US STYLIZED FACTS AND THEIR IMPLICATIONS FOR GROWTH THEORY

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Abstract

The macroeconomics literature heavily relies on stylized facts stemming from the assumption that actual economies operate near balanced growth paths. This paper investigates whether five such stylized facts do indeed characterize the US economy well and thus whether US growth can be reasonably characterized as approximately balanced. Evidence is found that US growth has been approximately balanced during the postwar period. By contrast, a large transition occurred between 1929 and 1946 during which the capital-output ratio plummeted while the net rate of return paid on capital soared. Notwithstanding these huge changes, the average growth rate of per capita output hardly budged between the periods 1889-1929 and 1947-1998. This fact is more consistent with exogenous growth theories than with endogenous growth theories.

Keywords

balanced growth, stylized facts, neoclassical growth theory,
endogenous growth theory, mean-stationarity, trend-stationarity

JEL Codes

O40, E32, C22

I. Introduction

The model economies proposed in the theoretical growth literature nearly universally have balanced-growth paths toward which they converge.[1] Along these balanced growth paths, extensive variables such as output, the capital stock, investment, and the income paid to capital grow at constant and identical rates, while ratios of the extensive variables are constant.

It is typically assumed either implicitly or explicitly that actual developed economies operate near balanced growth paths; e.g., the popular graduate macro-economics texts by Olivier Blanchard and Stanley Fischer (1989) and David Romer (1996).[2] In turn, this assumption implies the following *stylized facts* about these economies:[3]

(i) The growth rate of per capita output is mean-stationary;

(ii) The capital-output ratio is mean-stationary;

(iii) The rate of return paid on capital is mean-stationary;

(iv) The share of output paid to capital is mean-stationary; and

(v) The investment rate is mean-stationary.

The first four have been widely accepted at least since Nicholas Kaldor (1961) first stated them, and the fifth is a basic ingredient of the Solow (1956) growth model. See Paul Romer (1989) for an extensive discussion of these stylized facts as well as eight others.

In this paper, I investigate whether these stylized facts do indeed characterize the US economy well and thus whether US growth can be reasonably characterized as approximately balanced. I find that with some amendment, growth was approximately balanced during the period 1947-1998. By contrast, a large transition occurred between 1929 and 1946 during which the capital-output ratio plummeted while the net rate of return paid on capital soared. Notwithstanding these huge changes, the average growth

[1] See Robert Barro and Xavier Sala-i-Martin (1995) and Philippe Aghion and Peter Howitt (1998) for many examples of such models.

[2] The assumption is most explicit in Chapters 1 and 7 of Blanchard and Fischer and Chapters 1-4 of Romer. See also Robert King, Charles Plosser, and Sergio Robelo (1988), which is representative of the real-business-cycle literature in this regard.

rate of per capita output hardly budged between the periods 1889-1929 and 1947-1998. This fact is more consistent with exogenous growth theories than with endogenous growth theories.

The rest of the paper is organized as follows. Section II examines US data in order to evaluate stylized facts (i)-(v) and to formulate additional stylized facts. Section III uses a neoclassical framework to interpret the stylized facts formulated in section II. The resulting interpretation turns out to be strained, however, suggesting that technology is endogenous in empirically important ways. Section IV argues on the basis of the evidence presented in section II that this endogeneity of technology does not manifest itself in any empirically important endogeneity of the US trend growth rate. A wide class of endogenous growth theories is therefore empirically falsified. Finally, section V summarizes the paper.

II. Empirical Analysis

This section employs US data in order to evaluate the stylized facts (i)-(v) stated in the previous section. The objective is to determine the extent to which they describe regularities in the US data. I start with plots of the data and then move on to a formal econometric analysis of them. See the data appendix for a description of the data.

Figure 1 plots the growth rate of per capita output from 1889 to 1998. There was essentially no trend over the 1947-1998 and 1889-1929 periods. Furthermore, the sample means of 1.930 and 1.939 percent per annum in the two periods are virtually identical. Stylized fact (i) is therefore a remarkably robust feature of the data.

Figures 2-5 provide evidence on stylized facts (ii)-(v). Over the period 1947-1998, there is little, if any, trend apparent in the capital-output ratio, the net rate of return paid on capital, the net share of output paid to capital, and the net investment rate. By contrast, the depreciation rate on capital exhibits a pronounced upward trend, which manifests itself in upward trends in the gross rate of return paid on capital, the gross share of output paid to capital, and the gross investment rate. Finally, the capital-output ratio

[3] Because the theoretical growth literature has primarily dealt with deterministic models, these stylized facts are typically stated in terms of constancy rather than mean-stationarity. I use the latter characterization

and the gross and net shares of output paid to capital plummeted between 1929 and 1947, while the net and gross rates of return paid on capital rose markedly.

These observations suggest that the capital-output ratio, the net rate of return paid on capital, the net share of output paid to capital, and the net investment rate may well have been mean-stationary during the postwar period as stylized facts (ii)-(v) require. It is crucial, however, to amend stylized facts (iii)-(v) to include the adjective *net* and to limit their time frame to the postwar period. With the adjective *gross* or for periods that include the Great Depression and World War II, they appear to fail abysmally.

The gross rate of return paid on capital, the gross share of output paid to capital, and the gross investment rate apparently trended upward during the postwar period primarily because the depreciation rate trended upward. Why did this happen? Figure 6 provides at least part of the answer by plotting the average depreciation rate together with the ratio of the stock of equipment to the stock of structures.[4] Clearly, the rise in the average depreciation rate closely paralleled the rise in the equipment-structures ratio. As a general rule, equipment depreciates much more rapidly than structures. Therefore, even if every type of equipment and structure depreciated at a constant rate over the entire period, the average depreciation rate across all the different types should have increased over time. Although the upward trend in the equipment-structures ratio may well explain the rising depreciation rate, this explanation merely begs the question. An explanation is still required for why the equipment-structures ratio trended upward. Section 3 formulates such an explanation.

I now turn to a formal statistical analysis of the following ten series: the logarithms of the capital-output ratio, the gross and net rates of return paid on capital, the depreciation rate, and the equipment-structures ratio; the logistics of the gross and net shares of output paid to capital; the gross and net investment rates; and the growth rate of per capita output.[5] I first assess whether these series have nonzero trends, conditional on

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because actual economies are stochastic.

[4] I define structures here to include residential as well as nonresidential structures.

[5] I took logarithms of the variables that can lie anywhere on $(0,\infty)$ and logistics of variables that are constrained to lie on $(0,1)$. I left the variables that can lie anywhere on $(-\infty,\infty)$ in their levels. Therefore, the transformed variables can at least conceptually have trends with constant increments each period and covariance-stationary error terms. They can also be difference-stationary. Note that because the US is an open economy, the gross and net investment rates can in principle lie anywhere on $(-\infty,\infty)$. Furthermore, if

their being stationary around whatever trends they may have. I then assess whether they are indeed stationary.

