PRODUCTIVITY MEASUREMENT WITH
NONSTATIC EXPECTATIONS AND
VARYING CAPACITY UTILIZATION:
AN INTEGRATED APPROACH

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ABSTRACT

Typically measures of multifactor productivity growth have been
based on a production and optimization framework that assumes all
inputs are instantaneously adjustable, thus ignoring the important
impacts of short run fixity of certain inputs. This paper focuses
on the distinction between short and long run production behavior
represented by economic capacity utilization indexes, and on the
adjustment of observed productivity measures for the effects of
short run fixity characterized by these indexes. A dynamic optimization
model based on adjustment costs for quasi-fixed inputs is developed
to calculate capacity utilization adjustments for productivity growth
measures. The resulting framework is then used to identify
empirically the effects of capacity utilization, nonstatic expectations,
nonconstant returns to scale and adjustment costs for both capital
and labor on productivity growth in the U.S. manufacturing sector,
1947-1979.

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I. INTRODUCTION

Measures of multifactor productivity growth have long been linked to outward shifts in production isoquants or downward shifts in average cost curves. Typically, such links have been built on a production and optimization framework that assumes all inputs are instantaneously adjustable, and thus assumes also that there is no distinction between short and long run. This distinction can be very important, however, particularly when large shocks occur, for in such cases the characteristics of the firm's short run behavior during the initial part of the adjustment response may differ substantially from those occurring once long run equilibrium has been attained. This paper focuses attention on the implications for multifactor productivity measurement of increasing marginal adjustment costs for quasi-fixed inputs, and thus on the need to distinguish short- from long-run impacts.

Most of the models currently used for productivity analysis are based on the assumptions of full utilization or long run equilibrium and static expectations at all points in time for all inputs. More specifically, these models are typically based on the assumption that firms always use both technically and economically efficient input combinations. Thus productivity growth may be represented by $\partial \ln Y/\partial t - \varepsilon_{ft}$ (where Y is output, defined by the production function $Y = f(X)$, and t represents the state of technology), or by $\partial \ln C/\partial t - \varepsilon_{ct}$ (where C is total costs). Ohta (1975) has developed the dual relationship between ε_{ft} and ε_{ct} by showing that with constant returns to scale (CRTS) $\varepsilon_{ft} = \varepsilon_{ct}$ and with nonconstant returns to scale (NCRTS) $\varepsilon_{ft} = \varepsilon_{ct}\varepsilon_{cy}^{-1}$, where $\varepsilon_{cy} = \partial \ln C/\partial \ln Y$.

These representations of productivity, however, permit no distinction between short and long run since they are essentially based on a static or timeless model where all inputs are assumed instantaneously variable.

This problem was recognized in early studies of technical change such as that by Jorgenson and Griliches (1967), who attempted to adjust productivity measures for cyclical adjustment using capacity utilization (CU) indices. Such cyclical adjustments, however, have ambiguous inter-pretation and have been a source of dispute since they are not based on a theoretical foundation within which the short run-long run nature of productivity growth is isolated.

More recently, Berndt and Fuss (1981) and Baily (1981) have attempted to capture the effect of "disequilibrium" using the deviation of market- and implicit-valuation of the fixed capital stock faced by the firm. These studies are of crucial importance for focussing attention on the impacts of input stocks. Ambiguities still remain, however, concerning the roles of dynamic optimization and anticipatory expectations.

In order to facilitate interpretation of utilization decisions and resulting implications for productivity growth, an integrating framework is required to capture variations in utilization, anticipatory behavior and costs of adjustment, as well as the effects of nonconstant returns to scale. Such a framework, a dynamic optimization model of an imperfectly competitive firm producing at a point of long run nonconstant returns to scale with increasing marginal adjustment costs on quasi-fixed inputs and nonstatic expectations, has been constructed by

Morrison (1983b,1984). The model is based on costs of adjustment for
quasi-fixed inputs that induce slow adjustment by firms to "optimal"
or "desired" levels of the quasi-fixed inputs consistent with nonstatic
expectations on prices and output. The model is structured so one can
derive explicitly a system of short run demand equations for variable
inputs and accumulation equation(s) for quasi-fixed input(s) based
on an endogenous "flexible accelerator" or partial adjustment process,
as in Berndt, Fuss and Waverman (1979). Thus by characterizing the
corresponding cost curves one can determine the firm's optimal
adjustment path from the short to long run in response to a temporary
disequilibrium situation.

In this paper I show how various impacts on observed productivity
can be identified and measured within such a framework. The plan of
the paper is as follows. In Section II I first demonstrate that (i)
multifactor productivity measures are affected systematically by
divergence between long run equilibrium and short run (temporary)
equilibrium, hereafter denoted subequilibrium, (ii) a properly
defined index of capacity utilization (CU) can be used to quantify this
divergence, and (iii) the existence of nonstatic expectations,
adjustment costs, and nonconstant returns to scale affects the time
path of investment and thus the time pattern of measured productivity
growth through impacts on CU. In Section III I develop and report on
an empirically implementable econometric model that permits separate
identification of the effects of CU, nonstatic expectations, adjustment
costs and nonconstant returns to scale on productivity in the U.S.
manufacturing sector, 1947-1979. A primary finding is that both

subequilibrium and anticipatory behavior have substantial impacts on observed productivity measures. In addition, there is a notable difference between two alternative models used, which suggests that disaggregation of labor into production and nonproduction workers and recognition of the quasi-fixity of nonproduction workers are crucial for developing valid measures of productivity trends. Finally, in Section IV I focus on how this research integrates much of the previous literature on factor demands and productivity growth, and thus provides a framework within which to reconcile alternative approaches.

II. PRODUCTIVITY AND ITS COMPONENTS: A THEORETICAL ANALYSIS

Productivity growth is defined as the diminution in total costs from an increase in the state of technology (t) not explained by substitution between inputs--the residual ε_{ct}. In order empirically to identify the impacts on total productivity mentioned in the Introduction, a framework must be constructed in which deviations of capacity utilization (CU) from unity, nonstatic expectations, adjustment costs, and nonconstant returns to scale (NCRTS) are incorporated. This requires recognizing the constraints on the firm which result in subequilibrium utilization of the quasi-fixed inputs. Thus the analysis is structured around a cost function divided explicitly into variable and fixed cost components. The output or price choice for a firm facing a demand curve with finite elasticity is assumed to be a sequential decision, taken into account in the estimating model. I begin by using this general framework to identify the current subequilibrium--CU--and technical progress components of observed productivity growth. Additional extensions are considered in turn.

Assume the restricted or variable cost function can be represented by $G(x_j, \dot{x}_j, w_i, t, Y)$ where x_j is a vector of J quasi-fixed input quantities, $\dot{x}_j$ is the time derivative of x_j, and w_i is the vector of I variable input prices. Increasing marginal costs of adjustment due to $\dot{x}_j \neq 0$ affect variable costs according to $\partial G/\partial |\dot{x}_j| \geq 0$, $\partial^2 G/\partial |\dot{x}_j|^2 \geq 0$, and thus make the optimization problem a dynamic one.

As outlined in Lau (1978) and Berndt, Fuss and Waverman (1979), G represents minimum variable costs given x_j, w_i and Y, and under appropriate regularity conditions has standard properties including:

(1a) $\partial G/\partial w_i = v_i$ = cost minimizing variable i input demand, and

  b) $-\partial G/\partial x_j = Z_j$ = shadow value for quasi-fixed input j.

A "shadow value of investment" can be defined analogously as:

  c) $-\partial G/\partial \dot{x}_j = Z\cdot_j$ = the shadow value of $\dot{x}_j$.

