THE U.S. PRODUCTIVITY SLOWDOWN: A PEAK THROUGH THE STRUCTURAL BREAK WINDOW

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This paper provides a formal test of the null hypothesis of a unit root in the log-level of labor productivity against the alternative of linear trend stationarity with a one-time structural break in the level and slope of the trend at an a priori *unknown date. Using some newly developed time series tests, we show that the log-level of productivity is more accurately modeled as following a deterministic trend with a regime shift rather than as a unit root process. Some implications of the results for detrending and for testing cointegration relationships between productivity and other variables are discussed.* (*JEL* C22, O40)

I. INTRODUCTION

Productivity (total and labor) plays a prominent role in theories of economic growth, business cycles and labor demand. It is also widely accepted that productivity growth, whatever its cause, is a key determinant of the rate of increase in per capita output and living standards. It is thus not surprising that the productivity slowdown in the United States and elsewhere since the early 1970s continues to be a significant source of concern to economists and policy makers. According to one recent estimate, the slowdown has reduced current consumption by nearly 30%.[1] The productivity slowdown experienced in the United States during the post-war period is far from unique since many other industrialized countries have experienced a similar slowdown. More important, the severity of the productivity decline in the United States appears to be mild in comparison to other countries. While these observations are often made to emphasize that the problem faced by the U.S. is far from unique or severe, the concerns about competitiveness and the perceived decline in living standards in the United States have generated a rather pronounced and persistent negative reaction from the media as well as from some politicians. A possible explanation for the pronounced reaction in the United States to the productivity decline may largely be due to the persistent trade deficits being experienced by the country. There is a perception that the productivity slowdown will have an adverse long term effect on living standards.

Evidence based on growth accounting methods, to be reviewed later on in the paper, supports the view that reduced productivity growth was the primary factor for the slow-

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1. See De Long and Summers [1992].

ABBREVIATIONS

AIC: Aikake Information Criterion
GDP: Gross Domestic Product
GMM: Generalized method of moments
SC: Schwartz Criterion
TFP: Total Factor Productivity
WLU: Wilfrid Laurier University

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down of output growth in the U.S. and a number of other countries. This evidence is particularly important in that it absolves slower growth of inputs such as capital or labor as contributing factors of a slowdown in output growth. However, it introduces a puzzle as to what caused a slowdown in productivity since about 1973. While the causes and consequences of the productivity slowdown in the United States have been extensively analyzed, the slowdown continues to remain somewhat of a puzzle. Specifically, a wide variety of explanations have been offered for the productivity slowdown, with little consensus as to a clear-cut culprit. Moreover, the productivity slowdown appears to be at odds with a number of recent models of economic growth. We will have more to say about these issues later on in the paper. For the time being it suffices to say that most studies appear to informally support the view that a productivity slowdown did take place during the 1970s. The argument is so pervasive that the slowdown is often accepted as a stylized fact.

This paper has two objectives. The first objective is to present empirical evidence based on post-War annual data from 1947–1992 in support of the premise that the time series of the logarithmic level of the labor productivity variable in the United States (hereafter labor productivity) is not a difference-stationary process. Pretesting for unit roots in productivity in order to assess its long-run features is important due to the importance which the presence of a unit root can have for economic forecasting, macroeconomic modeling using the cointegration framework, and tests of Granger causality. We will present formal tests evidence that both supports and refutes the claim that the log-level labor productivity is a first-difference stationary process. The support for the null hypothesis of a unit root process in the labor productivity variable—against the alternative hypothesis of a linear trend stationary process—is found when the familiar Dickey-Fuller test is applied. However, a valid use of the conventional Dickey-Fuller test requires assumptions that the regression utilized for the test is correctly specified, which may not hold if the premise of a productivity slowdown is accepted. Moreover, the failure to allow a role for the productivity slowdown can introduce an uncertainty of a unit root in the first-difference of the labor productivity variable, especially if the productivity slowdown had a growth rate effect on the variable.

The uncertain unit root in the labor productivity growth series view, if true, has important implications for linear regression analysis involving the labor productivity growth variable. Regressions involving this variable have often been the focus of a number of recent econometric studies. Such studies either evaluate competing theories of business cycles (e.g., see Bernanke and Parkinson [1991]) or evaluate the reasons for the productivity slowdown (see Shapiro [1987]). A potential pitfall with such studies is that an uncritical use of regression analysis may involve the problem of "near-inconsistent regressions" according to the terminology of Mankiw and Shapiro [1985]. In other words, regressors and dependent variables are likely to be of different orders of integration, leading to inconsistent estimates (see Granger and Newbold [1974] and Phillips [1986]). The significance of the above problem follows directly from the results of analysis corresponding to the "spurious regression" problem since the near-inconsistent regression can be regarded as a special type of spurious regression.

The second objective of this paper is to empirically evaluate whether post-war annual data for the logarithm level of labor productivity can be more accurately characterized as a trend stationary process with a one-time shift in both the level and slope in a deterministic trend as opposed to a unit root process. To that end, we present some formal statistical evidence in support of the hypothesis that the log-level of productivity is a trend stationary process with a change in level and slope of the linear trend in the early seventies. Since the timing of the break cannot be interpreted as independent of the data, nor is it easy, as we argue below, to associate the structural break to a particular event, we follow the recent literature on unit root testing, which extends the important contribution of Perron [1989] in treating the break point as an unknown parameter to be estimated from the data. This treatment is designed to avoid biasing the results in favor of the structural shift hypothesis *ex post* (see Banerjee, Lumsdaine, and Stock [1992]; Christiano [1992]; Zivot and Andrews [1992]; Perron [1997]). The conclusion of stationarity about a broken trend has important implications for detrending the series and for modeling comovements of productivity with related variables.

Recent empirical evidence on structural breaks includes Ben-David and Papell [1995], who examine very long time series data for several countries and identify trend breaks in countries' levels of real GDP in the period spanning the two World Wars and the Great Depression. Another related paper by Bai, Lumsdaine and Stock [1991] focuses on obtaining relatively more efficient estimates of the year of break. In our analysis, the relative efficiency of the estimate of the break point is secondary to the main issues addressed.