I estimated the trend in each of these series by applying ordinary least squares to the equation

$$x_t = \alpha + \beta t + u_t, \quad t = 1, 2, \cdots, T, \tag{1}$$

where x_t is the series under consideration, t is an index of time, α and β are parameters, and u_t is an error term that is supposed to be stationary. One can then test the null hypothesis $\beta = 0$ against the alternative hypothesis $\beta \neq 0$ by comparing τ, an appropriately calculated *t*-ratio for β, with critical values from τ's distribution under the null hypothesis.

There is a difficulty, however. In order to calculate τ, one must account for the serial correlation in u_t, which is unknown *a priori*. The econometric appendix describes the method that I use for doing so. This method has the desirable property that the resulting τ is asymptotically distributed as standard normal under the null hypothesis. Unfortunately, the asymptotic distribution is a fairly poor guide for inference in finite samples of the size used here. In particular, one rejects the null hypothesis too often if one utilizes the standard normal distribution, and the size distortion increases with the serial correlation in the error term u_t. As a result, one must be circumspect in rejecting the null hypothesis. Furthermore, a value of τ that would lead to the rejection when the error term u_t is moderately serially correlated may not suffice when u_t is highly serially correlated. For this reason, any rejection should be coupled with an indication of how much serial correlation in u_t is consistent with that rejection and an assessment of whether the serial correlation is likely to be sufficiently mild to permit the rejection.

In order to provide such an indication, I employed Monte Carlo simulations. I characterized the serial correlation as straightforwardly as possible by assuming that u_t is a normally distributed first-order autoregression with the autoregressive parameter ϕ. For each value of ϕ in the set $\{-.99, -.98, \cdots, .99\}$. I estimated the empirical distribution of τ under the null hypothesis $\beta = 0$. On the basis of these empirical distributions, I then

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one wants to treat them similarly, the logistic transformation is precluded because the net investment rate has been negative at times.

determined the values of ϕ for which the estimates of τ reported below are statistically significant at the .05 level. The econometric appendix describes the procedure used in greater detail.

Table 1 reports estimates of the trends in the series under consideration over the period 1947-1998. For each of these estimates, the table also reports its *t*-ratio, the range of the autoregressive parameter consistent with rejection of the null hypothesis of no trend, and the ordinary least squares estimate of that parameter. According to the table, there is absolutely no evidence of trend in the growth rate of per capita output, the capital-output ratio, the net rate of return paid on capital, the net share of output paid to capital, and the net investment rate. By contrast, there is compelling evidence that the depreciation rate and the equipment-structures ratio trend upward. Even for an autoregressive parameter as large as .99, one can reject the null hypothesis of no trend at well under the .05 significance level. The evidence that the gross investment rate trends upward is also strong. One can reject the null hypothesis of no trend in it for autoregressive parameters as large as .84, which is much larger than the ordinary least squares estimate of this parameter. There is, however, no evidence for trend in the gross rate of return paid on capital and the gross share of output paid to capital. Nevertheless, logic dictates that these series trend upward since the depreciation rate almost certainly does and the net rate of return paid on capital and the net share of output paid to capital do not appear to trend.

It is also important to gauge the economic significance of the estimated trends as well as their statistical significance. As Figures 1-6 indicate, the growth rate of per capita output, the capital-output ratio, the net rate of return paid on capital, the net share of output paid to capital, and the net investment rate did not change by economically significant amounts over the postwar period. By contrast, the gross rate of return paid on capital, the gross share of output paid to capital, the gross investment rate, the depreciation rate, and the equipment-structures ratio did increase appreciably.

Table 2 reports Dickey-Fuller *t*-ratios for each of the series under consideration for the period 1947-1998. It provides strong evidence for the mean-stationarity of the series that do not appear to trend; i.e., the growth rate of per capita output, the capital-output ratio, the net rate of return paid on capital, the net share of output paid to capital, and the net investment rate. The evidence is also fairly compelling that the gross rate of return paid on capital, the gross share of output paid to capital, the gross investment rate, and the equipment-structures ratio are trend-stationary. By contrast, there is no evidence that the depreciation rate is trend-stationary. Furthermore, conditional on its actually being difference-stationary, its growth rate is estimated to be .0111 with a standard error of only .0022.[6] The depreciation rate is therefore well characterized as difference-stationary with positive drift.

I also investigated whether the growth rate of per capita output can be well characterized as mean-stationary in the period 1889-1929. Its estimated trend is -.00007 with a *t*-ratio of -0.22. Consequently, there is absolutely no evidence that it trended in that period. On the assumption that it does not trend, its Dickey-Fuller *t*-ratio is -8.25, which is statistically significant at well under the .01 level.[7] The evidence is thus compelling that the growth rate of per capita income was mean-stationary prior to the Depression.

III. Neoclassical Interpretation

The previous section provided evidence that the following stylized facts have characterized the postwar US economy:

(a) The growth rate of per capita output is mean-stationary;

(b) The capital-output ratio is mean-stationary;

(c) The net rate of return paid on capital is mean-stationary;

(d) The net share of output paid to capital is mean-stationary;

(e) The net investment rate is mean-stationary;

(f) The depreciation rate trends upward;

(g) The equipment-structures ratio trends upward;

(h) The gross rate of return paid on capital trends upward;

(i) The gross share of output paid to capital trends upward; and

(j) The gross investment rate trends upward.

[6] I computed the standard error using the Newey-West (1987) procedure with a window length of 5 years.
[7] The Akaike criterion indicated that no augmentation lags are necessary.

The purpose of this section is to interpret these stylized facts within a neoclassical framework.

Stylized facts (a)-(e) are straightforward implications of textbook neoclassical growth theory. Therefore, it is unnecessary to lay out such a model and derive them here. For such a derivation, see Romer (1996, Chapters 1 and 2) or Barro and Sala-i-Martin (1995, Chapters 1 and 2). Furthermore, stylized facts (g)-(i) are immediate consequences of stylized facts (c)-(e) and (f). Difficulties arise, however, in trying to formulate a model in which stylized facts (a)-(e) can hold at the same time that stylized facts (f) and (g) also hold.

In order to formulate such a model, equipment and structures must be distinct forms of capital. Furthermore, the agents must have a reason to shift from the former to the latter over time as required by stylized fact (f). One way of doing so is to assume that output is produced according to the technology

$$Y(t) = F[A(t)E(t), B(t)S(t), C(t)L(t)] \tag{2}$$

where t is a continuous index of time; Y is gross output; E and S are the stocks of equipment and structures; L is the labor supply, which is assumed for simplicity to equal the population; A, B, and C are the technical efficiencies of equipment, structures, and labor; and F(•) is an increasing, concave, twice continuously differentiable, and linear homogeneous function of its arguments. This function should not take the Cobb-Douglas form because the technical efficiencies of equipment, structures, and labor cannot be distinguished from one another in that case.