This expression represents the marginal cost savings involved if one

less unit of investment is required to reach a given level of capital

stock. It therefore represents the "flow" costs incorporated in the

dynamic framework.[1]

    Total costs are variable plus fixed costs or $C(Y,t,w_i,p_j,x_j,\dot{x}_j) = $

$G(Y,t,w_i,x_j,\dot{x}_j) + \Sigma_j p_j \cdot x_j$, where p_j is a vector of market rental

prices for the fixed inputs. The change in total costs from technical

progress, represented by $d\ell nC/dt$, is characterized by the full response

of both variable and quasi-fixed inputs to long run equilibrium levels:

(2) $$\frac{d\ell nC}{dt} = \frac{1}{C} \left[\left. \frac{dC}{dt} \right|_{x_j = \bar{x}_j} + \Sigma_j \frac{\partial C}{\partial x_j} \frac{dx_j}{dt} \right] \qquad .$$

This is a long run cost elasticity analogous to typical long run price

and output elasticities.[2] In effect the long run adjustment is a

geometric series of adjustments toward the desired quasi-fixed input

stocks x* which are assumed to close the "gap" between x and x*

by the proportion λ in each period. This decomposition captures the

flavor of the difference between short and long run producivity impacts,

but is not very useful for interpretation or linkages with the notion of

subequilibrium or CU. To facilitate such an interpretation, for the moment assume CRTS and expand expression (2):

$$(3) \quad \frac{d \ln C}{dt} = \frac{1}{C} \left[\frac{\partial C}{\partial t} + \frac{\partial C}{\partial Y} \frac{Y}{dt} + \Sigma_i \frac{\partial C}{\partial w_i} \frac{dw_i}{dt} + \Sigma_j \frac{\partial C}{\partial p_j} \frac{dp_j}{dt} \right. $$

$$ \left. + \Sigma_j \frac{\partial C}{\partial \dot{x}_j} \frac{d\dot{x}_j}{dt} \right] + \frac{1}{C} \left(\Sigma_j \frac{\partial C}{\partial x_j} \frac{dx_j}{dt} \right) $$

$$ = -\varepsilon_{Ct} + (1 - \Sigma_j \varepsilon_{Ct} - \Sigma_j \varepsilon_{\dot{C}j}) \frac{\dot{Y}}{Y} + \Sigma_i \frac{v_i w_i}{C} \frac{\dot{w}_i}{w_i} $$

$$ + \Sigma_j \frac{p_j x_j}{C} \frac{\dot{p}_j}{p_j} + \Sigma_j \frac{(p_j - z_j) x_j}{C} \frac{\dot{x}_j}{x_j} - \Sigma_j \frac{z_j \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j} \quad . $$

where $-\varepsilon_{Ct} = \partial \ln C / \partial t$, $\varepsilon_{CY} = \partial \ln C / \partial \ln Y$, $\varepsilon_{Cj} = \partial \ln C / \partial \ln x_j = (p_j - z_j) x_j / C$, $\varepsilon_{\dot{C}j} = \partial \ln C / \partial \ln \dot{x}_j = (-z_j \dot{x}_j / C)$, and $(1 - \Sigma \varepsilon_{Cj} - \Sigma \varepsilon_{\dot{C}j}) = \varepsilon_{CY}$ with constant returns to scale.[3] Cost diminution is specified to be positive; $\varepsilon_{Ct} = -\partial \ln C / \partial t$, so increasing productivity is represented by a larger instead of a smaller number. Note also that $d\dot{x}_j / dt$ represents the effect of a change in t on the desired long run capital stock and thus on investment.

Following Ohta (1975), note that since $C = \Sigma_j w_i v_i + \Sigma_j p_j x_j$, full long run $\dot{C}/C$ can also be represented as:

$$(4) \quad \frac{\dot{C}}{C} = \Sigma_i \frac{\dot{w}_i v_i}{C} + \Sigma_i \frac{w_i \dot{v}_i}{C} + \Sigma_j \frac{\dot{p}_j x_j}{C} + \Sigma_j \frac{p_j \dot{x}_j}{C} $$

$$ = \Sigma_i \frac{v_i w_i}{C} \frac{\dot{w}_i}{w_i} + \Sigma_i \frac{w_i v_i}{C} \frac{\dot{v}_i}{v_i} + \Sigma_j \frac{x_j p_j}{C} \frac{\dot{p}_j}{p_j} + \Sigma_j \frac{p_j x_j}{C} \frac{\dot{x}_j}{x_j} \quad . $$

Setting these two expressions for $\dot{C}/C$ equal to each other and cancelling on both sides leaves:

$$(5) \qquad \sum_i \frac{w_i v_i}{C} \frac{\dot{v}_i}{v_i} = -\varepsilon_{Ct} + (1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{\dot{C}j}) \frac{\dot{Y}}{Y} - \sum_j \frac{z_j x_j}{C} \frac{\dot{x}_j}{x_j}$$

$$- \Sigma \frac{z_{\dot{j}} \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j} , \quad \text{or}$$

$$\varepsilon_{Ct} = (1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{\dot{C}j}) \frac{\dot{Y}}{Y} - \sum_i \frac{w_i v_i}{C} \frac{\dot{v}_i}{v_i} - \sum_j \frac{z_j x_j}{C} \frac{\dot{x}_j}{x_j}$$

$$- \sum_j \frac{z_{\dot{j}} \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j} .$$

This expression is in fact the conventional productivity residual calculated as the difference between the change in output and the actual share-weighted sum of the changes in inputs or, in the dual, as the change in costs less the actual share-weighted sum of the changes in input prices. Note that equation (5) is valid if long run equilibrium and CRTS exist. The expression appears different than is usually seen because of the explicit recognition of the fixed input constraint--$\varepsilon_{Cj} \neq 0$, and of non-zero investment in temporary equilibrium--$\varepsilon_{\dot{C}j} \neq 0$. In the long run, however, (5) collapses to the usual expression since $z_j = p_j$ and $z_{\dot{j}} = 0$ so $\varepsilon_{Cj} = \varepsilon_{\dot{C}j} = 0$ for all j.[4]

The importance of the representation of ε_{Ct} in (5) can be illuminated by dividing both sides by $(1 - \Sigma_i\varepsilon_{Cj} - \Sigma_j\varepsilon_{\dot{C}j})$. This

results in:

$$(6) \quad \frac{\varepsilon_{Ct}}{1-\Sigma\varepsilon_{Cj}-\Sigma\dot{\varepsilon}_{Cj}} = \varepsilon'_{Ct} = \frac{\dot{Y}}{Y} - \frac{1}{1-\Sigma\varepsilon_{Cj}-\Sigma\dot{\varepsilon}_{Cj}} \ [\Sigma_i \ \frac{w_i v_i}{C} \frac{\dot{v}_i}{v_i}$$

$$+ \ \Sigma_j \ \frac{z_j x_j}{C} \frac{\dot{x}_j}{x_j} + \Sigma_j \ \frac{z \cdot_j \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j} \ ] \quad .$$

Interpretation of this requires one more step. Note that

$$(7) \quad 1-\Sigma\varepsilon_{Cj}-\Sigma\dot{\varepsilon}_{Cj} = \frac{C-\Sigma \ ^{(p_j-z_j)x_j}+\Sigma z\cdot_j \dot{x}_j}{C} = \frac{G+\Sigma z_j x_j+\Sigma z\cdot_j \dot{x}_j}{C}$$

$$= \frac{\text{shadow costs}}{\text{total costs}} = \frac{C^*}{C} \quad .$$

This definition of shadow costs is slightly different than the "gross" measure defined by Berndt and Fuss (1981) as $G + Z_k K$, where the contribution of the quasi-fixed inputs are weighted by their shadow instead of rental values. The Berndt-Fuss expression derives, however, from a static optimization framework where the contribution of investment to costs is not explicitly defined. With dynamic optimization, shadow costs are "net" of adjustment costs because the costs of putting the marginal unit of capital into place are recognized.[5]

