

(Un)Balanced Growth

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Since the late 1800s, real output in the United States has been growing at a steady rate of about 3.5 percent per year (see Figure 1).¹ With the exception of the 20 years between 1930 and 1950, the real aggregate capital stock of the United States has also been growing at that same steady rate. Thus, although output tripled and capital increased by a factor of 2.5 over this time period, the capital-output ratio remained roughly constant before 1930 and after 1950. Available data also indicate that the relative price of capital in terms of consumption goods has not changed much since the 1950s. In this article I review to what extent the stability of the aggregate capital accumulation pattern actually masks substantial changes in the composition of the aggregate capital stock—namely, changes in the relative importance of equipment and structures.

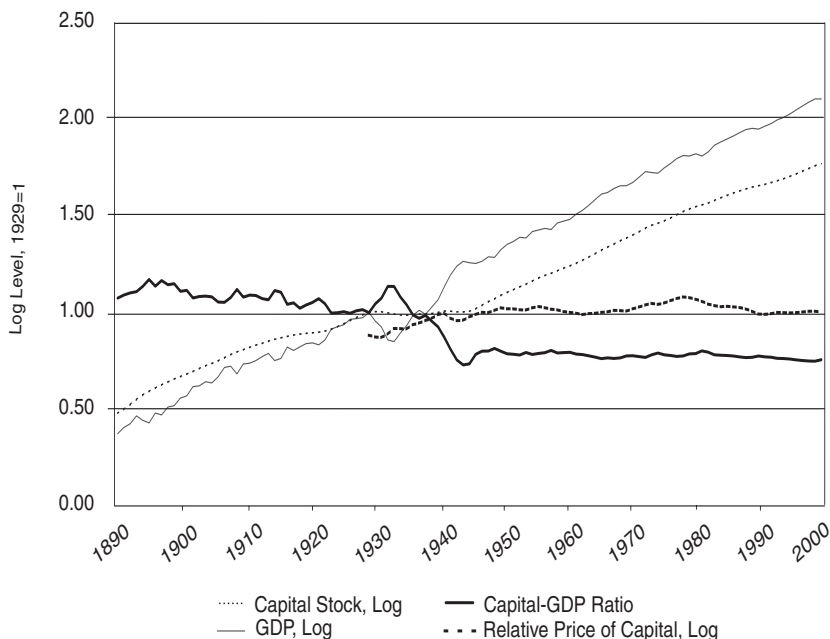
The observed stability of output and capital growth rates and the capital-output ratio are part of the “stylized facts” of growth (Kaldor 1957, 1961). The stylized facts also include the observations that the rate of return on capital and factor income shares have remained stable over long time periods in the United States and other industrialized countries.² These observed regularities suggest that a common theoretical framework might be able to account for the output and capital accumulation path of the U.S. economy and other industrialized economies over the last 100 years. Indeed, neoclassical growth theory was built around the stylized facts of growth.

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¹ Detailed descriptions of the data used in this paper are in the Appendix.

² The rate of return on capital as measured by the real return on equity in the United States has not changed much over time. Siegel (1998) calculates an average rate of return on equity of 7.0 percent for the time period 1802–1870, 6.6 percent for 1871–1925, and 7.2 percent for 1926–1997. Using BEA figures on nonfarm private business factor incomes, I calculate wage income shares for the time period 1929–2001. The average wage income share is 0.66 and varies between 0.63 and 0.72 with no discernible trend. If I exclude the housing sector, the average wage income share is 0.75 and varies between 0.71 and 0.84, again with no discernible trend.

Figure 1 Real Output and Capital in the Private Business Sector, 1889–2001



Notes: A detailed description of the data is in the Appendix.

Neoclassical growth theory assumes that there are two inputs to production: non-reproducible labor and reproducible capital. For a given level of technology, production is constant returns to scale in all inputs, and there are diminishing marginal returns for individual inputs. Technical change is taken as exogenous and is assumed to increase the marginal products of capital and labor for given amounts of inputs. Both inputs are assumed to be paid their marginal product, and the higher marginal product of capital induces more capital accumulation. In an equilibrium, capital accumulation proceeds at a rate such that the return on capital remains constant. Since the labor endowment is fixed, higher productivity and more capital increases payments to labor over time.