One of the implications of our result is that only a large shock occurring around 1973 had a permanent effect on labor productivity, while all other shocks had transitory effects. This result contrasts with the view, widely held since the study by Nelson and Plosser [1982], wherein most shocks have permanent effects on macroeconomic time series.

The rest of the paper is organized as follows. In section II we present some background on the productivity slowdown, briefly reviewing some stylized facts, suggested causes and relation to theory. In section III, after introducing the definition and source of data, we present empirical results from the tests of the hypotheses of stationarity and unit root for the labor productivity growth series. We discuss the motivation for testing the null hypothesis of a unit root in the log-level of labor productivity against the alternative of trend stationarity when the deterministic trend is subjected to a one-time crash-cum-growth change at an unknown point in time, as well as the test methodology, in section IV. In section V we present the empirical results for this test, both for the entire sample as well as for some sub-samples. The results for the subsamples help to provide evidence of robustness of the results from the full sample to excluding other possible large shocks. We offer some conclusions in section VI.

II. SOME BACKGROUND: STYLIZED FACTS, EXPLANATIONS, AND THEORY

The issue of whether business-sector output and labor productivity experienced a slowdown in the United States, and virtually all industrialized countries has been the subject of considerable debate and analysis. The investigation of causes of this slowdown and its consequences for economic policy has generated a considerable amount of literature (see Williamson [1991]). Some of the issues related to this paper were reviewed and summarized by two recent symposiums, one symposium organized by the *Journal of Economic Perspectives* (see Fischer [1988]) and the second sponsored by the Federal Reserve Bank of Kansas City (see Shigehara [1992]).

The use of growth accounting methods for annual data from 1960–1990 for the United States and a number of OECD countries has produced a number of stylized facts. One stylized fact is that sources of growth in the Gross Domestic Product (GDP) in the United States and several other OECD countries have changed over time. A second stylized fact is the productivity slowdown occurred in the United States in early seventies. Also, the slowdown in the rate of growth of GDP is due largely to the slowdown in productivity. Lastly, the slowdown in productivity was not unique to the United States but shared by several OECD countries.[2]

The existence of a productivity slowdown raises several important questions. What caused the widespread slowdown in productivity? Is productivity a trend stationary or a difference stationary process? The latter question is related to the issue of whether shocks to productivity have permanent or transitory effects, an issue of some importance both in econometric modeling involving the labor productivity series and in some areas of economic theory. Whether shocks to productivity have permanent or transitory consequences has ramifications, for example, for the construction and calibration of models of business cycles in which exogenous shocks to technology serve as a source of fluctuations.

As to the question of cause, there have been many candidate explanations proposed for the observed slowdown in productivity growth in the United States. The international scope of the slowdown as well as its apparent coincidence with the first oil price shock of 1973 led early observers to look for the source of the slowdown in the higher price of oil, though the past decade of cheap oil has not

2. See, for example, Shigehara [1992], Table 1.

been accompanied by a return to pre-1973 rates of productivity growth (see, for example, Hulten, Robertson and Wycoff [1987], and Jorgenson [1988]). Among the other suspects which have been investigated are: measurement problems (Baily and Gordon [1982], or Darby [1992]); changes in the legal environment, such as environmental legislation and worker health and safety regulations (Denison [1982]); changes in the growth rate of the labor force or its quality (Bishop [1989]); a slower rate of innovation or a failure to translate innovation into productivity-enhancing technologies (Nordhaus [1982] and Griliches [1994]); a slower adaptation to high-tech production methods resulting from the information technology revolution (David [1990] and Greenwood and Yorukoglu [1997]).

Most of these investigations have been conducted outside the context of explicit models of economic growth, whether of the neoclassical variety or models of the "new growth theory." In fact, many of the proposed explanations pre-date the new growth theory, which began with the contributions of Romer [1986] and Lucas [1988]. By the same token, though, few models in the new theory have attempted to tackle the productivity slowdown.[3]

It is important to point out that the productivity slowdown is not necessarily incongruent with the neoclassical growth theory, which takes the path of technological change as exogenously given. Still, the fact that the neoclassical model does not explain technological change does not mean that we cannot have presumptions about what are plausible or implausible paths for it to take. For example, in a reasonably parametrized Solow model, a near-total cessation of exogenous technological progress is needed in order to reduce the average growth rate of labor productivity from an initial steady state growth rate of 2.2% down to .4% over the subsequent 17 years—i.e., in order to replicate the U.S. experience for the two periods 1960–1973 and 1973– 1990. This is due to the model's transitional dynamics—because the economy adjusts gradually to the new steady state, if labor productivity is to average .4% per year over a short transitional period, the new growth rate of technological progress must be much less than .4% per year. Few observers of the U.S. economy would conclude that technological progress stopped sometime in the mid-1970s.

Also, as Griliches [1988] has noted, the fact that the slowdown is less pronounced in manufacturing—where one would imagine that technological progress plays a more important role—makes it difficult to accept explanations based on hitting the limits of technological advance.

Barring extreme changes in the growth rate of exogenous technological progress, there is not much scope for even fairly complicated variants of the neoclassical model to rationalize the productivity data. This is because growth rates in the neoclassical model are largely robust to exogenous interventions. There are many conceivable changes in economic conditions which will yield level effects, but not growth rate effects, except in transition. If transitional dynamics are rich enough, one can get fairly persistent changes in growth rates along transitions between steady states, but most computational evidence suggests the transitional dynamics in the neoclassical model are fairly weak. There is a trade-off here, too, in that for a given change in conditions which creates a level effect, the magnitude of the resulting transitional changes in growth rates is inversely related to the persistence of the transitional period.[4]

More disconcerting for the neoclassical model is the negative correlation between labor force growth and productivity growth when one looks at 10 to 20 year averages—sufficient time, one would suspect, to imagine that we are viewing at the least close approximations to steady states.[5] According to almost any version of the neoclassical model, productivity growth and labor force growth should be uncorrelated at that low a frequency. As Romer [1987] notes, even allowing for the possibility that we are not observ-

3. To put things in perspective, recall that Romer's initial increasing returns model was motivated by the very long run observation that rates of output growth in countries such as the United States, recent decades excepted, have been accelerating.