Substituting (7) into (6) yields:

$$(8) \qquad \varepsilon'_{Ct} = \frac{\varepsilon_{Ct}}{1-\Sigma\varepsilon_{Cj}-\Sigma\dot{\varepsilon}_{Cj}} = \frac{\dot{Y}}{Y} - \Sigma \frac{w_i v_i}{C*} \frac{\dot{v}_i}{v_i} - \Sigma \frac{Z_j x_j}{C*} \frac{\dot{x}_j}{x_j} - \Sigma \frac{Z\cdot_j \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j} \quad .$$

In (8) ε'_{Ct} is the expression for multifactor productivity with CU = 1, and is analogous to that derived by Berndt-Fuss; it adjusts observed productivity ε_{Ct} to account for subequilibrium. Essentially, (8) adjusts the shares so that the contribution of capital is weighted by its net shadow instead of rental value and it normalizes so that the sum of the resulting shares is equal to unity. There are three additional features of (8): (i) ε'_{Ct} can be interpreted as the product of a conventional productivity measure and a CU term, (ii) ε'_{Ct} can be shown to be equal to the production or primal side technical change measure adjusted for short run subequilibrium, ε'_{ft}, and (iii) ε'_{Ct} can directly be represented empirically using a parametric approach. I now pursue the first two points; the third is considered in the next section.

The value of the cost side measure, $C*/C$ or $(1 - \Sigma\varepsilon_{Cj}-\Sigma\dot{\varepsilon}_{Cj})$, can lie on either side of unity depending on whether the net shadow valuation of the quasi-fixed inputs exceeds or falls short of the market rental price.[6] Thus the observed "residual" productivity change multiplied by $1/CU = 1/(1 - \Sigma\varepsilon_{Cj} - \Sigma\dot{\varepsilon}_{Cj}) = C/C*$ reflects the effect only of technical progress, which may be larger or smaller than the combined observed productivity effect.

Development of the production-side representation of technical progress requires demonstrating the equivalence of ε'_{Ct} with a corresponding production-side measure ε'_{ft}. First note that with

fixed inputs the arguments of the production function must be divided

into the variable and fixed inputs, here v_i and x_j, so

$Y = f(v_i, x_j, \dot{x}_j, t)$. Thus,

$$(9) \quad \frac{d\ell nY}{dt} = \frac{\dot{Y}}{Y} + \Sigma_i \frac{v_i f_i}{f} \frac{\dot{v}_i}{v_i} + \Sigma_j \frac{x_j f_j}{f} \frac{\dot{x}_j}{x_j} + \Sigma_j \frac{\dot{x}_j f \cdot_j}{f} \frac{\ddot{x}_j}{\dot{x}_j} + \varepsilon_{ft}, \quad \text{or,}$$

$$\varepsilon_{ft} = \frac{\dot{Y}}{Y} - \Sigma_i \frac{v_i \mu f_i}{Y\mu} \frac{\dot{v}_i}{v_i} - \Sigma_j \frac{x_j \mu f_j}{Y\mu} \frac{\dot{x}_j}{x_j} - \Sigma_j \frac{\dot{x}_j \mu f \cdot_j}{Y\mu} \frac{\ddot{x}_j}{\dot{x}_j} \quad .$$

If productivity growth ε_{ft} is being measured from a point of

subequilibrium, the quasi-fixed inputs must be revalued to represent

the subequilibrium. This can be characterized by defining μ and f_j

from the firm's short run cost minimization problem:

$$(10) \quad \min C = \Sigma_i w_i v_i + \mu(Y - f(x_j, \dot{x}_j, v_i, t)) \quad .$$

Evaluation of (9) at the short run values derived from the first

order conditions of (10) results in:

$$(11) \quad \varepsilon'_{ft} = \frac{\dot{Y}}{Y} - \varepsilon_{CY}^{-1}[\Sigma \frac{v_i w_i}{C} \frac{\dot{v}_i}{v_i} + \Sigma \frac{z_j x_j}{C} \frac{\dot{x}_j}{x_j} + \Sigma \frac{z \cdot_j \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j}]$$

$$= \frac{\dot{Y}}{Y} - \frac{1}{1-\Sigma\varepsilon_{Cj}-\Sigma\varepsilon_{Cj}} [\Sigma \frac{v_i w_i}{C} \frac{\dot{v}_i}{v_i} + \Sigma \frac{z_j x_j}{C} \frac{\dot{x}_j}{x_j} + \Sigma \frac{z \cdot_j \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j}] = \varepsilon'_{Ct} \quad .$$

This final expression is directly analogous to ε'_{Ct} given by (8) above.

Duality of ε_{Ct} and ε_{ft} in the CRTS case along with the equality

between ε'_{ft} and ε'_{Ct} together imply that $\varepsilon_{ft}/CU = \varepsilon'_{ft}$ where

$Y^*/Y = 1/CU$. Thus the output CU measure is exactly dual to the

cost CU measure, provided long run CRTS and competition exist.

In summary, in this integrated approach the observed productivity change ε_{Ct} is distorted from a true technical progress measure by fixed inputs and resulting deviations in CU from unity. It is possible, however, to inpute the true technical progress impact ε'_{Ct} as the product of two parts, the observed productivity effect and the effect of short run rigidities or subequilibrium:

$$(12) \qquad \varepsilon'_{ft} = \varepsilon_{ft}/(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{\dot{C}j}) \quad \text{or} \quad \varepsilon'_{Ct} = \varepsilon_{Ct}/(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{\dot{C}j}),$$

where in the long run $\varepsilon_{Cj} = \varepsilon_{\dot{C}j} = 0$ so CU = 1 and $\varepsilon'_{Ct} = \varepsilon_{Ct} = \varepsilon_{ft} = \varepsilon'_{ft}$.

The cost-CU measure and its use as a link between short and long run productivity measures can be interpreted in various ways.[7] One interpretation of this CU measure is as a form of a "multi-input Tobin's q" measure. Specifically, ε_{Cj} depends crucially on the deviation between z_j and p_j, which is the basis for the calculation of marginal Tobin's q as z_k/p_k, where k represents capital, and where only the stock effects or gross shadow value of capital is considered. Therefore in the case of one quasi-fixed input, adjustment by Tobin's q as suggested by Berndt and Fuss is equivalent to multiplication by CU. When there are multiple quasi-fixed inputs, while the weighting of different quasi-fixed inputs for Tobin's q is ambiguous, the CU adjustment is clearly appropriate.

Another interpretation of the cost CU measure is as a ratio of short and long run returns to scale, where short run returns to scale are defined over variable factors given fixed capital $= \varepsilon_{CY}(sr) = (1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{\dot{C}j})$. This view of CU is consistent with Ohta; in order to isolate technical

change one must adjust by returns to scale, which in this case involves short run returns.

A final interpretation of the cost CU measure refers more to conventional methods of productivity measurement. Multiplication of the conventional measure by C/C^* in effect revalues the shares of each of the inputs and, therefore, the weight on the change in that input to reflect the utilization of the given capital stock instead of the measured share. This multiplication incorporates the true economic valuation of the capital stock--its shadow marginal productivity in conjunction with the other inputs--instead of its simple market transaction value.

The CU adjustment therefore is important and is consistent with alternative interpretations. Observed productivity changes must also, however, be recognized to depend on the existence of nonstatic expectations, adjustment costs and NCRTS. I now consider these additions to the basic structure.