Equation (2) and the linear homogeneity of F(•) imply that

$$\begin{aligned} 1 &= \mathrm{F}[(AE/K)(K/Y), (BS/K)(K/Y), CL/Y] \\ &= \mathrm{F}\left[A(K/Y)\left(\tfrac{z}{1+z}\right), B(K/Y)\left(\tfrac{1}{1+z}\right), C(L/Y)\right], \end{aligned} \tag{3}$$

where z is the equipment-structures ratio. Hence, stylized fact (b) can hold if, and only if,

$$\mathrm{F}_1\left[\dot{A}\frac{z}{1+z} + A\frac{\dot{z}}{(1+z)^2}\right] + \mathrm{F}_2\left[\dot{B}\frac{1}{1+z} - B\frac{\dot{z}}{(1+z)^2}\right] + \mathrm{F}_3\frac{d}{dt}\left[\frac{C}{(Y/L)}\right] = 0, \tag{4}$$

where subscripts on functions indicate derivatives with respect to the corresponding argument. After some rearrangement, equation (4) then implies that in the steady state,

$$\eta_1 g_A + \eta_2 g_B + \eta_3 g_C = \left(\tfrac{1}{1+z}\right)(\eta_2 - \eta_1) g_z + \eta_3 g_y \tag{5}$$

where g_A, g_B, g_C, and g_y are the growth rates of A, B, C, and per capita output Y/L; $\eta_1 \equiv AE\,\mathrm{F}_1/\mathrm{F}$; $\eta_2 \equiv AS\,\mathrm{F}_2/\mathrm{F}$; and $\eta_3 \equiv CL\,\mathrm{F}_3/\mathrm{F}$. The restrictions on the production function imply that these elasticities are positive and sum to one.

In neoclassical models, the agents can freely invest in equipment and structures and competition prevails. As a result, their net marginal products are equated to the net rate of return paid on capital. It then follows from stylized fact (c) that these net marginal products should be constant in the steady state. (The model under consideration here is nonstochastic.)

In order to obtain the net marginal products of equipment and structures, depreciation must be modeled. I assume that it is given by D(E,S), where D(•) is an increasing, concave and twice continuously differentiable linear homogeneous function of its arguments. I further assume that that the marginal depreciation rate for equipment (D_1) exceeds the marginal depreciation rate for structures (D_2); e.g., the machines in a factory wear out faster than the factory itself. Given this restriction, the average depreciation rate trends upward if, and only if, the equipment-structure ratio trends upward since

$$\tfrac{d}{dt}[\mathrm{D}(E,S)/K] = \tfrac{d}{dt}\mathrm{D}\left(\tfrac{z}{1+z},\tfrac{1}{1+z}\right) = (\mathrm{D}_1 - \mathrm{D}_2)\dot{z}/(1+z)^2. \tag{6}$$

Given the restriction $\mathrm{D}_1 > \mathrm{D}_2$, stylized facts (f) and (g) are thus necessary and sufficient for each other.

The net marginal products of equipment and structures are, respectively, $A\mathrm{F}_1(AE,BS,CL)$-$\mathrm{D}_1(E,S)$ and $B\mathrm{F}_2(AE,BS,CL)$-$\mathrm{D}_2(E,S)$. Because F_1(•), F_2(•), D_1(•), and D_2(•) are homogeneous of degree zero, the net marginal products can be rewritten as

$$A\mathrm{F}_1\left[(AK/Y)\left(\tfrac{z}{1+z}\right),(BK/Y)\left(\tfrac{1}{1+z}\right),CL/Y\right] - \mathrm{D}_1\left(\tfrac{z}{1+z},\tfrac{1}{1+z}\right)$$

and

$$B\mathrm{F}_2\left[(AK/Y)\left(\tfrac{z}{1+z}\right),(BK/Y)\left(\tfrac{1}{1+z}\right),CL/Y\right] - \mathrm{D}_2\left(\tfrac{z}{1+z},\tfrac{1}{1+z}\right).$$

In any steady state in which K/Y is constant, these expressions must be constant in the face of the drift in A, B, CL/Y, and z. Therefore, the following conditions must hold:

$$(1+\theta_{11})g_A + \theta_{12}g_B + \theta_{13}g_C = \left(\tfrac{1}{1+z}\right)(\theta_{12} - \theta_{11})g_z + \theta_{13}g_y \tag{7}$$

and

$$\theta_{21}g_A + (1+\theta_{22})g_B + \theta_{23}g_C = \left(\tfrac{1}{1+z}\right)(\theta_{21} - \theta_{22})g_z + \theta_{23}g_y, \tag{8}$$

where $\theta_{11} \equiv AE\,\mathrm{F}_{11}/\,\mathrm{F}_1$, $\theta_{12} \equiv AS\,\mathrm{F}_{12}/\,\mathrm{F}_1$, $\theta_{13} \equiv CL\,\mathrm{F}_{13}/\,\mathrm{F}_1$, $\theta_{21} \equiv AE\,\mathrm{F}_{21}/\,\mathrm{F}_2$, $\theta_{22} \equiv BS\,\mathrm{F}_{22}/\,\mathrm{F}_2$, and $\theta_{23} \equiv CL\,\mathrm{F}_{23}/\,\mathrm{F}_2$. In deriving equations (7) and (8), I have imposed the restrictions $E\,\mathrm{D}_{11} + S\,\mathrm{D}_{12} = 0$ and $E\,\mathrm{D}_{21} + S\,\mathrm{D}_{22} = 0$, which are implications of the linear homogeneity of D(•).

The equation system (5), (7), and (8) implies that for any given g_z and g_y, there is one, and only one, combination of g_A, g_B, and g_C.[8] As a result, stylized facts (a)-(e) can coexist with stylized fact (f). One can therefore always rationalize any observed values of g_z and g_y with unique values of g_A, g_B, and g_C. There is a problem, however. In a purely neoclassical framework, the vector (g_A,g_B,g_C) should be exogenous and hence should be capable of lying anywhere in $\Re^3$. Equations (5), (7), and (8) instead imply that it must lie on a two-dimensional manifold of $\Re^3$ since the vector (g_z,g_y) lies on $\Re^2$. How can this be? The most sensible answer is that economic agents are making choices about technology outside the model that lead to a functional relationship of the form $\Omega(g_A,g_B,g_C) = 0$. In other words, the neoclassical assumption of exogenous technology must be partly abandoned in order to complete the model. It is beyond the scope of this paper, however, to articulate such a model.