4. See Plosser's contribution to the Kansas City Fed symposium (Plosser [1992]). On the scope of transitional dynamics for explaining observed growth more generally, see King and Rebelo [1993].

5. This fact is noted in Romer [1987].

ing steady states, the response of the growth rate of labor productivity to a change in the growth rate of the labor force should still be small, if the elasticity of output with respect to the labor input is taken to be on the order of 2/3, the standard figure based on labor's share of national income. Romer offers some suggestions—based on a model where labor force size affects the incentives to invest in knowledge which substitutes for, rather than complements labor—as to why the elasticity of output with respect to labor may be quite a bit smaller than labor's share of national income. This suggests a possible explanation for the productivity slowdown as a consequence of an exogenous change in the growth rate of the labor force.

While the scope for changes in economic conditions to have growth rate effects is wider in 'endogenous growth' models, the productivity slowdown must still be viewed as something of a stumbling block for a number of them, particularly the R&D-based "endogenous technological change" models a la Romer [1990] and Aghion and Howitt [1992]. As is now well-known, these models contain 'scale effects'—ceteris paribus, increases in the *level* of resources devoted to R&D imply increases in growth rates. Given the continual increase in the amount of resources devoted to R&D activities in the U.S. throughout the post-World War II period, these models actually predict increasing rates of growth, other factors equal of course. If we assume that these models are even approximate descriptions of reality, then the magnitude of the offsetting changes in "other factors," which are not held equal in the data, must be quite large.

A recent exception in the endogenous technological change literature is the R&D-based model of Jones [1995], which is potentially consistent with the productivity data. In Jones's model, a permanent increase in R&D's share of output triggers a transitional path with an initially increasing, then declining rate of growth of labor productivity. Eventually, the growth rate of labor productivity falls back to its initial level. The immediate post-war period did coincide with a rough doubling in the measured share of R&D expenditures in U.S. output.[6] According to this interpretation, the decline in the rate of labor productivity growth from the high levels experienced in the first two decades of the post-war period can be understood as transitional dynamics rather than the result of a break in the process generating the productivity data.[7]

A second strand of endogenous growth models are the so-called "broad capital" models, which follow Lucas [1988] and Romer's original [1986] paper in achieving endogenous growth by broadening the definition of capital, typically by adding "human capital" as a reproducible factor of production, and arguing that diminishing returns do not set in for the resulting broader concept of capital.[8] Here too, the models in principle have a good deal of room for changes in conditions to generate sizable changes in growth rates. The bulk of the comparative dynamics exercises performed thus far for models of this sort have focused on the growth effects of fiscal policies, particularly factor income taxes, and inflation.[9] If the models ascribed large growth consequences to inflation, for example, we would have at least one potential explanation for the slowdown within this class of models. Another might lie in the models' responses to factor income taxes, which can sometimes be viewed more broadly as proxies for aspects of the legal or regulatory environment which weaken property rights.

The latitude for growth rate effects in these models, however, does not always translate into substantial effects of changes in either taxes or inflation when the models are given particular parametrizations. For example, if, to be consistent with the U.S. growth experience, models of this class are parametrized to be robust to a large intervention like the permanent and sizable increase in income taxes which occurred in the 1940s, it is difficult to imagine a single, isolated change in tax rates or the legal environment in the 1970s which could lead to changes in growth rates of the

6. As Jones notes, though, it is not entirely clear whether or not that increase in R&D's share was simply a measurement artifact. In particular, some portion of that increase may just reflect a re-labeling of job titles.

7. See also Young [1998]. In Young's model, if R&D leads to an increased variety of solutions to the same problem, additional resources devoted to R&D will lead to higher welfare but not faster growth.

8. For example, the papers of King and Rebelo [1990], Rebelo [1991], and Jones, et al. [1993].

9. See the papers of Stokey and Rebelo [1995] or Dotsey and Ireland [1996], and the references therein, for recent analyses of factor income taxation and inflation, respectively.

magnitude actually observed.[10] Likewise, Dotsey and Ireland [1996], using a variant of Romer's [1986] model, find only modest growth rate effects of inflation.

One conclusion which we might draw from this discussion is that while for many models of economic growth few exogenous changes in conditions, taken in isolation, seem capable of generating a quantitatively significant decline in productivity growth. It is possible that the confluence of several such changes—agglomerated into a 'shock' on a large scale—could have a significant quantitative effect. Moreover, for some of the models—the 'scale effect' R&D models—rationalizing the productivity slowdown most likely demands a very large shock with effects at some deep level. As Griliches [1988] states in reviewing some of the evidence for competing explanations, "Of course, there may not be a single cause—one murderer. Perhaps it is more like the Murder on the Orient Express—they all did it!" The idea of a confluence of more than one event is in line with our empirical methodology, which considers a large shock at an *a priori* unknown date; if we knew at the outset on the basis of theory that the oil price shock of 1973 was the only possible candidate shock, then we would certainly know its timing. The possibility that the slowdown had multiple causes thus buttresses the econometric case—based on the known biases in hypothesis tests of a unit root against a broken trend with an exogenously specified break date—in favor of estimating the timing of the shock from the data.