The conceptual importance of the extension to nonstatic expectations is that some current behavior of the firm may not correctly be imputed to responses in terms of current exogenous variables, but may result from anticipation of future economic conditions. Since the firm cannot respond instantaneously at a future point in time, it is rational for it to adjust partially before the exogenous change. Assuming that the observed productivity residual is a result only of rational optimizing firm behavior in terms of current variables may therefore omit important information that can further clarify the productivity residual.

Introduction of nonstatic expectations introduces several

complications. For example, with nonstatic expectations the economic

agent is not striving toward "desired" levels of quasi-fixed input stocks

$x^*(t)$ defined simply in terms of current variables, but instead can be

envisaged as moving toward the sum of $x^*(t)$ and a discounted weighted

average of the future desired stocks of x defined in terms of the

anticipated paths of exogenous variables, x^{**} : [8]

$$(12) \qquad \dot{x}(t) = \lambda(x^* - x + J) = \lambda(x^{**} - x) \qquad . \text{[9]}$$

In a model including nonstatic expectations the effect of $J \neq 0$ on

the CU measure can be captured by imputing the current $\dot{x}$ that would

allow a geometric progression to x^* instead of to x^{**}, and then

determining the levels of variable inputs necessary to produce actual

output and these imputed investment levels, instead of those including all

anticipatory behavior. Two alternative CU measures can then be

calculated, (i) a current value measure CU_{cv}, and (ii) an imputed

present value measure CU_{pv}. The difference between these can be

attributed to anticipatory behavior.

CU_{cv} is based on measurement within the full nonstatic expectations

model and includes both subequilibrium and nonstatic expectations effects.

Calcualtion of CU_{pv} requires purging from ε_{cj} and $\varepsilon_{\dot{c}j}$ for all j

the effects of investment due purely to anticipatory behavior, rather

than that attributed to current exogenous variables. This results in

the adjusted CU measure $(1 - \Sigma\varepsilon_{cj} - \Sigma\varepsilon_{\dot{c}j})' = CU_{pv}$.

Adjustment of a conventional productivity growth measure by dividing

by $(1 - \Sigma\varepsilon_{cj} - \Sigma\varepsilon_{\dot{c}j})$ has been interpreted as revaluing input shares to

reflect the full utilization of the quasi-fixed inputs including all

observed variable input use. By contrast, adjustment by

$(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{\dot{C}j})'$ incorporates the idea that variable inputs used for

anticipatory investment should not be evaluated as if they were

contributing to current productivity.

Note that this procedure for purging the effects of anticipatory

behavior, although it attributes all current variable input demand to

decisions based on current variables, does not categorize all variable

input demands as those corresponding to current output production. To

sharpen measures of technical change it is however necessary to purge

costs of adjustment corresponding to all investment, not just antici-

patory investment, from the productivity calculation. To accomplish

this, $(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{\dot{C}j})''$ or CU_{net} can be derived as a subequilibrium

indicator net of all investment costs that distort measurement of cost

diminution. By construction this measure purges the shares of variable

inputs of all input use that is not directly productive in terms of

augmenting current output levels.

The final adjustment of productivity measures requires incorporation

of NCRTS. The importance of this extension in the preceding analysis

based on CRTS is first evident in equation (3); the substitution of

$(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{\dot{C}j})$ for ε_{CY} is valid only with CRTS. To see this, note

that:

$$(14) \qquad \frac{d\ln C}{d\ln Y} = \frac{Y}{C} \left[\frac{\partial C}{\partial Y} + \Sigma_j \frac{\partial C}{\partial x_j} \frac{dx_j}{dY} + \Sigma_j \frac{\partial C}{\partial \dot{x}_j} \frac{d\dot{x}_j}{dY} \right] \qquad .$$

With nonconstant returns to scale, $d\ln C/d\ln Y = \eta$ where $1/\eta$ captures

long run returns to scale, and $d\ln x_j/d\ln Y = d\ln\dot{x}_j/d\ln Y = \eta_j \neq \eta \neq 1$.

Thus (14) reduces to:

(15) $\qquad \eta = \varepsilon_{CY} + \Sigma \eta_j (\varepsilon_{Cj} + \varepsilon_{Cj}^{\cdot})$ $\quad$ or $\quad$ $\varepsilon_{CY} = \eta[1 - \Sigma_j (\dfrac{\eta_j}{\eta}) (\varepsilon_{Cj} + \varepsilon_{Cj}^{\cdot})]$

If the cost function is homothetic, $\varepsilon_{CY} = \eta(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot})$. In this case overall returns to scale are decomposed into two parts, a sub-equilibrium component, $(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot})$ and a returns to scale component, η. Adjusting the observed productivity measure represented by (5) for NCRTS then yields

$$ (16) \quad \varepsilon_{Ct} = \eta(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot})\frac{\dot{Y}}{Y} - \Sigma \frac{w_i v_i}{C} \frac{\dot{v}_i}{v_i} - \Sigma \frac{z_j x_j}{C} \frac{\dot{x}_j}{x_j} - \frac{z_{\cdot j} \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j} \quad . $$

The adaptation of ε_{Ct} for subequilibrium is analogous to the CRTS case since CU represents short run relative to long run returns to scale, or $\eta(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot})/\eta = 1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot}$ (see Morrison (1983c)). Thus:

$$ (17) \quad \varepsilon_{Ct}' = \frac{\varepsilon_{Ct}}{1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot}} = \eta\frac{\dot{Y}}{Y} - \frac{1}{1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot}} [\Sigma \frac{w_i v_i}{C} \frac{\dot{v}_i}{v_i} + \Sigma \frac{z_j x_j}{C} \frac{\dot{x}_j}{x_j} $$

$$ + \Sigma \frac{z_{\cdot j} \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j}] $$

or,

$$ (18) \quad \frac{\varepsilon_{Ct}'}{\eta} = \frac{\dot{Y}}{Y} - \frac{1}{\eta(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot})} [\Sigma \frac{w_i v_i}{C} \frac{\dot{v}_i}{v_i} + \Sigma \frac{z_j x_j}{C} \frac{\dot{x}_j}{x_j} + \Sigma \frac{z_{\cdot j} \dot{x}_j}{C} \frac{\ddot{x}_j}{\dot{x}_j}] \quad . $$

Note that from (15), since ε_{CY} equals $\eta(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot})$, (18) in turn equals ε_{Ct}'. It follows that:

$$ (19) \quad \frac{\varepsilon_{Ct}'}{\eta} = \frac{\varepsilon_{Ct}}{(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot})\eta} = \frac{\varepsilon_{ft}}{(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot})} = \varepsilon_{ft}' \quad . $$

In the nonhomothetic case, as discussed in Morrison (1983c) the CU measure

is not simply $(1 - \Sigma\varepsilon_{Cj} - \Sigma\varepsilon_{Cj}^{\cdot}) = $ SHCOST/TCOST but must instead be

adjusted by differential scale effects for different inputs, as follows:

$$(20) \qquad \frac{\varepsilon_{Ct}'}{\eta} = \frac{\varepsilon_{Ct}}{\eta[1- \dfrac{\Sigma\eta_j(\varepsilon_{Cj}+\varepsilon_{Cj}^{\cdot})}{\eta}]} = \frac{\dot{Y}}{Y} - \frac{1}{\eta[1- \dfrac{\Sigma\eta_j(\varepsilon_{Cj}+\varepsilon_{Cj}^{\cdot})}{\eta}]}[\Sigma\frac{w_i v_i}{C}\frac{\dot{v}_i}{v_i}$$

$$+ \Sigma\frac{z_j x_j}{C}\frac{\dot{x}_j}{x_j} + \Sigma\frac{z_j^{\cdot} x_j}{C}\frac{\ddot{x}_j}{\dot{x}_j}]$$

$$= \frac{\varepsilon_{Ct}}{CU\cdot\eta} = \frac{\varepsilon_{ft}}{CU} = \varepsilon_{ft}' \qquad .$$

With nonconstant returns to scale, the shares are thus adjusted to

reflect the fact that some increases in "efficiency" or decreases in

cost are simply due to scale effects. The NCRTS adjustment alters the

cost shares to represent output shares--purging the share of the scale

effect that decreases costs with no true increase in input efficiency.

