similar for both electric utilities located within and outside states with the deregulation plan.

V. Conclusions

This study develops a dynamic model to measure the TFP growth decomposition in the presence of inefficiency. The dynamic TFP growth is decomposed into the combined scale effects, the combined efficiency gain or loss effects, and the technical change effect. The dynamic TFP growth is used as a measure to examine how the electric utilities react to the deregulation of the production of electricity; in particular, to evaluate how different electric utilities will perform that are located within or outside of states with the restructuring plan.

The results indicate that the TFP grew by 2.26 percent per annum. This TFP growth is attributed to the combined scale effects of 0.34 percent, the combined efficiency effects of 0.69 percent, and the technical change effect of 1.22 percent. The dynamic TFP grew by 1.66 percent per annum for electric utilities located within states with the deregulation plan and 3.30 percent per annum for those located outside. Electric utilities located outside of states with the deregulation plan had a TFP progress over the period 1987-1999. There was a significant progress of the TFP growth in 1993 and small regresses in 1990 and 1994. Electric utilities located within states with the deregulation plan showed a significant regress of the TFP in 1990 and a modest regress during the period of 1994-1995. However, there is an increase of TFP progress after the deregulation period which can be explained by the anticipation of the deregulation. Electric utilities located within states with the deregulation plan reacted to these regulatory changes in advance. This led to the significant regress of TFP in 1990. The more modest regress of the TFP during the period of 1994-1995 indicated a learning process from the changes in 1992.

The approach developed in this paper to decompose of dynamic TFP growth in the presence of inefficiency leads to the recognition of the efficiency gains or losses as contributions to growth. The components can be reliably measured econometrically allowing for endogenous dynamic decisions and once this decomposition is measured, the prospect of measuring the impact of regulation as a force retarding production and allocation efficiencies.

REFERENCES

Bauer, P. W., "Decomposing TFP Growth in the Presence of Cost Inefficiency, Non-constant Returns to Scale, and Technological Progress," *Journal of Productivity Analysis* 1:4 (1990a), 287-300.

Bernstein, J. I.., T. P. Mamuneas and P. Pashardes, "Technical Efficiency and Growth in U.S. Manufacturing," *Review of Economics and Statistics* 86:1 (2004), 402-412.

Caves, D. W., L. R. Christensen and J. A. Swanson, "Productivity in U.S. Railroads, 1951-1974," *Bell Journal of Economics* 11:1 (1980), 166-181.

Christensen, L. R. and D. W. Jorgenson, "U.S. Real Product and Real Factor Input, 1928-1967," *Review of Income and Wealth* 16 (1970), 19-50.

Considine, T. J., "Cost Structures for Fossil Fuel-Fired Electric Power Generation," *The Energy Journal* 21:2 (2000), 83-104.

Cornwell, C., P. Schmidt, and R. C. Sickles, "Production Frontiers with Cross-Sectional and Time-Series Variation in Efficiency Levels," *Journal of Econometrics* 46:1-2 (1990), 185-200.

Denny, M., M. Fuss, and L. Waverman, "The Measurement and Interpretation of Total Factor Productivity in Regulated Industries, with and Application to Canadian Telecommunications," in T. G. Cowing and R. E. Stevenson (Eds.), *Productivity Measurement in Regulated Industries*. New York: Academic Press (1981).

Esptein, L. G., "Duality Theory and Functional Forms for Dynamic Factor Demands," *Review of Economic Studies* 48 (1981), 81-95.

Epstein, L.G. and M. G. S. Denny, "The Multivariate Flexible Accelerator Model: Its Empirical Restrictions and an Application to U.S. Manufacturing," *Econometrica* 51 (1983), 647-674.

Fabrizio, K. K., N. Rose and C. Wolfram, "Does Competition Reduce Costs? Assessing the Impact of Regulatory Restructuring on U.S. Electric Generation Efficiency." NBER Working Paper No. 11001 (Decemeber 2004).

Griliches, Z., "The Sources of Measured Productivity Growth: U.S. Agriculture, 1940-1960," *Journal of Political Economy* 71 (1963), 331-346.

———, "Research Expenditures, Education, and the Aggregate Agricultural Production," *The American Economic Review* 54 (1964), 961-974.

Luh, Y.- H. and S. E. Stefanou, "Productivity Growth in U.S. Agriculture under Dynamic Adjustment," *American Journal of Agricultural Economics* 73:4 (1991), 1116-25.

McLaren, K. R. and R. J. Cooper, "Intertemporal Duality: Application to the Theory of the Firm," *Econometrica* 48 (1980), 1755-1762.

Nadiri, M. I. and M. A. Schankerman, "The Structure of Production, Technological Change, and the Rate of Growth of Total Factor Productivity in the U.S. Bell System." in T. G. Cowing and R. E. Stevenson (Eds.), *Productivity Measurement in Regulated Industries* (New York: Academic Press, 1981).

Nishimizu, M. and J. M. Page, Jr., "Total Factor Productivity Growth, Technological Progress and Technical Efficiency Change: Dimensions of Productivity Change in Yugoslavia, 1965-1978," *The Economic Journal* 92:368 (1982), 920-936.