Our perspective, then, is this: we view the oil price shock of 1973 as but one dimension of a large composite shock to productivity—where the other dimensions might involve changes in the legal or regulatory environment, changes in the growth rate of the labor force, inflation, and so forth. We follow recent literature in treating the occurrence date of this shock as an unknown parameter to be estimated from the data instead of exogenously selected after the data has been observed or referring to past studies. One of our objectives as stated in the introduction is to analyze the time series properties of productivity when the occurrence of this shock is treated as an episodic event. In summary, we treat two types of shocks to productivity—a large, rare shock and other regular shocks—from two different distribution functions. We provide some formal evidence in support of the premise that the trend in the log-level of productivity is linear except for a sudden change in its level and slope around 1973. In addition, it is argued that once the break in the trend function is allowed and the "demeaned" growth in productivity is obtained for calculating a measure of persistence as suggested by Cochrane [1988], it is easily shown that the effects of all shocks except for the large shock are largely transitory (see Perron [1993] for some related evidence).

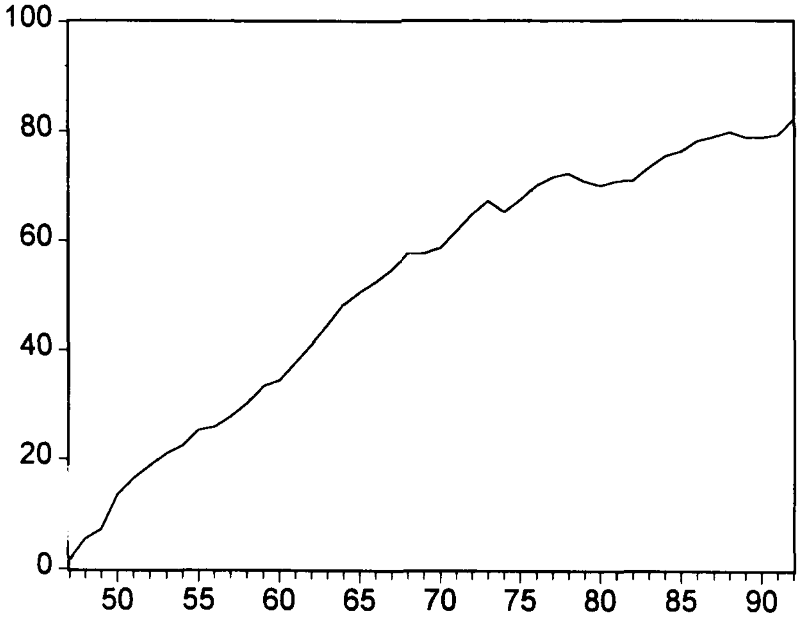
III. THE DATA ON LABOR PRODUCTIVITY AND THE UNCERTAIN UNIT ROOT HYPOTHESIS

The annual time series data from 1947–1992 used in this study were obtained from the Bureau of Labor Statistics and are reported in the *Economic Report of the President*. Labor productivity is defined as output per hour of all persons in the non-farm business sector (this sector includes everything except government operations, non-profit organizations and agriculture). Growth in productivity, from a growth accounting standpoint, depends upon growth of the capital-labor ratio and growth in total factor productivity. We do not consider total-factor (or multi-factor) productivity (TFP)—where trends have generally moved in line with labor productivity in the United States—in this paper, since its measurement is more controversial. Moreover, while the use of the TFP measure is often preferred at the conceptual level by economists, its use is less popular in policy circles. Moreover, data on TFP are sometimes not available at all, and even when the data are available, a long time series is not available and they are slow to be updated.

The time plot of logarithmic level of labor productivity, y_t, is given in Figure 1. The plot shows that the productivity variable has considerable persistence. Moreover, the persistence is inadequately represented by the canonical empirical representation for the variable as a linear deterministic trend. This is evidenced from the behavior of the first eight sample autocorrelations of the residuals from

10. This parametrization exercise is carried out in Stokey and Rebelo [1995].

FIGURE 1
The Time Plot of the Logarithmic Level of Labor Productivity in the U.S., 1947–1992



a regression of the log-level of labor productivity variable on a linear trend, which are: 0.89, 0.77, 0.64, 0.55, 0.48, 0.40, 0.33 and 0.25. These sample autocorrelations decay very slowly, suggesting that labor productivity in the United States is more likely characterized as a unit root process instead of a linear trend stationary process.

This conjecture is confirmed when the familiar Dickey-Fuller test of the null of a unit root against the alternative of trend stationarity is performed. The use of this test yields a test statistic value of $\tau_\tau = -0.886$ for the truncation lag value of k equal to six, which is smaller than the critical value for the asymptotic distribution of the test statistic of –3.53. In performing this test, the value of the truncation lag was determined using the data-dependent method called the 't-sig' by Ng and Perron [1995]. This data-dependent method for selecting the lag length k has been shown to lead to the unit root test statistic having stable size and good power as compared to other data-based selection methods based on the information criterion such as the AIC (Hall, 1994). The 't-sig' procedure for the selection of k follows a general-to-specific recursive method, starting with a regression including lags up to some maximum order—say, $k = 8$—and eliminating lags until the t-statistic on the last lag is significant at some level and all greater (up to the maximum order) are insignificant. Significance of the last lags is determined from a two-sided 10% test based on the asymptotic normal distribution.

It is important to note that a failure to reject the null hypothesis of a unit root result is not sensitive to the method of lag order selection of just used. Both the Schwartz (SC) and Aikake (AIC) information criteria for selecting the lag length are minimized at zero lags, in which case the value of the test statistic is $\tau_\tau = -1.40$. In fact, the sample values of τ_τ are well within the 5% acceptance region for all truncation lag lengths from zero to eight.

This result is hardly surprising given that many macroeconomic time series have been known to have this characteristic, as shown by Nelson and Plosser [1982], using Dickey-Fuller-type tests. If the result that the labor productivity variable is difference stationary is true, then it would imply that all shocks to productivity have a permanent effect. Furthermore, it would suggest that fluctuations in the first-difference of labor productivity are stationary around a constant mean.

The evidence presented above is, however, in conflict with other empirical evidence showing that productivity in the United States experienced a structural break during the early seventies. Failure to model the influence of a productivity slowdown may have biased the test results in favor of a unit root hypothesis, if we use arguments similar to those in Perron [1989]. Below we present two kinds of formal test evidence to show that productivity in the United States has an uncertain unit root.