IV. Exogenous vs. Endogenous Growth[9]

The most pronounced features of Figures 2 and 3 are not the stability of the capital-output ratio and the net rate of return paid on capital during the postwar period, but rather the large and highly statistically significant changes that these variables underwent between 1929 and the postwar period. The capital-output ratio was 3.68 years in 1929, almost 71 standard errors above its postwar mean of 2.06 years. The net rate of return paid on capital was 5.95 percent per annum in 1929, over 9 standard errors below its postwar mean of 9.20 percent per annum.[10] By contrast, per capita output grew at

[8] I am assuming here that the Jacobean of the equation system (6), (8), and (9) is everywhere nonzero.
[9] The argument in this section is similar to one advanced by Charles Jones (1995a).
[10] I calculated the standard errors underlying this statement and the previous one using the formula

virtually the same rate during the period 1889-1929 as it grew during the postwar period: 1.939 vs. 1.930 percent per annum. The *t*-ratio for the difference between these two sample means is –0.02, which is not statistically significant at any conventional level.[11]

These observations are consistent with a class of models that I shall call *exogenous growth* models for expositional simplicity. Such models include not only neoclassical models like those of Robert Solow (1956) and David Cass (1965) but also semiendogenous growth models like those of Charles Jones (1995b) and Paul Segerstrom (1998) and endogenous growth models like those of Barro and Sala-i-Martin (1995, Chapter 8) and Aghion and Howitt (1998, pp. 420-425) in which the trend growth rate is determined at the world rather than the country level. I shall reserve the term *endogenous growth models* for models in which the trend growth rate of the US economy is endogenous with respect to its own environment to an empirically important extent.

Consider the following scenario in the context of an exogenous growth model. The Great Depression and World War II led capital to decumulate rapidly between 1929 and 1947. Accompanying these large one-time events were large exogenous fundamental changes in the environment; e.g., marginal tax rates on capital increased sharply and an unfunded social security system was introduced. These permanent changes ratified the reductions that the one-time shocks induced, thereby largely eliminating the need for transition dynamics during the postwar period. Along the resulting balanced growth path, the capital-output ratio was greatly reduced while the net rate of return paid on capital

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$$\sqrt{\frac{\hat{\gamma}_0 + 2\sum_{j=1}^{5}(1-j/6)\hat{\gamma}_j}{T[1-\min(\hat{\phi},1)]^2}},$$

where $\hat{\phi}$ is the ordinary-least-squares estimate obtained by regressing the variable under consideration on its value lagged one year and $\hat{\gamma}_j$ is the *j*th sample autocorrelation of the residuals from this regression. Monte Carlo simulations similar to those described in the econometric appendix reveal that the difference in capital-output ratios is statistically significant at well under the .01 level for every autoregressive parameters in the set $\{-.99,-.98,\cdots,.99\}$. The ordinary least squares estimate of this parameter is .709, which is well under the maximum value in the significance interval. The difference in net rates of return paid on capital is statistically significant at the .05 level for autoregressive parameters in the set $\{-.99,-.98,\cdots.98\}$. The ordinary least squares estimate of this parameter is .684, which is also well under the maximum value in the significance interval.

[11] I estimated this *t*-ratio by fitting the growth rate of output to an intercept and a dummy variable that was one in the period 1890-1929 and zero otherwise. I included the years 1890-1929 and 1947-1998 in the sample and used the Newey-West procedure with a window length of five years to account for any serial correlation and heteroskedasticity in the error term.

was considerably increased. By contrast, the average growth rate was essentially unaffected because the trend growth rate is exogenous by assumption.

On the other hand, the observations are difficult to reconcile with endogenous growth models. I illustrate this point with two types of models. The first type makes output proportional to the capital stock. The plunge in the capital-output ratio must therefore have resulted from a large permanent increase in the factor of proportionality in the production function. As a result, the net rate of return paid on capital must also have increased. So far, so good. The enhanced net rate of return on capital, however, should have increased the trend growth rate of per capita output, contrary to what actually happened.

If capital is defined broadly to include not only physical capital but also human capital, the ratio of physical capital to output can drop if there is an offsetting increase in human capital. At first blush, this explanation may seem plausible. After all, the US population is much more educated now than it was in 1929. On closer inspection, however, the explanation fails. According to John Kendrick (1976), the ratio of human capital to output actually fell between 1929 and 1947.[12]

In the second type of model, entrepreneurs seek to profit from making innovations that enhance labor efficiency in final goods production. The more profitable such innovations are *ceteris paribus*, the more rapidly labor efficiency grows. In order to make these ideas more concrete, suppose that final goods are produced with the technology $\Phi(K,CL)$, where $\Phi(\bullet)$ is an increasing, concave, twice continuously differentiable, and linear homogeneous function of its arguments.[13] Suppose further that the growth rate of labor efficiency is increasing in $L\Phi_2(K,CL)$, the marginal product of labor efficiency.

Now, consider a scenario in which the environment changes between 1929 and 1947, thereby inducing the steady-state capital-output ratio to decrease. Such a change in the environment should be associated with an increase in the rate of return paid on capital, as indeed happened. It should also be associated with a decrease in the growth

[12] The real net stock of human capital increased by 53.0 percent between 1929 and 1947, while real GDP increased by 59.3 percent. The sources are Kendrick's Table B-28 and a CD-Rom from the Bureau of Economic Analysis.

[13] For expositional simplicity, I abstract from equipment, structures, and changes in their efficiencies in this section.

rate of labor efficiency and hence the growth rate of per capita output, contrary to what actually occurred.[14]

As a specific example of this type of model, consider Aghion and Howitt (1998, Chapter 3). In this model, growth results from research and development, which is carried out to profit from the innovations that it generates. For any given environment, the model has a balanced growth path characterized by a constant capital-output ratio and a constant growth rate of per capita output. As in Cass's neoclassical growth model, an increase in the marginal tax rate on capital decreases the steady-state capital-output ratio, increases the pretax rate of return paid on capital, and leaves the after-tax interest rate unchanged. The steady-state growth rate does not remain unchanged, however, because the profitability of innovations is reduced. In particular, the lower capital intensity implies lower final output and hence a smaller market and a smaller stream of future profits for each innovation *ceteris paribus*. At an unchanged after-tax interest rate, this stream of future profits has a smaller present value. Entrepreneurs therefore cut back on research and development, and the steady-state growth rate of per capita output decreases, contrary to what actually happened.

V. Summary

This paper provides strong evidence that Kaldor's stylized facts have held in the United States during the postwar period. Specifically, the capital-output ratio, the net rate of return paid on capital, the net share of output paid to capital, and the net investment rate have been mean-stationary.