Ohta, M., "A Note on the Duality between Production and Cost Functions: Rate of Return to Scale and Rate of Technical Progress," *Economic Studies Quarterly* 25:3 (1974), 63-65.

Rungsuriyawiboon, S. and S. E. Stefanou, "Dynamic Efficiency Estimation: An Application in US Electric Utilities," *Journal of Business and Economic Statistics, forthcoming*.

Solow, R. M., "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics* 39 (1957), 312-320.

Stefanou, S. E., "Returns to Scale in the Long Run: The Dynamic Theory of Cost," *Southern Economic Journal* 55 (1989), 570-579.

Table 1. Definition of the Inefficiency Components

Symbol	Expression	Description
ζ_x	$(1-(1/\tau_x))(wx^{o*})$	The change of technical inefficiency from actual variable inputs use evaluated at the actual variable inputs prices
ζ_k	$(1-(1/\tau_k))(J_k^a\dot{K}^{o*})$	The change of technical inefficiency from actual net investment use evaluated at the marginal actual value of capital
ζ_λ	$(1-\lambda)(wx^{b*})$	The change of allocative inefficiency from actual variable inputs prices evaluated at the behavioral variable inputs use
ζ_μ	$(1-\mu)(J_k^a\dot{K}^{b*})$	The change of allocative inefficiency from the marginal actual value of capital evaluated at the behavioral net investment use

Table 2. Definition of the Components of Dynamic Productivity Decomposition in the Presence of Inefficiency

Symbol	Expression	Description
Impact of changing variable inputs		
$\hat{F}_v$	$\sum_n^N \left(w_n^b x_n^{b*}/rJ^a\right)\hat{x}_n^{b*}$	- The proportional growth of the behavioral variable inputs demand
$\hat{F}_{vx}$	$\sum_n^N \left(\zeta_{xn}/rJ^a\right)\hat{x}_n^{o*}$	- Technical efficiency gain/loss effects from the change of variable input use
$\hat{F}_{v\lambda}$	$\sum_n^N \left(\zeta_{\lambda n}/rJ^a\right)\hat{x}_n^{b*}$	- Allocative efficiency gain/loss effects from the change of variable input use
Impact of changing net physical investment		
$\hat{F}_I$	$\left(J_k^b \dot{K}^{b*}/rJ^a\right)\hat{\dot{K}}^{b*}$	- The proportional growth of the behavioral net physical investment demand
$\hat{F}_{Ik}$	$\left(\zeta_k/rJ^a\right)\hat{\dot{K}}^{o*}$	- Technical efficiency gain/loss effects from the change of net investment use
$\hat{F}_{I\mu}$	$\left(\zeta_\mu/rJ^a\right)\hat{\dot{K}}^{b*}$	- Allocative efficiency gain/loss effects from the change of net investment use
Impact of changing marginal value of capital stock		
$\hat{F}_J$	$\left(J_k^b \dot{K}^{b*}/rJ^a\right)\hat{J}_k^b$	- The proportional changes in the endogenously determined marginal behavioral values of quasi-fixed factor stocks
$\hat{F}_{Jk}$	$\left(\zeta_k/rJ^a\right)\hat{J}_k^a$	- Technical efficiency gain/loss effects from the change of marginal value of capital
$\hat{F}_{J\mu}$	$\left(\zeta_\mu/rJ^a\right)\hat{J}_k^b$	- Allocative efficiency gain/loss effects from the change of marginal value of capital
Impact of changing steady state capital stock		
$\hat{F}_{qs}$	$\left(\left(\left(c - rJ_k^a\right)K\right)/rJ^a\right)\hat{K}$	- The proportional growth in quasi-fixed factor levels at the long-run equilibrium
Impact of technical change		
$\hat{A}$	$(1/y)(dF/dt)$	- A shift in the production technology or the technical change

Table 3. Proportional Growth of Output and the Scale- and Efficiency-Related Components over Time, 1987-1999

Year	SE	$\hat{F}_v$	$\hat{F}_{qs}$	$\hat{F}_I$	$\hat{F}_J$
1987-1991	1.475	-0.0073	0.0049	-0.0255	0.0144
1992-1995	1.350	-0.0081	-0.0013	0.0159	0.0189
1996-1999	1.262	-0.0032	0.0119	-0.0064	0.0180
1987-1999	**1.371**	**-0.0063**	**0.0051**	**-0.0069**	**0.0169**
Year	$\hat{Y}$	$\hat{F}_{vx}$	$\hat{F}_{v\lambda}$	$\hat{F}_{I\mu}$	$\hat{F}_{J\mu}$
1987-1991	-0.0132	0.0017	0.0125	-0.0106	-0.0000
1992-1995	0.0937	0.0014	0.0126	0.0274	-0.0008
1996-1999	0.0436	-0.0001	0.0036	0.0082	0.0014
1987-1999	**0.0372**	**0.0011**	**0.0098**	**0.0069**	**0.0002**