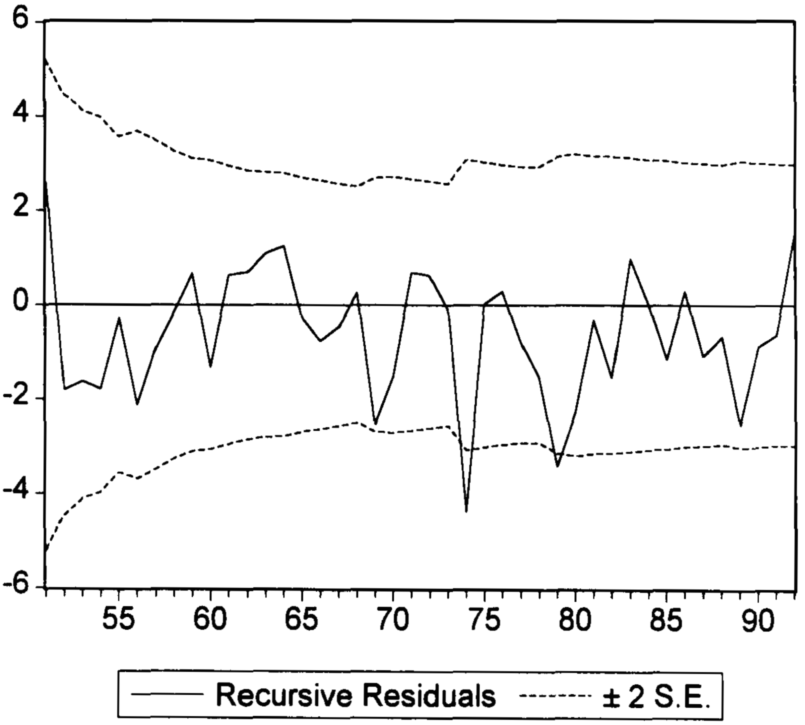
One kind of evidence utilizes the test framework proposed by Dickey and Pantula [1987], who have emphasized the need to ensure that the variable does not have a second unit root before accepting the test evidence of a unit root. Their advice requires first testing the null of a unit root in the first-difference of the labor productivity variable. The test of the null hypothesis of a unit root in the first-difference against the alternative of trend stationarity with an intercept, using an augmented Dickey-Fuller test, rejects the null hypothesis. Specifically, the sample value of $\hat{\tau}_\mu = -4.79$ is obtained for the first-difference productivity variable, which is less than the critical value of –2.93 for the asymptotic distribution at a 0.05 significance level for a truncation lag of $k = 0$. Once again we have used the t-sig sample-based method for selecting the truncation lag; the null is also rejected if k is selected using the AIC ($k = 2$) or SC ($k = 0$).

However, an opposite conclusion is obtained when the test framework developed by Kwiatkowski, Phillips, Schmidt and Shin [1992] is used. These authors recommend testing the null of level stationarity against the alternative of a unit root for the variable. The use of Kwiatkowski [1992] et al.'s testing framework produced a value for the test statistic of $\hat{\eta}_\mu = 1.161$ corresponding to truncation lag-length of $k = 0$, analogous to the choice of lag for the Dickey- Fuller test. The use of this test rejects the null of trend stationarity at the 0.05 significance level since the sample value of the test statistic exceeds the asymptotic critical value of this test statistic of 0.463 as tabulated by Kwiatkowski [1992] et al. This conclusion is robust to any choice of lag length up to a maximum of $k = 8$.

Thus, the use of two different testing frameworks yields opposite conclusions about the time series properties of the first-difference of labor productivity, casting doubt about the validity of the unit root test result in labor productivity. One interpretation of the conflicting test results is that the labor productivity variable has an uncertain unit root. Another interpretation of the apparent conflict in test results from two different methods is that the underlying data generation process for the alternative hypothesis used for testing the null of a unit root in labor productivity is inappropriate or misspecified. The misspecification of the underlying data generation process for the first-difference variable (that is productivity growth) is evidenced from the plot of recursive residuals given in Figure 2 for the regression of the variable $(y_t - y_{t-1})$ on an intercept and its lagged value $(y_{t-1} - y_{t-2})$; the residuals are shown along with a two standard error band. This model has adequate model diagnostics with the exception of a failure to pass the one-step-ahead predictive test criterion. This is evidenced from the plot in Figure 2, which shows two points lying outside the two standard error band in the sense that the t-statistic is numerically greater than two in the absolute sense. The evidence in Figure 2 indicates that the model for the first-difference of labor productivity conditional on the variable being trend stationary is misspecified based on the criterion of one- period-ahead prediction errors. The prediction failure of the trend stationary first-difference of labor productivity, we conjecture is due to the failure to model the role of the productivity slowdown episode.

In the following section, we will briefly outline the testing framework used for testing the null of a unit root in labor productivity against the alternative of the variable being trend stationary with one possible break point in its intercept and in its slope. The use of this test framework is motivated by the historical evidence on the productivity slowdown hypothesis presented in Section II as well as the evidence presented above.

FIGURE 2
The Recursive Residuals Along with Two Standard Error Bands for the Regression
$y_t - y_{t-1} = \beta_1 + \beta_2 (y_{t-1} - y_{t-2}) + u_t$



IV. UNIT ROOT, TREND AND STRUCTURAL CHANGE IN THE LABOR PRODUCTIVITY: METHODOLOGY

It can be argued that the lack of support for the null hypothesis that labor productivity is a difference-stationary process presented in the previous section could be the direct result of inappropriate use of the alternative hypothesis for the test. The relevant alternative should be a linear trend with a change in the level and slope at an unknown point in time rather than a linear trend stationarity. This view is consistent with the nature of the trend in the series, which has one sudden decrease in its level as well as a sudden change in slope around the time of the first oil price shock. The series also exhibits other changes in pattern around the time of the Korean War and the second oil price shock but the magnitude of these changes is small compared to the change described earlier. This observation supports the use of a linear trend with a one-time change in the trend function.[11] Another feature of interest is that the transition path to the new trend function following the change in the level around the first oil price shock is gradual rather than sudden. This suggests that the "innovation outlier" framework might be more appropriate (for more details see Perron [1997]).