III. EMPIRICAL ILLUSTRATION

I now turn to an empirical implementation of the decomposition of the path of productivity growth over time. Specifically, I attempt to assess empirically the role of subequilibrium, adjustment costs, nonstatic expectations, and NCRTS in determining the 1949-1979 path of productivity growth in U.S. manufacturing.[10] I proceed first to summarize the measures used to decompose observed productivity growth and to isolate technical progress.

The measure of productivity used as a reference point is ε_{Ct}. This is the conventional measure of cost-side total factor productivity calculated from the data on actual cost shares and changes in cost and input prices as the (negative) difference between $\dot{C}/C$ and the share-weighted sum of input prices $\dot{w}_i/w_i$ and $\dot{p}_j/p_j$. It is also a justifiable measure of productivity growth given long run equilibrium, instantaneous adjustment, static expectations, and CRTS. The decomposition of ε_{Ct} is carried out by generalizing each of these restrictions. For expositional purposes, to represent ε_{Ct} I rely on the conventional index of the state of technology or level of productivity denoted A_t, where $\varepsilon_{Ct} = \dot{A}/A$.

Some of the observed productivity residual ε_{Ct} may arise simply from short run "rigidities" rather than from technical progress. A more appropriate measure to isolate the impact of subequilibrium has been shown to be $\varepsilon'_{Ct} = \varepsilon_{Ct}/CU' = \varepsilon_{Ct}/CU_{pv}$; the corresponding productivity index is denoted A'_t. This is the first adjustment to be analyzed below.

In addition, observed changes in productivity may arise from

nonstatic expectations. To adjust for nonstatic expectations it is sufficient simply to measure $\varepsilon_{Ct}'' = \varepsilon_{Ct}/CU_{CV}$, and the resulting state of technology A_t''. CU_{CV} is a temporary equilibrium indicator based on current instead of intertemporal optimization. This is the second adjustment to be discussed.

Since some observed productivity may also result from fluctuations in variable input use for investment, the corresponding adjustment costs should be purged in order to derive a sharper measure of technical progress. This is accomplished by calculating $\varepsilon_{Ct}''' = \varepsilon_{Ct}/CU_{net}$, and cumulating these growth rates to derive the index of productivity levels, A_t'''. This is the third adjustment to be assessed.

This third measure, however, reflects true technical progress only if the technology exhibits CRTS. Otherwise, the apparent productivity changes resulting from scale effects are incorrectly attributed to technical progress. To adjust for this it is necessary to multiply by returns to scale, or in the notation above, to calculate $\varepsilon_{Ct}'''' = \varepsilon_{Ct}'''/\eta$ and the associated A_t''''.

This final expression for ε_{Ct}'''' is the technical progress residual after adjusting for the full set of structural and behavioral factors considered above. It may therefore be used to determine whether, during periods of volatility, changes in the economic situation usually attributed simply to "productivity" are instead attributable to other direct and indirect impacts.

The model I use to construct and estimate these measures is from Morrison (1983b). Briefly, this model assumes capital is quasi-fixed and that costs of adjustment occur for net capital formation. An

alternative specification compared here also includes nonproduction workers (N) as a quasi-fixed factor; labor is "hoarded" in the sense that there are costs of adjustment on net investment in the "stock" of nonproduction workers. The firm is assumed to produce output using capital and three variable inputs, labor (L) (or production workers (P) for the alternative specification), energy (E), and nonenergy inter- mediate materials (M). The firm's optimization process involves maximizing at each time t the present value of the future stream of profits given expected paths of the exogenous variables--output demand and input prices--and adjustment cost relations. This is accomplished sequentially (as in Morrison (1983a)) by minimizing variable costs for any output and quasi-fixed input levels, setting output price according to a short run condition of equality between marginal revenues and costs to determine the output level, and finally by choosing an optimal investment plan, conditional on the quasi-fixed input stocks at time t.

The firm's decisions are represented, given an explicit form for the variable cost function G, by a system of demand equations for its variable inputs, an output price equation, and investment equations analogous to (13) for the quasi-fixed inputs incorporating nonstatic expectations. Parameter estimation by maximum likelihood procedures results in a full specification of short and long run elasticities. Specifically, the model permits calculation of CU, ε_{Ct}, ε_{Cj}, $\varepsilon_{\dot{C}j}$, and ε_{CY}.[11]

In the first column of Table 1A, I report the conventionally measured index of the state of technology A_t. Productivity indices calculated from the adjusted productivity growth estimates are presented

in the next four columns for the one quasi-fixed input model as A_t', A_t'', A_t''', and A_t''''. Analogous productivity measures for the alternative two quasi-fixed input model, recognizing the short run fixity of both K and N, are presented in Table 1B.

Although these conventional year-by-year measures provide some indication of the post-1973 productivity slowdown, the impacts of the adjustments are not immediately evident. I therefore summarize the information contained in Tables 1A and 1B using average annual productivity growth rates over selected time periods; these are presented in Table 2. This temporal breakdown is based on the common divisions into time periods of pre-1965, 1965 to 1973, and post-1973.

The first point to note from Table 2 is that the measures calculated at the two levels of labor aggregation differ slightly. Over the entire time period 1949-1979, the traditionally measured average annual multi-factor productivity increase measured using four inputs, K, L, E, and M, was .83% per year, whereas once L is disaggregated into N and P productivity growth over this period appears one tenth larger--.90%/year. The post-1965 slowdown also appears more noticeable when both nonproduction and production workers are considered separately than when they are aggregated. This difference is largest precisely when the greatest compositional changes occurred within L; such changes are obscured by aggregation.

Overall, from either model, a substantial amount of productivity decline is evident since 1949-1965. A great deal of the productivity growth change, however, appears to have taken place before 1973, as was also noted by Norsworthy et al. (1979). In particular, although from

Table 1A

Total Factor Productivity Indices, One Quasi-Fixed
Input Model U.S. Manufacturing, 1972 = 1.0

Year	A_t	A'_t	A''_t	A'''_t	A''''_t
1949	.8149	.8197	.8176	.8116	.8255
1950	.8356	.8400	.8381	.8327	.8457
1951	.8518	.8560	.8541	.8490	.8613
1952	.8552	.8593	.8574	.8524	.8645
1953	.8660	.8699	.8680	.8633	.8749
1954	.8613	.8653	.8634	.8586	.8705
1955	.8871	.8904	.8888	.8849	.8951
1956	.8795	.8829	.8813	.8771	.8880
1957	.8742	.8778	.8762	.8720	.8831
1958	.8896	.8931	.8915	.8872	.8972
1959	.8953	.8987	.8971	.8928	.9024
1960	.9141	.9170	.9153	.9112	.9191
1961	.9172	.9200	.9183	.9143	.9218
1962	.9418	.9435	.9419	.9385	.9435
1963	.9396	.9415	.9399	.9364	.9416
1964	.9627	.9632	.9624	.9603	.9632
1965	.9699	.9700	.9696	.9680	.9704
1966	.9606	.9613	.9604	.9582	.9613
1967	.9596	.9603	.9594	.9571	.9603
1968	.9702	.9705	.9699	.9682	.9706
1969	.9745	.9748	.9742	.9727	.9747
1970	.9636	.9637	.9631	.9615	.9644
1971	.9782	.9785	.9781	.9770	.9788
1972	1.0000	1.0000	1.0000	1.0000	1.0000
1973	1.0262	1.0254	1.0265	1.0284	1.0266
1974	1.0155	1.0148	1.0158	1.0172	1.0165
1975	1.0078	1.0070	1.0079	1.0088	1.0088
1976	1.0258	1.0251	1.0267	1.0291	1.0278
1977	1.0408	1.0399	1.0421	1.0458	1.0436
1978	1.0474	1.0463	1.0492	1.0536	1.0513
1979	1.0546	1.0536	1.0572	1.0626	1.0604