Table 4. Components of Dynamic Total Productivity Growth, 1987-1999 (Average Values in Percentage)

Year	TFP	Scale Effect	Efficiency Effect	Technical Change
1987-1991	0.99	-0.51	0.19	1.31
1992-1995	0.71	1.17	1.60	-2.06
1996-1999	5.39	0.59	0.42	4.39
1987-1999	**2.26**	**0.34**	**0.69**	**1.22**

Table 5. Components of Dynamic Total Productivity Growth (Average values by group of firms in percentage)

Year	TFP	Scale Effect	Efficiency Effect	Technical Change
Regulated Firms				
1987-1991	1.22	-0.26	-0.59	2.07
1992-1995	4.89	1.90	1.83	1.16
1996-1999	4.30	0.51	0.77	3.02
1987-1999	**3.30**	**0.64**	**0.57**	**2.08**
Deregulated Firms				
1987-1991	0.85	-0.67	0.66	0.86
1992-1995	-1.80	0.72	1.47	-3.99
1996-1999	6.12	0.64	0.18	5.29
1987-1999	**1.66**	**0.16**	**0.76**	**0.73**

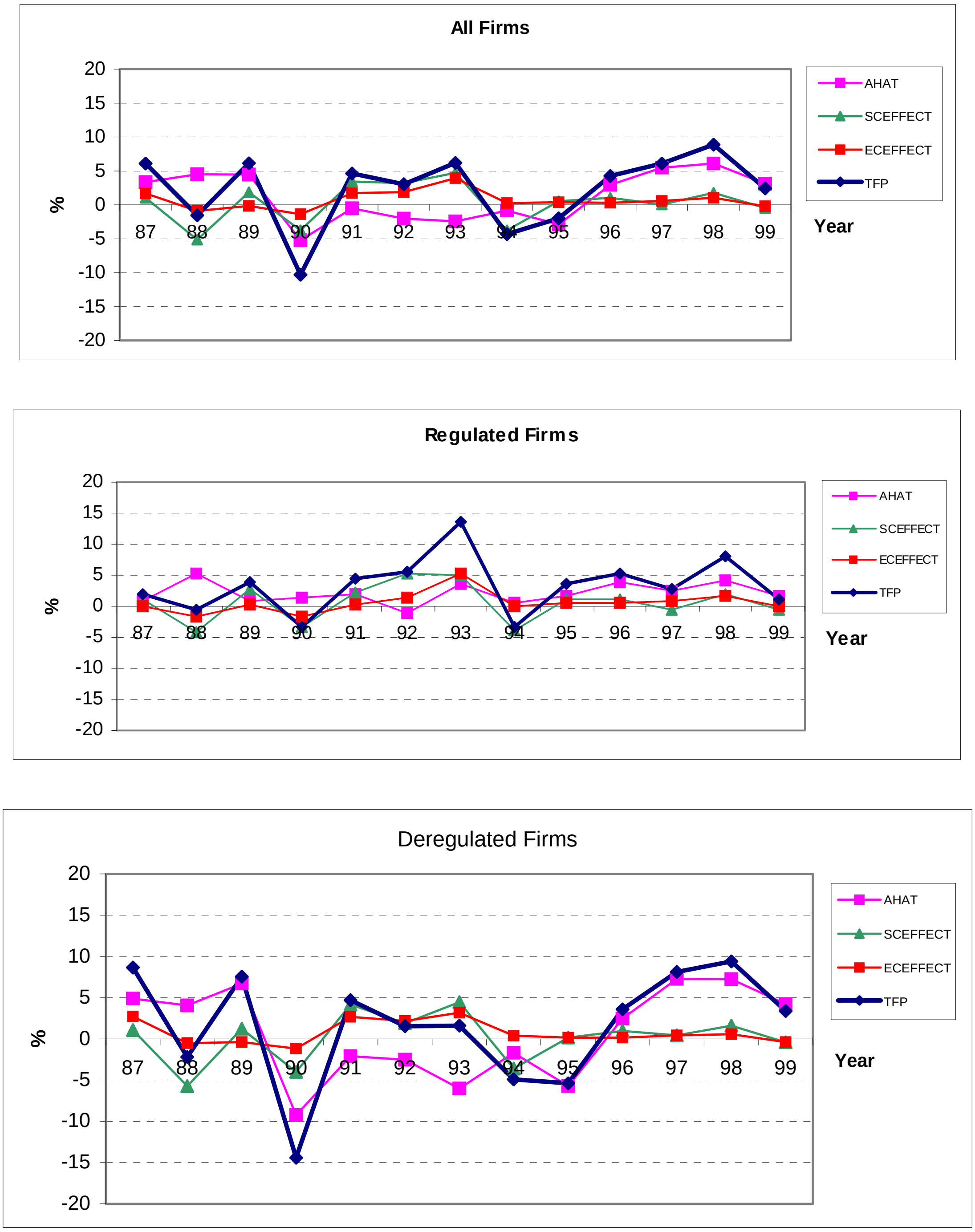

Figure 1. Plots of Total Factor Productivity Growth over Time