After inspecting the plot of the series, it would be tempting to choose the timing of the break to be a year such as 1973. However, the

11. This approach also seems to be supported by the longer historical record. As observers such as Lord Kaldor [1961] have noted, labor productivity in economies such as the U.S. has historically grown at fairly constant rates over very long intervals of time. See, for example, Figure 2.1 in Maddison [1982].

exogenous choice of the break year would be inappropriate given that this date has to be viewed as correlated with the data. In an ex post sense—that is, after inspecting the data and its plot—we might be able to postulate that other exogenous events are unlikely to have had a major impact on productivity growth. However, this premise would not be plausible *ex ante*. In addition, as we have argued above in discussing the possible explanations of the slowdown, it would be difficult to assign to 1973 a particular event which caused the slowdown. In view of this we follow the recent literature for using the methodology where the year of the break is estimated from the data. This is done by treating the year of the break as an unknown parameter of the model, using the t_{α}^{*} method for this purpose as suggested by Perron [1997]. This method is a slight variation of the Zivot and Andrews [1992] method. For recent applications in different contexts see Raj [1992] and Raj and Slottje [1994]. Finally, the choice of the date of the break is an important problem in the testing for the unit root since both finite sample and asymptotic distributions of the test statistic depend upon the extent of correlation between the break year and the data.

Modeling the one-time structural break requires a choice among a number of alternative models of the nature of the break. A number of models have been suggested in the literature. These include the "crash," the "growth change" and the "crash-cum growth change" models. In what follows we use the crash-cum growth change model, which encompasses the other models. This choice is consistent with the plot of the variable. It is true that the use of a more restricted model can be advantageous in some instances since it avoids the use of irrelevant regressors; however, the use of the constrained model could also imply substantial loss of power of the test, and could even make the testing framework inconsistent. We also need to make a choice between the "additive outlier" and the "innovation outlier" framework for performing the test described above. This choice is concerned with how the transition to the new growth path occurs. In the former framework the change to the new trend occurs *instantaneously* while in the latter case the change to the new trend occurs gradually. The latter framework is more appealing and plausible as argued before, and will be used in the testing framework.

The formulation of the model under the null hypothesis of the unit root is:

$$(1)\quad y_t = b + y_{t-1} + \psi(L)(e_t + \delta D(T_b)_t + \mu DU_t),$$

where $DU_t = 1$ if $t > T_b$ and 0 otherwise, and $D(T_b)_t = 1$ if $t = T_b + 1$ and 0 otherwise. The lag polynomial $\psi(L)$ is possibly of infinite order with $\psi(0) = 1$. This model specifies the first-difference of the variable as a moving average process. Accordingly, if z_t is the noise function of the series, then $z_t = A(L)^{-1} B(L)e_t = \psi(L)e_t$ where the finite-order polynomials $A(L)$ and $B(L)$ are assumed to have roots outside the unit circle, and e_t is assumed to be i.i.d. $(0, \sigma^2)$. In this framework the immediate effect of the change in the intercept is δ while the long-run impact is given by $\psi(1)\delta$. In the same vein, the immediate impact of the change in the slope is μ while the long run impact is given by $\psi(1)\mu$.

The underlying data generation process under the alternative hypothesis is:

$$(2)\quad y_t = \eta + \beta t + \Phi(L)(e_t + \theta DU_t + \gamma DT_t^{*}).$$

where $\Phi(L) = (1 - \alpha L)^{-1} A(L)^{-1} B(L)$, with $A(L)$ and $B(L)$ defined as before, and $DT_t^{*} = t - T_b$ if $t > T_b$ and 0 otherwise. Here the immediate impact of the shock on the intercept under the alternative hypothesis is given by the parameter θ, while the long-run impact is measured by $\Phi(1)\theta$. Similarly, the immediate impact of the change in a slope is γ, while the long-run impact is $\Phi(1)\gamma$.

The null and the alternative hypothesis can be nested in the following model:

$$(3)\quad y_t = \eta + \theta DU_t + \beta t + \gamma DT_t^{*} + \delta D(T_b)_t + \alpha y_{t-1} + \sum_{i=1}^{\infty} c_i \Delta y_{t-i} + u_t,$$

where the c_i's are the coefficients corresponding to the autoregressive representation of the moving average polynomial. Moreover, the polynomial is of infinite order whenever the moving average components are present. In order to implement this test the infinite lag

TABLE I

Empirical Results from the Test of the Null Hypothesis of a Unit Root against the Alternative of a Deterministic Trend Stationarity with a One-Time Break in Trend; Labor Productivity Series, 1947–1992

Time Period	Break Year T_b	Lag k	$\hat{\beta}$	$\hat{\theta}$	$\hat{\gamma}$	$\hat{\alpha}$	$t_{\hat{\alpha}}$	p-value
1947–1992	1973	6	3.09 (5.80)	1.58 (1.79)	–2.00 (–5.35)	.74	–5.29	≤.03
1959–1992	1973	6	3.14 (5.30)	1.75 (1.92)	–2.04 (–5.34)	.71	–5.36	≤.03
1947–1978	1972	5	3.40 (6.02)	–3.15 (–2.65)	–0.68 (1.91)	.62	–6.02	≤.01
1950–1978	1972	5	3.04 (5.25)	–4.10 (–3.09)	–0.20 (–0.48)	.75	–5.29	≤.03

Notes: The main entries in the table correspond to the one-tailed test, while those in the parenthesis correspond to the two-tailed tests. The last column reports p-values associated with the t-statistic $t_{\hat{\alpha}}$ for testing $\alpha = 1$. The choice of k is based on the 't-sig' method (See Ng and Perron [1995] and Perron [1997].

order must be approximated with a finite number of lags. The empirical implementation of the test requires making choices for the truncation lag length (represented by the parameter k) to approximate the infinite sum and the year of the break, T_b. There are many methods for choosing the break points (e.g. Banerjee, Lumsdaine and Stock [1992]; Zivot and Andrews [1992] and Christiano [1992]). One popular method of choosing the break year minimizes the t-statistic for testing the hypothesis that $\alpha = 1$. This method requires that the investigator estimate all possible values of the break date T_b, with trimming—that is, for the range of values $(0.15T, 0.85T)$, where T is the sample size (Zivot and Andrews [1992]).