The term *net* is critical in this statement since the depreciation rate on capital has trended upward persistently and statistically significantly during the postwar period. As a

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[14] $K/Y = 1/\Phi(1,CL/K)$ since $\Phi(\bullet)$ is linear homogeneous. As a result, K/Y can decrease if, and only if, K/CL decreases. The marginal products of K and C can be rewritten as $\Phi_1(K/CL,1)$ and $L\Phi_2(1,CL/K)$ since $\Phi_1(\bullet)$ and $\Phi_2(\bullet)$ are homogeneous of degree zero in their arguments. The decrease in K/CL therefore increases the marginal product of capital and decreases the marginal product of labor efficiency. The latter effect lowers the growth rate of labor efficiency, and the former effect raises the rate of return paid on capital on the presumption that the marginal product and the rate of return paid on capital move together. In the steady state, the decrease in the growth rate of labor efficiency implies that an equal reduction in the growth rate of per capita output since K/Y, K/CL, and hence Y/CL are constant.

result, the *gross* rate of return paid on capital, the *gross* share of output paid to capital, and the *gross* investment rate have also trended upward during the postwar period. These upward trend in the depreciation rate is associated with a pronounced upward trend in the equipment-structures ratio. These upward trends are difficult to rationalize in a purely neoclassical growth model, suggesting that the neoclassical assumption of exogenously fixed technology should be relaxed.

The paper also finds strong evidence that the growth rate of per capita output was mean-stationary in both the 1889-1929 and the 1947-1998 periods. Furthermore, the sample means over the two periods are virtually identical and not statistically significantly different at any reasonable level. The growth rate of per capital output stayed remarkably constant despite a plunge in the capital-output ratio and a large increase in the rate of return paid on capital. Two popular types of endogenous growth models are difficult to reconcile with this finding.

Data Appendix

My measures of the capital stock equipment (*E*) and structures (*S*) are the real net private stock of equipment and nonresidential plus residential structures. The data come from Table 15KRE of "Net Stock Estimates of Fixed Reproducible Wealth, 1925-1997," which I downloaded from www.bea.gov/bea/dn2.htm as posted in July 1999. I shifted the BEA's data forward one year since I measure capital at the beginning of the year while they report it at the end of the year. The total capital stock (*K*) is just $E+S$.

My measure of output (*Y*) is the real gross domestic product for 1929-1998 and real gross national product for 1889-1928. The former is line 1 from NIPA Table 1.2,[15] and the latter is series A1 of *Long Term Economic Growth*. I spliced the latter to the former at 1929.

My measure of the gross investment rate is real gross investment from line 6 of NIPA Table 1.2 divided by *Y*. Real private depreciation (*D*) is line 6 of NIPA Table 1.10. The net investment rate is the gross investment rate less D/Y.

[15] All NIPA data come from a February 1999 CD-Rom issued by BEA and www.bea.doc.gov/bea/dn1.htm as posted in August 1999.

I estimated the real income paid to capital using the formula:

$$NKI = \sigma NNP - NFI \tag{1}$$

with

$$\sigma \equiv 1 - COMP/(NI - PI), \tag{2}$$

where *NKI* is the real net domestic income paid to capital, *NNP* is the real net national product, *NFI* is real net foreign income, *COMP* is nominal employee compensation, *NI* is nominal national income, and *PI* is proprietors' income. Several assumptions are implicit in this calculation: the share of proprietors' income paid for the proprietors' labor services is the same as is paid for labor services elsewhere; all net foreign income is paid to capital; indirect taxes are shifted forward equally onto both labor and capital; and the share of real net national product paid to capital is the same as the share of nominal net national product paid to labor. The net rate of return paid on capital and the net share of output paid to capital are then *NKI*/*K* and *NKI*/*Y*, respectively. The gross rate of return paid on capital is the net rate of return plus *D*/*K*, and the gross share of output paid to capital is the net share plus *D*/*Y*. *NNP* is line 10 of NIPA Table 1.10, *NFI* is the difference between lines 4 (real gross national product) and 1 (real gross domestic product), and *NI*, *COMP*, and *PI* are lines 1, 2 and 9 of NIPA Table 1.14.

I downloaded the population data for 1900-1998 from the Census Bureau's web page www.census.gov/population/estimates/nation/popclockest.txt as posted in August 1999. The data for 1889-1899 are series A7 from *Historical Statistics of the United States*. Per capita output is real GDP divided by this series.

Econometric Appendix

Following Andrews and Monahan (1993), I estimate the *t*-ratio for β as

$$\tau \equiv \hat{\beta}\left[1 - \min(\hat{\phi}, 1)\right]\sqrt{\frac{\sum_{t=1}^{T} t^2 - \left(\sum_{t=1}^{T} t\right)^2 / T}{\hat{\gamma}_0 + 2\sum_{j=1}^{J}[1 - j/(J+1)]\hat{\gamma}_j}}\ , \tag{3}$$

where $\hat{\beta}$ be the estimator of β obtained from applying ordinary least squares to equation (1), $\hat{\phi}$ is the ordinary least squares estimator of ϕ in the equation

$$\hat{u}_t = \phi \hat{u}_{t-1} + v_t, \quad t = 2, 3, \cdots, T, \tag{4}$$

$\hat{\gamma}_j$ is the jth sample autocovariance of $\hat{u}_t - \min(\hat{\phi}, 1)\hat{u}_{t-1}$, J is a positive integer, $\{\hat{u}_t\}$ are the residuals from applying ordinary least squares to equation (1), and v_t is an error term.

The basic idea underlying this estimator is straightforward. One first estimates ϕ in order to remove most of the serial correlation in u_t. This first step is a *sine qua non* for τ to have decent finite-sample properties when u_t exhibits appreciable serial correlation. The estimator for ϕ is, however, restricted to be no more than one since u_t is maintained to be stationary and *a fortiori* nonexplosive.[16] One then applies the Newey-West (1987) nonparametric estimator in order to account for any remaining serial correlation.

Andrews and Monahan have shown that under the null hypothesis $\beta = 0$, τ converges in distribution to standard normal as the sample size T and the window length J approach infinity while $J/T^{1/4}$ approaches zero and that τ diverges under the alternative hypothesis $\beta \neq 0$. In practice, however, the resulting estimator performs fairly poorly for samples of the size considered in this paper.

Table 3 characterizes the distribution of τ on the assumption that the error term u_t is a normally distributed first-order autoregression, $J = 5$, and $T = 52$.[17] The table compares various statistics of the standard normal distribution with those of the distributions associated with autoregressive parameters .00, .50, .75, .90, and .95. Clearly, these five distributions are appreciably wider than the asymptotic distribution. Furthermore, the larger ϕ is, the wider they become. One therefore tends to reject the null hypothesis too often if one utilizes the standard normal distribution. As a result, one must be circumspect in rejecting the null hypothesis. A value of τ that would lead to rejection when u_t is moderately serially correlated may be too small in magnitude to justify rejection when u_t is highly serially correlated. For this reason, rejection should be coupled with an indication of how much serial correlation in u_t is consistent with that rejection.