Within the framework of neoclassical growth theory, the stylized facts are interrelated. The rate of return on capital, r , is the gross rental rate, u , minus the value of depreciation, δp , plus any capital gains due to changes in the

Figure 2 The Relative Price of New Capital Goods, 1929–2001

Notes: A detailed description of the data is in the Appendix.

price of capital, Δp , divided by the price of capital:

$$r = \frac{u - \delta p + \Delta p}{p} = \frac{uk}{y} \frac{y}{pk} - \delta + \frac{\Delta p}{p}. \quad (1)$$

Conditional on a constant depreciation rate, δ , and a constant price of capital, $\Delta p = 0$, the stability of either two of the three time series—capital-output ratio, capital income share, and rate of return on capital—implies the stability of the third time series.

In neoclassical growth theory, growth is driven by technological change, and capital accumulation responds to technical change, but the source of technical change is not explored. Greenwood, Hercowitz, and Krusell (1997) have argued that technical change in the sector that produces equipment capital is a major source of growth. Their argument for relatively faster technical change in this sector is based on the long-run decline of the relative price of equipment capital. Since the 1960s, the price of equipment capital relative to the price of consumption goods has been falling by about 40 percent, whereas the relative

price of structures has been increasing by about 10 percent (see Figure 2).³ If the relative price of equipment capital has been declining, then the producers of equipment capital must have become relatively more efficient.

Greenwood et al. (1997) evaluate the long-run contribution of different sources of technical change, including the response of capital accumulation to technical change. This is a reasonable procedure since long-run growth depends not only on exogenous technical change, but also on the endogenous capital accumulation response to technical change. But in order to determine the capital accumulation response to hypothetical time paths of technical change, one needs a theory of growth. Greenwood et al. (1997) use a straightforward extension of the aggregate neoclassical growth model to their multi-sector view of the economy, and they use a standard characterization of long-run growth. In particular, they assume that the long-run equilibrium growth path is balanced; that is, all variables grow at constant but possibly different rates. The stylized growth facts represent a balanced growth path (BGP) for the aggregate economy.

In order to obtain a balanced growth path, Greenwood et al. (1997) have to assume that the elasticity of substitution between inputs is unitary; that is, production is Cobb-Douglas (CD) in all sectors of the economy. I argue that the accumulation of equipment and structures in the second half of the 20th-century United States is not characterized by balanced growth. In particular, I argue that equipment capital has become relatively more important over time. This means that the stylized facts of growth do not apply to a more disaggregate view of the economy.⁴ It also means that one cannot argue for a unitary elasticity of substitution between inputs based on growth path properties alone.

The changing composition of the aggregate capital stock does have implications for the implicit aggregate depreciation rate. Because the relative share of equipment capital has increased and equipment capital depreciates relatively faster than structures, the implicit aggregate depreciation rate has increased substantially since the 1980s. With a constant return on capital and a constant capital income share, neoclassical growth theory would then imply that the economy should move towards a new BGP with a lower aggregate capital-output ratio, which we have not observed. Thus, growth theory now appears to be at odds with the stylized facts of growth, at least for the last 20 years.

³ Alternative measures of the relative price of equipment and software that try to account better for changes in product quality (Cummins and Violante 2002) indicate an even bigger decline, about 90 percent, over the same time period.

⁴ This observation alone should not be too surprising since we have known for a long time about the extent of structural change in the U.S. economy and its limited impact on the growth path of the aggregate economy. See, for example, Kuznets' (1971) work on the secular decline of the agricultural sector and the corresponding increase of the service sector.

In Section 1, I describe a balanced growth path for a simple growth model where the relative price of capital is changing on the BGP. In the model are two types of capital: equipment and structures. I show that the capital-output value ratios are constant over time on the BGP but that the capital-output quantity ratios are not constant. In Section 2, I first review the long-run evidence on the ratio of the real capital stock to output. I find that from the late 1800s to the present, the ratio of structures to GDP has been steadily declining, and the ratio of equipment capital to GDP has been steadily increasing since 1950. I then review the evidence on the ratio of the capital value to output value for equipment and structures for the United States from 1950 on and find that these ratios also do not remain constant. It thus appears that we can find evidence for BGP properties of the U.S. economy at the level of aggregate capital only. I then return to the evidence of stable aggregate capital-output ratios and argue that this in fact appears to be evidence against, rather than for, balanced growth since the 1980s because the depreciation rate of the aggregate capital stock has increased substantially since the 1980s. In Section 3, I discuss some implications for modeling long-run growth and economic policy.