Table 1B

Total Factor Productivity Indices, Two Quasi-Fixed Input Model U.S. Manufacturing, 1972 = 1.0

Year	A_t	A'_t	A''_t	A'''_t	A''''_t
1949	.7872	.7872	.7835	.7794	.7921
1950	.8018	.8009	.7977	.7939	.8062
1951	.8214	.8195	.8167	.8135	.8249
1952	.8322	.8299	.8270	.8240	.8346
1953	.8438	.8410	.8380	.8354	.8450
1954	.8488	.8458	.8431	.8406	.8501
1955	.8695	.8658	.8629	.8610	.8686
1956	.8658	.8622	.8593	.8574	.8654
1957	.8659	.8614	.8585	.8565	.8646
1958	.8905	.8879	.8863	.8838	.8909
1959	.8914	.8888	.8872	.8847	.8917
1960	.9148	.9126	.9115	.9093	.9143
1961	.9192	.9171	.9159	.9138	.9183
1962	.9439	.9419	.9406	.9392	.9411
1963	.9415	.9395	.9383	.9368	.9391
1964	.9673	.9651	.9656	.9645	.9666
1965	.9674	.9652	.9657	.9646	.9667
1966	.9591	.9570	.9574	.9562	.9586
1967	.9629	.9608	.9613	.9603	.9626
1968	.9758	.9743	.9738	.9732	.9740
1969	.9808	.9796	.9786	.9781	.9782
1970	.9768	.9750	.9739	.9734	.9737
1971	.9875	.9869	.9870	.9868	.9876
1972	1.0000	1.0000	1.0000	1.0000	1.0000
1973	1.0190	1.0194	1.0178	1.0185	1.0164
1974	1.0018	1.0012	.9999	.9996	.9990
1975	1.0022	1.0018	1.0004	1.0001	.9996
1976	1.0175	1.0187	1.0178	1.0181	1.0180
1977	1.0289	1.0308	1.0304	1.0312	1.0316
1978	1.0329	1.0351	1.0348	1.0356	1.0365
1979	1.0391	1.0420	1.0416	1.0426	1.0441

Table 2

Average Total Factor Productivity Growth Rates
Observed and Adjusted, U.S. Manufacturing, Selected Periods

Time Period	ε_{ct}	ε'_{ct}	ε''_{ct}	ε'''_{ct}	ε''''_{ct}
Only Capital Quasi-Fixed					
1949-1979	.00835	.00813	.00833	.00873	.00811
1949-1965	.01094	.01058	.01071	.01107	.01015
1965-1973	.00708	.00696	.00715	.00760	.00706
1973-1979	.00391	.00388	.00423	.00469	.00464
Capital and Non-Production Labor Quasi-Fixed					
1949-1979	.00900	.00909	.00923	.00943	.00895
1949-1965	.01297	.01282	.01316	.01342	.01253
1965-1973	.00651	.00686	.00659	.00682	.00629
1973-1979	.00280	.00313	.00331	.00335	.00385

Key: Alternative residual ε_{ct} Measures Based on Assumptions of:

ε_{ct} = residual measure: instantaneous adjustment, static expectations, no costs of adjustment, and CRTS

$\varepsilon'_{ct} = \varepsilon_{ct}/CU_{pv}$: static expectations, no costs of adjustment and CRTS

$\varepsilon''_{ct} = \varepsilon_{ct}/CU_{cv}$: no costs of adjustment and CRTS

$\varepsilon'''_{ct} = \varepsilon_{ct}/CU_{net}$: CRTS

$\varepsilon''''_{ct} = \varepsilon'''_{ct}/\eta$: Final

1949-1965 the average annual growth rate (AAGR) was 1.1% to 1.3%,

between 1965 and 1973 it dropped to .65% to .70%. From Tables 1A and 1B,

this appears to be a result of two significant declines in productivity,

one in 1966-1967 and another in 1970. Thus the AAGR over the sub-

period from 1965-1970 was negative--approximately -.1% to -.2%. This

period could be a strong contender for the title of "productivity

growth slowdown."

Compared to the 1965-1973 period, post 1973 the AAGR dropped

further, to approximately .41 to .44%--only about 35% of the productivity

growth rate observed in 1949-1965. This reflects, of course, the

celebrated recent "productivity growth slowdown." This productivity growth

slowdown is, however, driven by the productivity decreases of only a

couple of years. If, for example, a researcher in 1977 were considering

the productivity decline from 1973 it would appear much more imposing;

the 1973-1976 period exhibited a slight productivity decrease of

approximately -.01% per year. From 1976 on the AAGR in productivity

began to attenuate this evidence of stagnation; total factor productivity

between 1976 and 1979 again began to grow at about .7% to .9% per year,

close to that occurring between 1949 and 1965.

Hence there appear to be two periods when large downward shifts in

productivity growth occurred, namely, the late 1960's and the few years

subsequent to 1973. Together these result in a rather substantial overall

effect on 1965-1979 productivity growth as compared to the previous

fifteen years, but they do not present conclusive evidence of a unique

sudden slacking off of productivity growth post-1973 in U.S. manufacturing.

These trends in observed productivity growth are attenuted somewhat

by the impact of the adjustments outlined above. The first adjustment to
the productivity measure is that for subequilibrium. The empirical
significance of this adjusted productivity measure, reported as A_t' in
Table 1 and in terms of AAGR as ε_{ct}' in Table 2, differs across models.
With the adjustment, in the one quasi-fixed input model the residual
decreases in all sub-periods, but by the largest proportion in the
earlier years; part of the relatively large growth in productivity
observed in earlier periods appears to have been due to the effects
of subequilibrium. For the two quasi-fixed input model productivity
growth appears larger for both later time periods for A_t' than for
A_t, particularly for the 1973-1979 time period. This constitutes evidence
on the role of labor hoarding as well as fixity of capital in accounting for
subequilibrium effects.

The above results reveal a modest decrease in the dispersion of
productivity measures over time with the subequilibrium adjustment. In
addition, the late 1960s still appears as a period of poor productivity
performance and the two years after 1973 seem ever more catastrophic as
a result of large unexpected shocks, particularly for the two quasi-
fixed input model.

The second adaptation of the productivity growth measure to ε_{ct}''
is more dramatic. The adjustment for nonstatic expectations in the one
quasi-fixed input model results in a larger productivity residual for all
time periods—even larger than the unadjusted ε_{ct} measure for the two
later time periods. This suggests a tendency for anticipatory investment
to have a depressing effect on traditional productivity growth measures.
This same tendency is evident for the two quasi-fixed input model.