I estimated the statistics reported in Table 3 as follows. First, I carried out 20,000 simulations of the data-generating process

$$x_t = \phi x_{t-1} + \varepsilon_t, \tag{5}$$

[16] I thank Masao Ogaki for pointing out that this restriction should be imposed on the estimator for ϕ.

[17] The postwar samples have 52 observations. I use a window length of 5 years in calculating all of the t-ratios reported in Table 1.

with

$$x_1 = \text{NIID}\left(0, \tfrac{1}{1-\phi^2}\right) \tag{6}$$

and

$$\varepsilon_t \sim \text{NIID}(0,1), \quad t = 2, 3, \cdots, 52, \tag{7}$$

for the given value of the autoregressive parameter $\phi \in$ (-1,1). Then, with J = 5, I used equation (3) to calculate a realization of τ for each of these 20,000 samples. Finally, I calculated the mean, standard deviation, and the various fractiles of these 20,000 realizations of τ. On the maintained assumption that u_t is a normally and identically distributed first-order autoregressive process, these statistics are consistent estimates of the fractiles from the true distribution of the estimator τ for T = 52, J = 5, and the given value of ϕ.

The method outlined in the text for conditioning the rejection of the null hypothesis β = 0 on the degree of serial correlation in u_t is an elaboration on the procedure described in the previous paragraph. I performed the simulations for every $\phi \in \{-.99,-.98,\cdots,.99\}$, obtaining 20,000 realizations of τ for each of the 199 ϕs. Let τ^* be the estimate of τ obtained using real data. I searched each of these 199 samples for the realizations that lie outside the interval $\left(-|\tau^*|, |\tau^*|\right)$ and divided the number of such realizations by 20,000.[18] I then determined the values of ϕ for which this fraction is no more than .05. If no such values existed, I entered "none" in Table 1. In the other cases, a largest value of ϕ existed satisfying this criterion. Let that value be denoted ϕ_{max}. It turned out in practice that all smaller values of ϕ also satisfied the criterion. The set of such ϕs can therefore be denoted [-.99,ϕ_{max}], which is labeled the significance interval in Table 1. Apparently, 20,000 Monte Carlo simulations sufficed to remove all ambiguity.

[18] This method uses both tails of the simulated distributions of τ. It should be more accurate than using only one tail if the true distributions are symmetric. Table 3 certainly casts no doubt on this assumption. The significance intervals reported in Table 1, however, would have been little different, had I used only one tail.

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Table 1. Estimates of β and Associated Statistics from Trend Regressions for the Period 1947-1998

Series	*Estimate of β*	*T-Ratio*	*Significance Interval*	*Estimate of ϕ*
Growth Rate of Real GDP	.00001	0.07	none	.003
Log Capital-Output Ratio	-.00053	-0.73	none	.706
Log Net Rate of Return	-.00019	-0.09	none	.763
Logistic of Net Share	-.00089	-0.11	none	.666
Net Investment Rate	-.00012	-0.63	none	.408
Log Depreciation Rate	.00990	8.45	[-.99,.99]	.879
Log Equipment-Structures Ratio	.01477	8.81	[-.99,.99]	.811
Log Gross Rate of Return	.00267	2.21	none	.647
Logistic of Gross Share	.00293	1.50	none	.793
Gross Investment Rate	.00060	3.78	[-.99,.84]	.384

Notes. The sample length T is 52, and the window length J is 5. The significance interval refers to the range of values of ϕ in the set {-.99, -.98, ···, .99} for which Monte Carlo simulations indicate that the null hypothesis $\beta = 0$ would be rejected less than five percent of the time on the basis of the t-ratio reported in the second column.

Table 2. Dickey-Fuller T-Ratios for 1947-1998

Series	*Without Trend*	*With Trend*
Growth Rate of Real GDP	-7.93[a] (0)	-6.19[a] (1)
Log Capital-Output Ratio	-3.23[b] (1)	-3.31[c] (1)
Log Net Rate of Return	-3.41[b] (0)	-3.38[c] (0)
Logistic of Net Share	-3.33[b] (0)	-3.41[c] (0)
Log Depreciation Rate	-0.77 (0)	-2.07 (0)
Log Equipment-Structures Ratio	-0.88 (2)	-4.47[a] (1)
Net Investment Rate	-4.39[a] (0)	-4.33[a] (0)
Log Gross Rate of Return	-3.04[b] (0)	-3.54[b] (0)
Logistic of Gross Share	-3.47[b] (1)	-3.85[b] (1)
Gross Investment Rate	-2.94[b] (0)	-4.38[a] (0)

Note. The integer in parentheses is the number of lags of Δx_t that augment the Dickey-Fuller regression. The number of lags was selected in order to minimize the Akaike criterion subject to being no greater than four. The subscripts a, b, and c indicate statistical significance at the .01, .05, and .10, respectively.

Table 3. Comparison of Estimated Statistics for τ with Those of the Standard Normal Distribution

Statistics	***N(0,1)***	τ (ϕ = .00)	τ (ϕ = .50)	τ (ϕ = .75)	τ (ϕ = .90)	τ (ϕ = .95)
Mean	0.00	0.00	0.01	0.01	0.02	0.00
Std. Dev.	1.00	1.24	1.28	1.47	1.97	2.46
.01 Fractile	-2.33	-3.06	-3.21	-3.94	-5.15	-6.86
.05 Fractile	-1.65	-2.02	-2.04	-2.35	-3.10	-3.84
.10 Fractile	-1.28	-1.54	-1.51	-1.67	-2.20	-2.68
.25 Fractile	-0.67	-0.78	-0.77	-0.80	-0.98	-1.19
.50 Fractile	0.00	0.01	-0.00	0.02	0.01	-0.00
.75 Fractile	0.67	0.79	0.79	0.82	1.00	1.19
.90 Fractile	1.28	1.54	1.58	1.72	2.21	2.70
.95 Fractile	1.65	2.01	2.10	2.37	3.18	3.90
.99 Fractile	2.33	3.04	3.25	3.82	5.38	6.93

Notes. The statistics are calculated for $T = 52$ and $J = 5$.