1. BALANCED GROWTH WITH MULTIPLE CAPITAL GOODS

I now describe a simple three-sector growth model with two types of capital and a fixed labor supply based on Greenwood, Hercowitz, and Krusell (1997). Technical change is labor-augmenting and sector specific. I will discuss under what restrictions balanced growth can occur—all variables grow at constant but not necessarily equal rates. In particular, I am interested in BGPs where the relative price of capital changes over time. I will focus on the production structure of the economy and disregard any restrictions on preferences necessary for a BGP. I will assume that, for the implied time paths of prices, a constant labor supply and the implied constant consumption growth rate are consistent with an equilibrium.

A Three-Sector Economy

Consider an economy that produces three goods: a consumption good, c , and two investment goods—equipment, x_e , and structures, x_s . Inputs to the production of any of the three goods are labor, n , and the stocks of the two capital goods—equipment, k_e , and structures, k_s . Assume that there is perfect mobility of labor and capital between the production sectors. Let $\rho_i \geq 0$ denote the fraction of labor allocated toward the production of the type $i = c, e, s$ good. Analogously, let $\phi_i \geq 0$ and $\mu_i \geq 0$ denote the fraction of the equipment capital stock and the structures stock allocated toward the production of type i goods. Capital stocks and labor allocated to each sector are limited by the

total endowment of each input:

$$\phi_c + \phi_e + \phi_s \leq 1, \mu_c + \mu_e + \mu_s \leq 1, \text{ and } \rho_c + \rho_e + \rho_s \leq 1. \quad (2)$$

Production is constant returns to scale (CRS), and technical change is labor-augmenting:

$$c = C(\phi_c k_e, \mu_c k_s, A_c \rho_c n), \quad (3)$$

$$x_e = E(\phi_e k_e, \mu_e k_s, A_e \rho_e n), \text{ and} \quad (4)$$

$$x_s = S(\phi_s k_e, \mu_s k_s, A_s \rho_s n). \quad (5)$$

The effective labor input in a sector equals employment times labor-specific productivity, A_i . Labor-specific productivity may differ across sectors and may change at different but constant rates. Time is continuous, and the rate of change of labor-specific productivity is $\hat{A}_i = \gamma_i$.⁵ Investment augments the existing capital stock after depreciation, $\delta_i > 0$:

$$\dot{k}_e = x_e - \delta_e k_e, \text{ and} \quad (6)$$

$$\dot{k}_s = x_s - \delta_s k_s. \quad (7)$$

Balanced Growth with Constant Returns to Scale

On a BGP, all variables change at constant rates.⁶ Since total employment is fixed by assumption, this means that, on a BGP, employment in each sector is constant. Thus, the fraction of labor allocated to each sector, ρ_i , is constant. Given the resource constraint for equipment capital, the rate at which the use of equipment capital grows in each sector must be the same as the growth rate of total equipment capital. Therefore, the fraction of equipment capital, ϕ_i , allocated to each sector remains constant on a BGP. By the same argument, the fraction of structures, μ_i , allocated to each sector remains constant.

The equations for capital accumulation, (6) and (7), imply that on a BGP, the investment-capital stock ratio is constant for each capital type:

$$\hat{k}_e = \frac{x_e}{k_e} - \delta_e, \text{ and } \hat{k}_s = \frac{x_s}{k_s} - \delta_s. \quad (8)$$

Thus, investment in new capital goods grows at the same rate as does the stock of capital:

$$\hat{k}_e = \hat{x}_e, \text{ and } \hat{k}_s = \hat{x}_s. \quad (9)$$

⁵ In the following, a dot represents the time derivative of the variable, $\dot{y} = dy/dt$, and a hat denotes the growth rate of the variable, $\hat{y} = \dot{y}/y$.

⁶ Variables may remain constant on a BGP; that is, their rate of change is zero.

Since production is CRS, we can rewrite the production functions as

$$c/k_e = C(\phi_c, \mu_c k_s/k_e, n\rho_c A_c/k_e), \quad (10)$$

$$x_e/k_e = E(\phi_e, \mu_e k_s/k_e, n\rho_e A_e/k_e), \quad \text{and} \quad (11)$$

$$x_s/k_s = S(\phi_s k_e/k_s, \mu_s, n\rho_s A_s/k_s). \quad (12)$$

A sufficient condition for a BGP to exist is then that each argument in the rescaled production functions, (10) to (12), is constant; that is,

$$\hat{k}_s = \hat{k}_e = \hat{A}_c = \hat{A}_e = \hat{A}_s. \quad (13)$$

Note that, without imposing any additional restrictions on the form of the production functions, a BGP exists only if labor-augmenting technical change proceeds at the same rate in each sector.