The distincition between subequilibrium adjustment to ε_{ct}' and the
further nonstatic expectations adjustment to ε_{ct}'' is that the former

reveals the impact of unexpected subequilibrium which is not properly accommodated--subequilibrium occurs in terms of present as well as current valued variables--whereas the latter documents the effect of anticipated changes. This implies that although when the firm is optimistic productivity measures adjusted for nonstatic expectations likely improve, at times when the firm's expectations are incorrect ε''_{ct} may fall. To illustrate the implications of this, reconsider the indices in Tables 1A and 1B. Although ε''_{ct} between 1973 and 1976 appears uniformly better than ε'_{ct}, events in 1974 still had very depressing effects as firms attempted to adjust to a subequilibrium resulting from unanticipated shocks in 1973.

The revision to account for total adjustment costs of ε''_{ct} to ε'''_{ct} simply augments, as expected, the trends found for the expectations adjustment. Specifically, when net investment corresponding to current exogenous variables is also purged, so that input use only for produced output and not investment is attributed to the productivity measure, productivity appears more robust over the entire period. In total, over the 1949-1979 period the combined effect of these revisions to ε_{ct} in the two quasi-fixed input model indicates that productivity growth was approximately .94% per annum in contrast to the .90% corresponding to contemporaneous observations. This tendency is even more pronounced for the final sub-period. The unadjusted measure indicates .28% AAGR over the 1973-1979 period, whereas with the three adaptations the AAGR becomes .335%, about a 20% increase. Results for the one quasi-fixed input model are similar.

Additional information about the first three adjustments may be

obtained by considering the alternative CU indicators directly. These indices are presented in Table 3 as CU_{pv}, CU_{cv}, and CU_{net} respectively for the two models. The most obvious difference among the indices is that the CU_{cv} and CU_{net} indicators reach values above unity less often than the CU_{pv} measure. As discussed further in Morrison (1984), this is a priori appealing; CU indicators including nonstatic expectations tend to fall short of unity any time the firm is investing additionally in anticipation of, for example, output increases not justified on the basis of current economic conditions.

Comparison of the overall patterns of the CU indices yields several other interesting implications. Consider the "preferred" two quasi-fixed input model CU measures. In the first few years and in the early 1960s $CU_{pv} > 1 > CU_{net}$, indicating optimistic investment and a shortage of capacity in terms of present value investment, even though current observation indicates excess capacity. In 1952 to 1953, 1955 to 1956 and 1963 there is a shortage of capacity in both present and current value terms, inducing additional investment. In the late 1950s and from 1967 on both CU_{pv} and CU_{cv} tend to fall short of unity, although CU_{pv} is typically closer to one. This indicates that although firms were optimistic about the future their optimism justified only cautious investment plans, since capacity was underutilized even in terms of present value. Finally, in 1969 and 1973 pessimism appears to have been prevalent; $CU_{pv} < 1 < CU_{cv}$, indicating a currently observed shortage of capacity which actually corresponds to a slight excess of available capacity given expectations of future conditions. The numbers for the one quasi-fixed input model are slightly different; they tend in

Table 3

Capacity Utilization Indices
U.S. Manufacturing

Year	CU_{pv}	CU_{cv}	CU_{net}	CU_{pv}	CU_{cv}	CU_{net}
	One Quasi-Fixed Input			Two Quasi-Fixed Inputs		
1949	1.0225	1.0198	.9989	1.0595	.9968	.9741
1950	1.0232	1.0135	.9807	1.0594	1.0227	.9900
1951	1.0243	1.0188	.9898	1.0504	1.0216	.9910
1952	1.0247	1.0168	.9888	1.0402	1.0475	1.0230
1953	1.0272	1.0192	.9917	1.0439	1.0503	1.0092
1954	1.0241	1.0195	.9934	1.0195	.9644	.9488
1955	1.0310	1.0155	.9762	1.0340	1.0406	1.0028
1956	1.0302	1.0184	.9786	1.0155	1.0396	1.0046
1957	1.0206	1.0208	1.0149	.9924	.9793	.9662
1958	1.0083	1.0084	1.0097	.9579	.9098	.9261
1959	1.0211	1.0198	1.0024	.9842	1.0128	.9914
1960	1.0304	1.0307	1.0183	.9801	.9600	.9459
1961	1.0321	1.0313	1.0081	.9755	.9871	.9739
1962	1.0466	1.0439	1.0110	.9942	.9953	.9673
1963	1.0539	1.0409	.9927	1.0049	1.0346	1.0039
1964	1.0614	1.0231	.9606	1.0097	.9438	.9291
1965	1.0069	.9983	.9351	1.0304	.9396	.9519
1966	1.0604	1.0024	.9371	1.0013	.9930	.9879
1967	1.0444	1.0173	.9620	.9710	.9582	.9314
1968	1.0307	1.0000	.9448	.9566	1.0300	.9986
1969	1.0232	1.0096	.9651	.9405	1.0584	1.0109
1970	.9892	.9863	.9708	.8815	.8721	.8719
1971	.9884	.9756	.9374	.9007	.8169	.8070
1972	1.0162	.9966	.9498	.9543	.9622	.9428
1973	1.0324	.9906	.9237	.9759	1.0651	1.0233
1974	1.0192	1.0111	.9641	.9456	.9587	.9075
1975	.9806	.9644	.9112	.8726	.8234	.8241
1976	.9956	.9589	.8904	.9070	.8799	.8509
1977	1.0148	.9716	.9001	.9377	.9024	.8733
1978	1.0136	.9289	.8439	.9361	.9210	.9041
1979	.9996	.9041	.8079	.9050	.9122	.8905

general to be higher, and do not capture such phenomena as the pessimism
of 1969 and 1973.

The last productivity adjustment to consider is that for NCRTS. The
AAGR for ε_{ct}'''' is the final column of Table 2 indicate that although
overall productivity growth estimates 1949-1979 are substantial with
effects of scale economies purged, this is not true for 1973-1979. In
fact for the two quasi-fixed input case the reverse is true for 1973-1979.
The difference in growth rates for both models between the earlier and
later years is diminished further with this adaptation.

Recall that this scale adjustment recognizes the difference between
decreasing costs due to (i) pure technical progress and (ii) scale
economies. Over the 1949-1973 time period on average both of these
effects were evident. As a result, removing the scale effect imputes a
lower growth rate to technical progress. However, when output grows at a
lower or negative rate, the reverse can occur, i.e., lower productivity
growth is incorrectly attributed to reductions in the growth rate of
technical progress. During the sluggish growth years of 1973-1979 this
appears to have occurred; productivity change adjusted for this effect
increases to over 40% of the observed productivity change 1949-1979, and
to over 60% of that observed from 1965 to 1973.

In summary, empirical decomposition of the productivity residual to
isolate the technical progress effects independently of subequilibrium,
anticipatory behavior, and economies of scale yields important overall
conclusions. These include: (i) the anomaly of the observed post-1973
productivity growth slowdown measured using conventional methods appears
overstated; (ii) the primary impact generating this measured result is,

in a one quasi-fixed input model, that of anticipatory expectations; however, if the model incorporates two quasi-fixed inputs then the primary cause is that of subequilibrium, and (iii) the productivity growth slowdown appears to have begun earlier than 1973, perhaps as early as 1965.

This empirical exercise indicates that distinct effects of various components of observed productivity growth can be identified using the procedures developed in this paper, and illustrates the richness of the decomposition framework. Significantly, the adjustments do not necessarily decrease the productivity residual or "measure of our ignorance." In fact, overall they increase the residual in all periods discussed. Nonetheless, they do indicate that much of the relative productivity growth slowdown can be attributed to a combination of these impacts.

IV. CONCLUDING REMARKS

In these concluding remarks I briefly summarize how different

existing approaches to subequilibrium productivity measurement can be

viewed as special cases of the model developed here.