The methods of selecting the lag parameter k are also many (for an overview, see Perron [1997]). One popular data-dependent method of selecting k is the 't-sig' method. This method selects the value of k, say k^*, such that the last lag in an autoregression of order k^* is significant and the last coefficient of order greater than k^* is insignificant.[12]

V. EMPIRICAL RESULTS AND THEIR INTERPRETATIONS

The empirical results from using the testing methodology briefly outlined in the previous section are given in Table I. In column 1 the sample period is given. The main points of interest are the results from the entire sample. The sub-sample results are also useful in the sense that they provide an assessment of the robustness of the main results of the test procedure to excluding the influence of other potential "large" shocks to the variable. These other large shocks are those corresponding to either the Korean War or the second oil price shock or both of these shocks. To anticipate one of the conclusions of the robustness analysis, it is found that the null hypothesis of a unit root is rejected in favor of the alternative of a segmented trend for the entire sample as well as for all sub-samples. Moreover, the estimate of the break year is fairly robust to the choice of the sample period except where the sample size is smallest.

The estimates of the lag length and the break year are presented in columns 2 and 3, respectively. The estimates of other key parameters of the model (3) along with the t-statistics are given in columns 4 to 6. Specifically, $\hat{\beta}$ is the estimate of the pre-break slope coefficient, $\hat{\theta}$ is the estimate of the change in the intercept and $\hat{\gamma}$ is the estimate the change in the slope of the trend function. The parameters relating to the test of the unit root hypothesis are given in columns 7 and 8. For example, $\hat{\alpha}$ is the estimate of coefficient α, while the t-statistic for the null hypothesis that $\alpha = 1$ is $t_{\hat{\alpha}}$. The last column gives the p-values for the test based on the asymptotic distribu-

12. See Ng and Perron [1995].

tion of the test statistic given in Zivot and Andrews [1992].

The outcome of the test statistic can be described as follows. The unit root, or $\alpha = 1$ is rejected against the alternative of trend stationarity with a one-time change at an endogenous point in time for the full sample period, 1947–1992. This conclusion is robust to excluding the other potential shocks, which may also have had similar large effects *ex ante*. Specifically, the sample period 1947–1978 excludes the second oil price shock, the sample period 1950–1992 excludes the Korean War shock, and the sample period 1950–1978 excludes both shocks. The estimate or selection of the break year T_b yields the year 1973 of the break for the entire sample and the sub-sample excluding only the Korean War (1950–1992). The break year estimate is 1972 for the other two sub-samples, 1947–1978 and 1950–1978. The estimate of the break year turns out to be around the year of the first oil price shock, although other events closer to this event may have also contributed to the break.

In the autoregressive model (3) the t-statistics of the level, change in level, trend, and change in trend are asymptotically normally distributed since the unit root is rejected for the variable. The change in the level and slope of the trend in labor productivity are both highly significant at the 5% significance level. The evidence supports the premise that a productivity slowdown did take place in the United States during the post-War II period. In summary, it is likely that events of the early 1970s, including the many-fold rise in price of oil and other structural changes, have had a permanent effect on the long term behavior of the productivity series.

The evidence presented above should not be taken as saying that the trend function in productivity is deterministic, but rather something quite different. The notion of the one-time break in the deterministic trend function implies that the coefficients of the trend function are determined by factors which do change, albeit only infrequently—factors which might include aspects of technology, the inflation environment and other aspects of macroeconomic policy, institutional and legal arrangements for organizing economic activity, population growth rates and perhaps even tastes, customs or norms. In contrast the innovations or smaller shocks which affect the stationary or cyclical components of the series are frequent. The one-time structural break in the deterministic trend framework is essentially a convenient or parsimonious way for removing the influence of the infrequent large shock from the noise function and placing it in the deterministic function without a specific model for the stochastic behavior of the relevant parameters such as the intercept and the slope.

The support for the framework of a one-time change in the deterministic trend has implications for detrending the series.[13] The use of the innovation outlier framework, which translates into a nonlinear trend function showing that a gradual adjustment to the new growth path takes place, is a little more cumbersome in comparison with the additive outlier model. In the latter case the trend function is segmented and it is more straightforward to compute. The precise method of calculating the nonlinear trend is explained by Perron [1994], which we have used here. It involves first estimating the following model:

$$(4) y_t = c + bt + \theta DU_t + \gamma DT_t^* + \sum_{i=1}^{p} a_i y_{t-i} + e_t,$$

where the least-squares estimates $(\hat{c}, \hat{b}, \hat{a}_i)$ are used to obtain estimates of (μ, β, φ) in (2). The lag length p is chosen endogenously in the same procedure that selected the break point T_b. The estimates of the parameters μ, β, φ are then obtained as follows:

$$\hat{\mu} = \hat{c} - (\hat{b}\hat{d}) / \hat{A}(1)$$

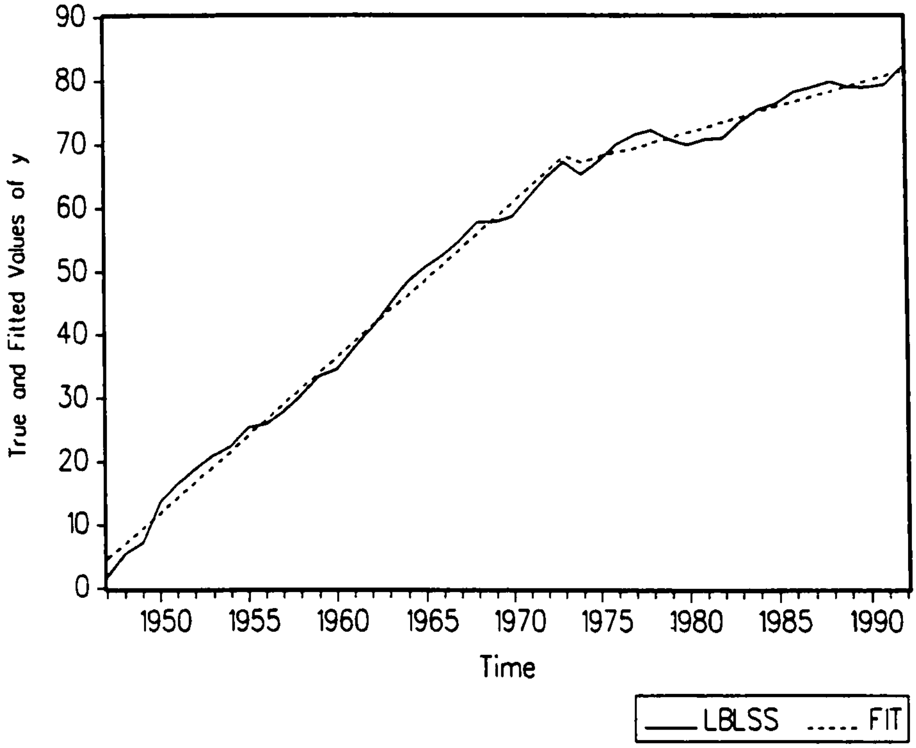
where

$$\hat{d} = \sum_{i=1}^{p} i\, \hat{a}_i,$$

is the mean lag and

13. Our focus here is purely on what is the appropriate transformation to render the series stationary. In particular, we do not identify the resulting stationary component as the "business cycle" component of the series. This would be futile in any case, as we are only considering annual data.

FIGURE 3
The Time Plot of the Fitted Segmented Trend and the Actual Data for the Logarithmic Level of Labor Productivity (y), 1947–1992



$$\hat{A}(1) = 1 - \sum_{i=1}^{p} \hat{a}_j;\ \hat{\beta} = \hat{b}/\hat{A}(1);$$

and

$$\hat{\varphi}(L)^{-1} = \hat{A}(L) = 1 - \sum_{i=1}^{p} \hat{a}_i.$$

These relations correspond to approximating the general ARMA process for the noise component by a finite sample approximation. The final step is to compute the trend function:

$$(5) \qquad TR_t = \hat{\mu} + \hat{\beta}t + \hat{A}(L)(\hat{\theta}DU_t + \hat{\gamma}DT_t^*).$$

In Figure 3, we have plotted this trend function along with the original values of the log of the labor productivity variable. As is evident from the graph, the general pattern of the trend function fits the general pattern of the data. Besides the informal investigation of the possible stationarity of the noise component or the cyclical component—the difference between the actual and trend values plotted in Figure 3—one might calculate the sample autocorrelation function of the detrended series. These sample autocorrelations (not shown) show rapid decay. In contrast, the sample autocorrelations of the residuals from a least-squares regression of the series on a constant and linear time trend show slow decay. This latter pattern of autocorrelations for linearly detrended productivity parallels those found by Nelson and Plosser [1982] for most macroeconomic series.

The results of this paper also have implications for multivariate time series analysis involving the productivity variable with other co-moving variables. In particular, models of multivariate dynamics involving labor productivity and other variables in cointegrating or common-trend relations might more accurately depict equilibrium relationships by allowing for a regime shift than by not allowing for such a break. Such analysis is not pursued here since it is beyond the scope of this paper.

VI. CONCLUDING REMARKS

The view that labor productivity growth can be characterized as having a stochastic trend rather than a deterministic trend is prevalent. This view is in agreement with the seminal result of Nelson and Plosser [1982] who found that most macroeconomic variables have a univariate time series structure with a unit root. This view is also embodied in many applications of the neoclassical growth model, in particular applications to business cycle theory (see, for example, King et al. [1991]). However, the observed evolution of productivity taken from a long-run perspective of a century or longer indicates a linear trend in productivity, subjected to an occasional episodic shock which can alter both the intercept and slope of the trend function. We followed some recent trends in time series research and modeled the timing of this shock as a parameter to be estimated from the data. Our empirical results indicate that such a change in the slope and intercept of the trend function in U.S. labor productivity occurred sometime around 1973. It is easy to show, following calculations similar to those by Perron [1993], who used a measure due to Cochrane [1988] of the persistence of shocks, that all regular shocks other than the episodic shock of 1973 have a small permanent effect.

This result has several macroeconomic implications. First, our result can be viewed as a formal statistical justification for detrending the labor productivity variable with a break in the linear trend in 1973. Moreover, our result supports an alternative position between the two extremes that all shocks to productivity have a permanent effect or that all shocks have a transitory effect. We show that occasional major events such as those of the early 1970s can have a permanent effect, though such events are quite rare. Most shocks to productivity have only a transitory effect. This, in turn, would seem to have implications for the construction of those business cycle models in which fluctuations are driven at least in part by exogenous changes in technology. Such models are typically calibrated or their parameters estimated using the generalized method of moments (GMM) under the assumption that the logarithm of the technology variable follows either a linear trend with stationary disturbances or a random walk with positive drift. Both calibration and estimation exercises are performed assuming that postwar U.S. data are generated by one of the two types of process.

Our result also has important implications for econometric modeling involving the productivity variable. Failure to model the influence of the large shock can produce misleading or biased results or even lead to spurious regressions. Misspecification due to failure to adequately model structural break in the deterministic trend component may bias the results in favor of the lack of equilibrium or cointegrating relationships between productivity and variables related to it, even if such relationships existed. Finally, our results suggest that extrapolating a deterministic trend for the purpose of long-horizon forecasting can yield inaccurate results since it is based on the assumption that no major break in the trend would occur.

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