Relative goods prices do not change on the BGP of a competitive equilibrium if technical change proceeds at the same rate in each sector. In a competitive equilibrium, profit maximizing firms take prices as given and hire inputs until an input's rental rate is equalized with the value of the marginal product of that input. Because inputs are perfectly mobile across sectors, they are paid the same rental rate no matter where they are employed. The conditions for optimal input use are then:⁷

$$u_e = p_e E_e(\phi_e k_e, \mu_e k_s, A_e \rho_e n) \quad (14)$$

$$= p_s S_e(\phi_s k_e, \mu_s k_s, A_s \rho_s n) = C_e(\phi_c k_e, \mu_c k_s, A_c \rho_c n),$$

$$u_s = p_s S_s(\phi_s k_e, \mu_s k_s, A_s \rho_s n) \quad (15)$$

$$= p_e E_s(\phi_e k_e, \mu_e k_s, A_e \rho_e n) = C_s(\phi_c k_e, \mu_c k_s, A_c \rho_c n), \quad \text{and}$$

$$w = C_n(\phi_c k_e, \mu_c k_s, A_c \rho_c n) A_c \quad (16)$$

$$= p_e E_n(\phi_e k_e, \mu_e k_s, A_e \rho_e n) A_e = p_s S_n(\phi_s k_e, \mu_s k_s, A_s \rho_s n) A_s.$$

Normalize the price of the consumption good to one, and let p_e (p_s) denote the price of new equipment (structures) in terms of consumption goods. Let w denote the real wage, that is, the price of labor in terms of consumption goods, and let u_e (u_s) denote the rental rate of equipment (structures) capital. The rate of return on investment in either of the capital goods is also equalized:

$$r = \frac{u_e - \delta_e p_e + \dot{p}_e}{p_e} = \frac{u_s - \delta_s p_s + \dot{p}_s}{p_s}. \quad (17)$$

We now see that if labor-augmenting technical change proceeds at the same rate in each sector, the relative price of capital will be constant on a BGP. Because production is CRS—that is, homogeneous of degree one—the first derivatives of the production function (marginal products) are homogeneous

⁷ The notation, I_i for $I = C, E, S$ and $i = e, s, n$, denotes the partial derivative of the function I with respect to the input i .

of degree zero. We can therefore rewrite equation (14) as

$$p_e = \frac{C_e (\phi_c, \mu_c k_s / k_e, n \rho_c A_c / k_e)}{E_e (\phi_e, \mu_e k_s / k_e, n \rho_e A_e / k_e)}, \quad (18)$$

and, on a BGP, all ratios on the right-hand side are constant. The same argument applies to the relative price of structures.

Balanced Growth With Unitary Elasticity of Substitution

We can construct a BGP where relative goods prices change at a constant rate if production in each sector is of the Cobb-Douglas variety. On a BGP, the total derivative of consumption (3) with respect to time is⁸

$$\dot{c} = C_e \phi_e \dot{k}_e + C_s \mu_s \dot{k}_s + C_n \dot{A}_c \rho_c n. \quad (19)$$

This expression gives us the growth rate of consumption goods in terms of the growth rates of inputs and labor-augmenting technical change:

$$\frac{\dot{c}}{c} = \frac{C_e \phi_e k_e}{C} \frac{\dot{k}_e}{k_e} + \frac{C_s \mu_s k_s}{C} \frac{\dot{k}_s}{k_s} + \frac{C_n A_c \rho_c n_c}{C} \frac{\dot{A}_c}{A_c}. \quad (20)$$

Let $\eta_{Ij} \equiv (\partial I / \partial k_j) (k_j / I)$ denote the input elasticity of type I production with respect to the type j capital good. Then we can write the BGP growth rates for outputs as⁹

$$\hat{c} = \eta_{C,e} \hat{k}_e + \eta_{C,s} \hat{k}_s + (1 - \eta_{C,e} - \eta_{C,s}) \hat{A}_c, \quad (21)$$

$$\hat{x}_e = \eta_{E,e} \hat{k}_e + \eta_{E,s} \hat{k}_s + (1 - \eta_{E,e} - \eta_{E,s}) \hat{A}_e, \text{ and} \quad (22)$$

$$\hat{x}_s = \eta_{S,e} \hat{k}_e + \eta_{S,s} \hat{k}_s + (1 - \eta_{S,e} - \eta_{S,s}) \hat{A}_s. \quad (23)$$