In many previous studies researchers have attempted to purge

cyclical effects from their productivity calculations by comparing only

"peak" years in the cycle. The justification offered for such a

procedure is that CU rates are at their maximum so that variations from

this level are not a factor affecting productivity growth. The theo-

retical model outlined in this paper suggests that this approach is

valid <u>provided</u> measured CU is the same in each of these peak years.

The framework presented here also reveals that CU, calculated

appropriately, involves a total output or total cost measure and thus

adjusts all input shares in the productivity calculation rather than

only one input, say capital. However, if utilization only of capital is

varying, this approach justifies the use of a capital utilization

measure to adjust the capital share in productivity calculations, as long

as the shares are re-scaled to equal unity. For example, the method

advocated by Berndt and Fuss (1981) is a special case of the capacity

utilization approach presented here, where the shadow value of capital--

represented by Tobin's q--is interpreted as a measure of the utilization

of capital compared to its long run equilibrium. Similarly, Hulten

(1983) presents a method of adjusting productivity measures for

capital utilization by recognizing shifts in cost curves from the

short run revaluation of capital.

More generally, the cost CU measure with one quasi-fixed input not

only includes all the information contained in Tobin's q--for both indicators depend on a comparison between z_k and p_k --but also is directly dual to the quantity side. The primal output CU measure, incorporating the effects of utilization of the quasi-fixed input(s) on output, also depends on the deviation between z_k and p_k. The shadow revaluation concept and the more conventional quantity-based capacity utilization adjustment can thus be recognized and reconciled as "two sides of the same coin."

In addition, with only one quasi-fixed input, capital, cost or output CU measures are a function only of capital utilization. In the more general case with multiple quasi-fixed inputs, the economic derivation of CU measures provides a justification for optimally weighting the utilization of the individual quasi-fixed inputs into an overall CU subequilibrium measure, and therefore contains more information than Tobin's q.

The incorporation of nonstatic expectations into the models is also important. The existence of nonstatic expectations implies that if firms expect increases in output demand or input prices that will increase present value costs of investing in the future relative to the present, current anticipatory investment will be carried out which will appear excessively high given current levels of capacity. This will result in lower levels of CU and lower levels of productivity for variable inputs than if the firm were myopic.

Empirically this framework provides a useful structure within which to assess the productivity residual by identifying independently the effects that should not be attributed solely to technical progress. Although this study does not provide an explanation of the residual in the

sense that the residual after the adjustments is larger than before, it does provide important insights. Analysis of the productivity residual suggests, for example, that even with CU adjustments the productivity slowdown commenced at an earlier date than is often assumed. Since dating the "productivity slowdown" and the impact of CU adjustments on this dating is a point of contention in the literature, the framework presented here is particularly relevant for assessing the alternative arguments.

In summary, the integration of the various technical and behavioral impacts considered in the model developed here provides a systematic framework that incorporates a number of existing approaches as special cases. It therefore provides a useful framework within which to assess, both theoretically and empirically, productivity growth and its inter-relation with cyclical indicators such as Tobin's q and CU. Finally, it is a particularly useful structure within which to pursue more extensive empirical research on comparison of differential interna-tional productivity trends and analysis of more micro data such as that for electric utilities, where the interactions between productivity and CU and the effects of fixity of different inputs are of crucial importance.

FOOTNOTES

1   See Morrison (1984) for a related discussion of the use of this shadow value of investment. Note that the use of the gross value of capital $Z_k K = -G_k K$ or the net value $Z_k K = -(G_k K = G_k^{\cdot} \dot{K})$ depends on the relevant problem and interpretation. The net value should be used when the dynamic optimization framework is explicitly characterized, but in principle adjustment costs are not observed and therefore may not be picked up in conventional measures. This provides one reason firms may appear to be further from optimal Y than is actually the case; Morrison (1984) shows that the gross measures more closely pick up trends in the traditional measures. Numerically, however, for the output and cost-CU indices the results differ very little between the net and gross specifications.

2   See Berndt, Fuss and Waverman (1979) for an extensive discussion of these types of elasticities.

3   The form of this representation for ε_{cy} was developed in Morrison (1983c) from Lau (1978) with only one quasi-fixed input and no dynamic behavior. This results in $d\ln C/d\ln Y = \partial C/\partial Y (Y/C) + \partial C/\partial K (dK/dY)(Y/C) = 1$, since with CRTS $d\ln K/d\ln Y = 1$. Thus $\varepsilon_{cy} + \varepsilon_{ck} = 1$ with CRTS. The generalization is consistent with Lau's analysis.

4   Although it is not as obvious, (5) represents a conventional ε_{ct} measure even without long run equilibrium imposed. To see this rewrite (5) as:

$$(5a) \qquad \varepsilon_{ct} = \frac{\dot{Y}}{Y} - \Sigma_j \frac{p_j x_j}{C} \frac{\dot{x}_j}{x_j} - \Sigma_i \frac{w_i v_i}{C} \frac{\dot{v}_i}{v_i} + \Sigma_j \varepsilon_{cj} [\frac{\dot{x}_j}{x_j} - \frac{\dot{Y}}{Y}]$$

$$+ \Sigma_j \varepsilon_{cj} [\frac{\ddot{x}_j}{\dot{x}_j} - \frac{\dot{Y}}{Y}] \quad .$$

The first term on the right hand side of (5a) is the traditional characterization of long run productivity. The latter two terms capture the adjustment of the "augmented" quasi-fixed input stocks to the "desired" level corresponding to exogenous variables including the new output level and includes the costs of this adjustment represented by $\ddot{x}_j/\dot{x}_j$. Because of CRTS it must be the case both that $\dot{x}_j/x_j - \dot{Y}/Y = d\ln$ $x_j - d\ln Y = 0$ and $\ddot{x}_j/\dot{x}_j - \dot{Y}/Y = d\ln \dot{x}_j - d\ln Y = 0$ for all j.

5   For further discussion of net versus gross shadow values and their empirical content, see Morrison (1984).

6   The ideas that this measure is based on are developed further in Morrison (1983d) for one quasi-fixed input, capital (K).

7   See Morrison (1983c).

8   The basis for this assertion stems from Morrison (1983b) and
Nickell (1978), where it is shown that the path of capital, or the
investment plan given a current capital stock, can be represented by a
flexible accelerator adjustment path toward the current "target" capital
stock defined in terms of current exogenous variables plus a term
capturing the effect of all future exogenous variable changes.

9   J is defined within the framework of Morrison (1984) as:

$$(13a) \quad \frac{1}{\lambda G_{\dot{K}\dot{K}}} \int_t^\infty e^{(\lambda-r)(s-t)} ((G_{KK}+rG_{\dot{K}\dot{K}})(K_s^*-K_t^*)+G_{K\dot{P}}\dot{P}_s+G_{K\dot{Y}}\dot{Y}_s)ds \quad ,$$

where λ is a diagonal adjustment matrix dependent on r and the
parameters of the variable cost function G. Variable input demands in
turn depend on current variables including the current levels of invest-
ment in quasi-fixed factors.

10   The data on prices and quantities of output, capital, nonproduction
and production labor, energy and intermediate material inputs for U.S.
Manufacturing 1947-1981 were graciously provided by Ernst R. Berndt and
David O. Wood. For a discussion of these data, which were constructed
similarly to those reported in Berndt and Wood (1975), see Berndt and
Wood (1984).

11   Note that any model which allows these elasticities to be calculated
may be used as the basis for empirical application of this decomposition
procedure. For example, any econometric model based on a short run or
"restricted" cost function allowing for NCRTS can be used to determine
the impact of subequilibrium and NCRTS on productivity. Distinguishing
the effects of adjustment costs and nonstatic expectations, however,
requires a full dynamic model and an explicit expectations process
respectively.

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