Figure 1. The Growth Rate of Real Per Capita Output

1889-1998

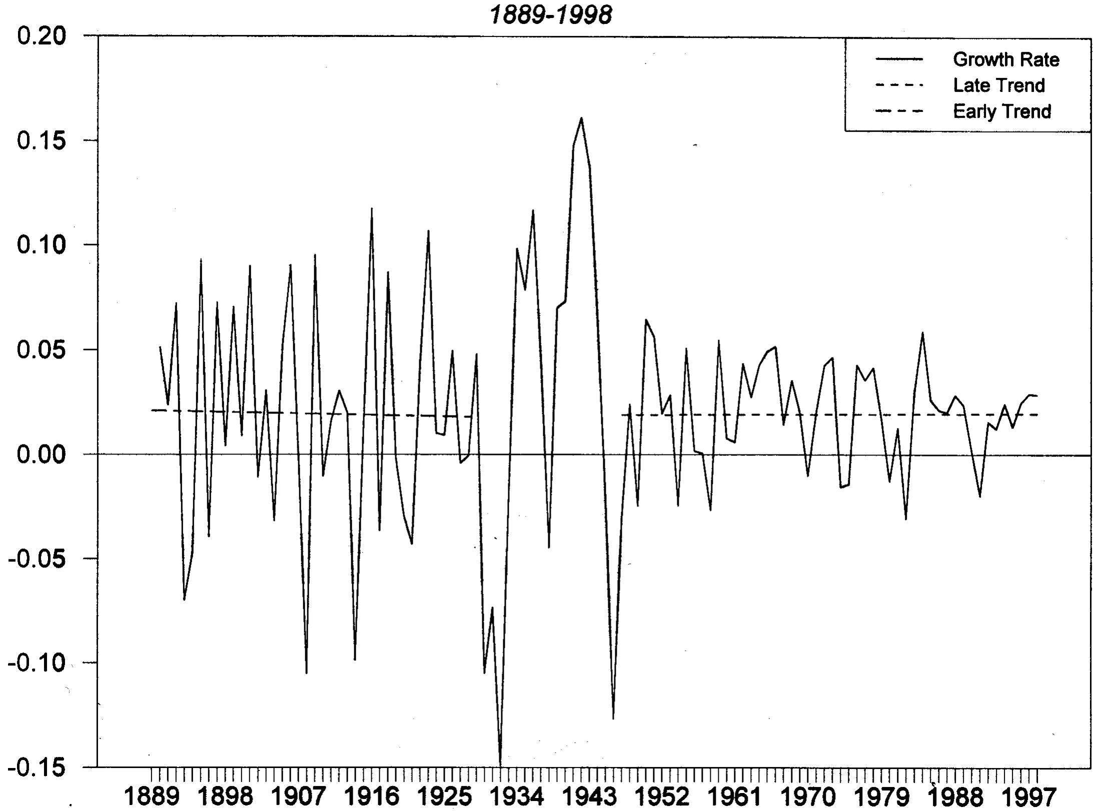

Figure 2. The Capital-Output Ratio

1926-1998

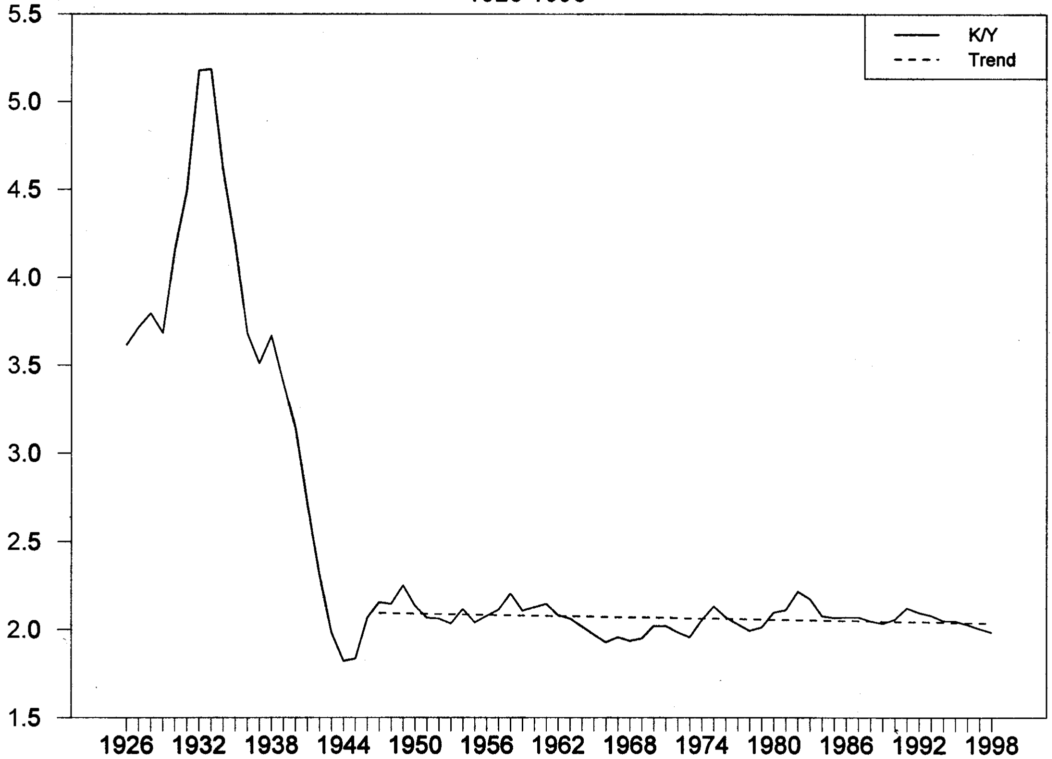

Figure 3. Components of the Rate of Return Paid on Capital

1929-1998

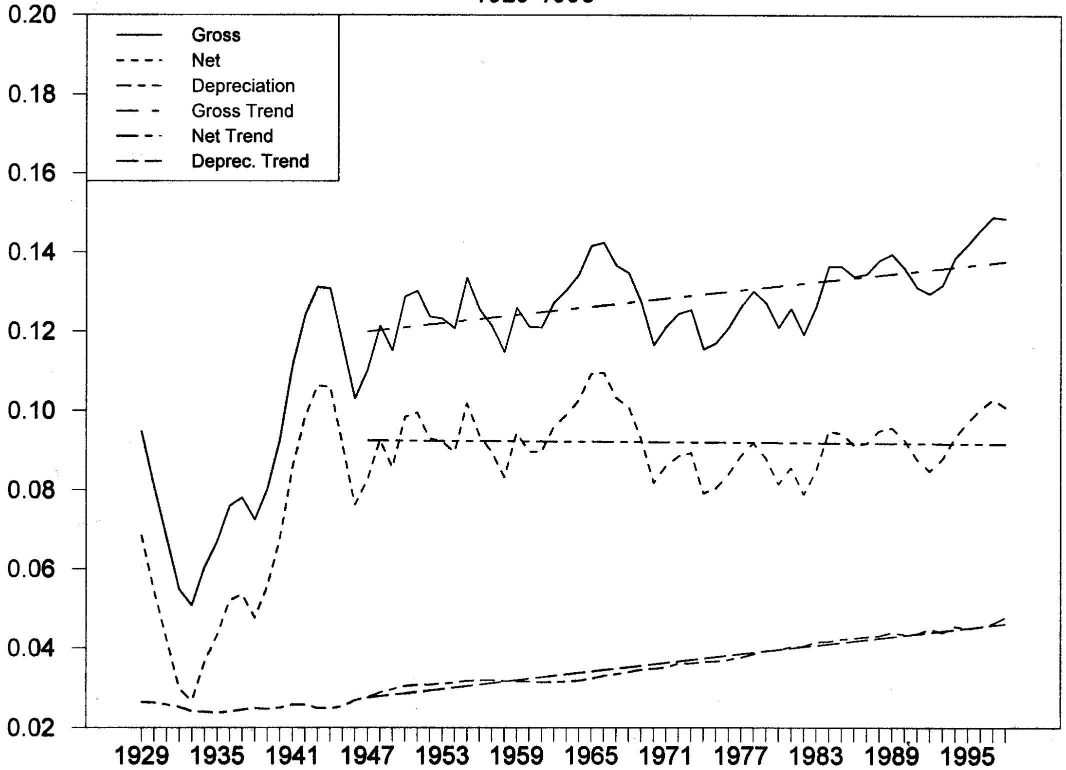

Figure 4. Gross and Net Shares of Output Paid to Capital

1929-1998

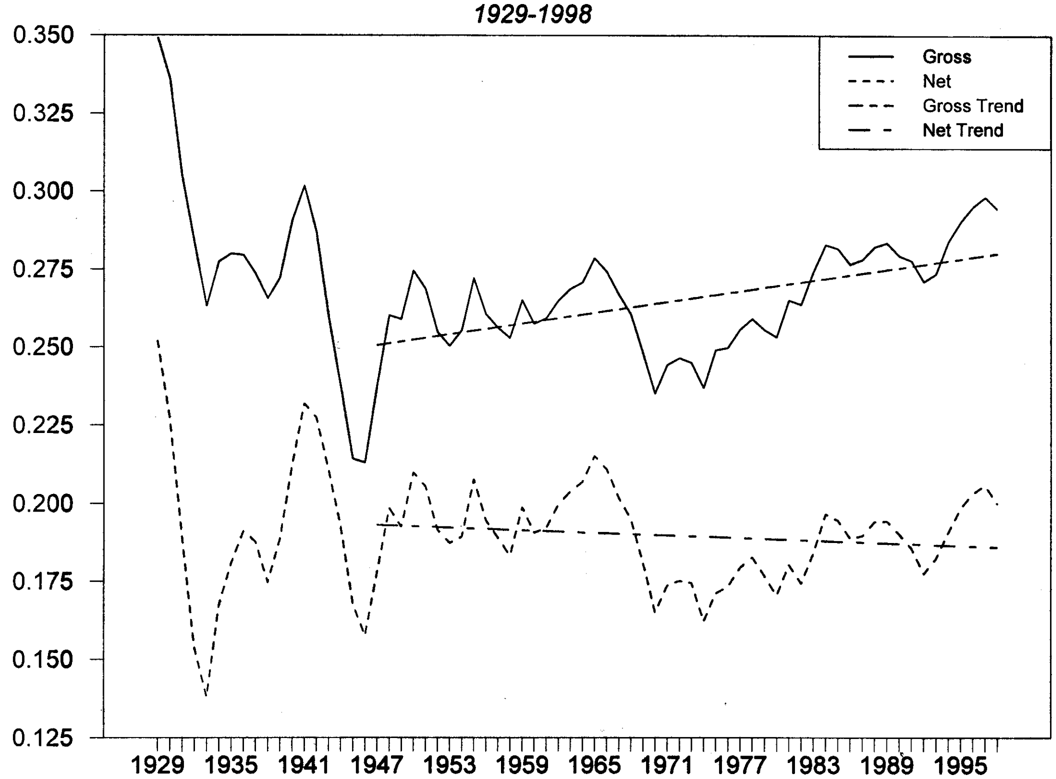

Figure 5. Gross and Net Investment Rates

1889-1998

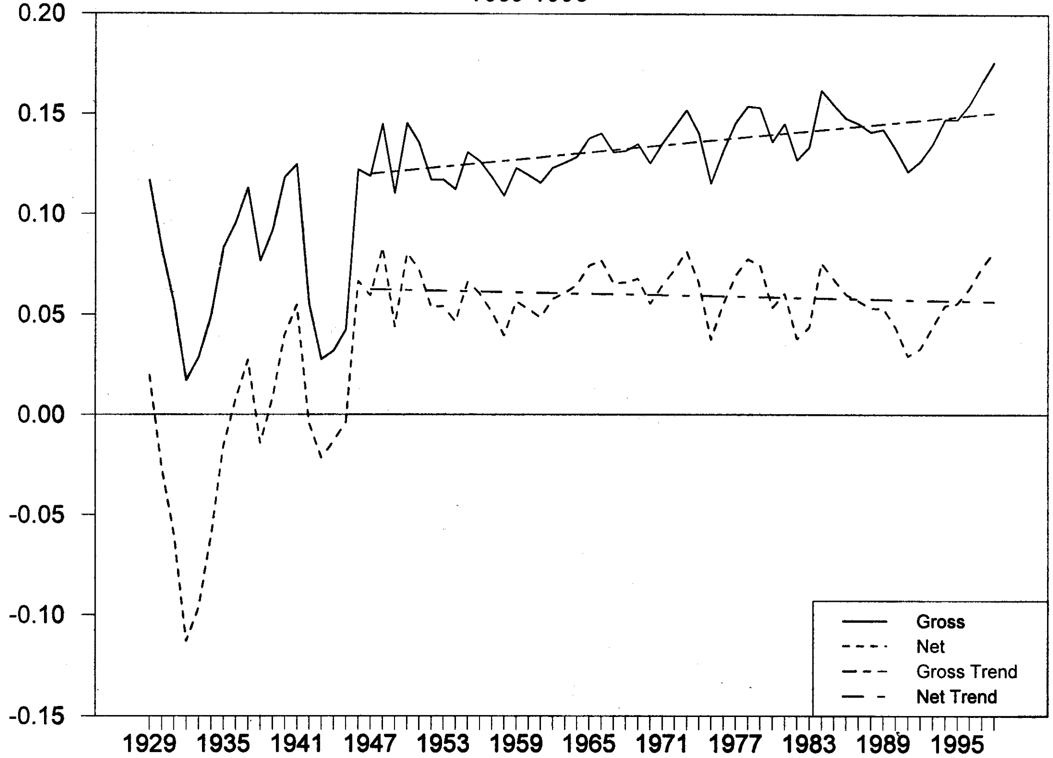

Figure 6. The Average Depreciation Rate

and the Equipment-Structures Ratio, 1929-1998