On a BGP, investment grows at the same rate as the capital stock (9), implying the following system of equations for the growth rates of consumption and capital goods:

$$\hat{c} = \eta_{C,e} \hat{k}_e + \eta_{C,s} \hat{k}_s + (1 - \eta_{C,e} - \eta_{C,s}) \hat{A}_c, \quad (24)$$

$$(1 - \eta_{E,e}) \hat{k}_e - \eta_{E,s} \hat{k}_s = (1 - \eta_{E,e} - \eta_{E,s}) \hat{A}_e, \text{ and} \quad (25)$$

$$-\eta_{S,e} \hat{k}_e + (1 - \eta_{S,s}) \hat{k}_s = (1 - \eta_{S,e} - \eta_{S,s}) \hat{A}_s. \quad (26)$$

Thus, a BGP with potentially different rates of labor-augmenting technical change exists if the input elasticities are constant. That is, the production functions are of the Cobb-Douglas (CD) variety. For example, the production

⁸ I have used the fact that the total labor endowment is constant, and, on a BGP, the fraction of resources allocated to each sector remains constant.

⁹ Because of constant returns to scale, the input elasticities sum to one.

function for consumption goods is

$$c = (\phi_c k_e)^{\eta_{C,e}} (\mu_c k_s)^{\eta_{C,s}} (A_c \rho_c n)^{1-\eta_{C,e}-\eta_{C,s}}, \quad (27)$$

with $\eta_{C,e}, \eta_{C,s}, 1 - \eta_{C,e} - \eta_{C,s} \geq 0$. Analogous expressions hold for the production of new equipment and structures. For CD production functions, the elasticity of substitution between inputs is unitary. That is, cost minimizing firms respond to a 1 percent increase in the relative price of an input with a corresponding 1 percent reduction in the relative usage of that input such that the cost share of the input remains constant at the input elasticity.¹⁰

We can now derive expressions for the rate of change of relative capital goods prices. Using the CD production structure, we can rewrite the condition for the profit maximizing use of equipment capital (14) as

$$u_e = \frac{\eta_{C,e} c}{\phi_c k_e} = p_e \frac{\eta_{E,e} x_e}{\phi_e k_e} = p_s \frac{\eta_{S,e} x_s}{\phi_s k_e}. \quad (28)$$

Given the constant input elasticities and the constant allocation shares of total equipment capital, this expression implies that the rates of change for relative prices are given by

$$\hat{p}_e = \hat{c} - \hat{k}_e \text{ and } \hat{p}_s = \hat{c} - \hat{k}_s \quad (29)$$

Thus, the relative price of capital in terms of consumption goods will change if capital accumulation proceeds at a different pace than does consumption growth. On the other hand, even if capital accumulation proceeds at a different pace than does consumption growth, the value of the capital stock relative to the value of consumption will remain constant. Finally, equation (28) for equipment and the corresponding expression for structures also imply that the rate of return on investment in either of the capital goods is constant.

The implications of the CD production structure for a BGP are most easily seen if we further simplify the production structure and assume that input elasticities (income shares) are equal in all industries, $\eta_{I,j} = \eta_j$ (see, for example, Greenwood, Hercowitz, and Krusell 1997). In this case, consumption and capital growth rates on the BGP are

$$\hat{c} = \eta_e \hat{A}_e + \eta_s \hat{A}_s + (1 - \eta_e - \eta_s) \hat{A}_c, \quad (30)$$

$$\hat{k}_e = (1 - \eta_s) \hat{A}_e + \eta_s \hat{A}_s, \text{ and} \quad (31)$$

$$\hat{k}_s = \eta_e \hat{A}_e + (1 - \eta_e) \hat{A}_s. \quad (32)$$

The rates of change for relative prices are

$$\hat{p}_e = (1 - \eta_e - \eta_s) (\hat{A}_c - \hat{A}_e), \text{ and } \hat{p}_s = (1 - \eta_e - \eta_s) (\hat{A}_c - \hat{A}_s). \quad (33)$$

¹⁰ This fact is immediate from equations (14) to (16) and the constant input elasticities.

Note that the relative price changes directly reflect differences in the rates of labor-augmenting technical change.

Finally, we can define real output as total output in terms of consumption goods:

$$y = c + p_e x_e + p_s x_s.$$

Since capital investment grows at the same rate as capital stocks and since the value of capital grows at the same rate as consumption, real output grows at the same rate as consumption.

2. OBSERVATIONS ON CAPITAL ACCUMULATION IN THE UNITED STATES, 1869–2001

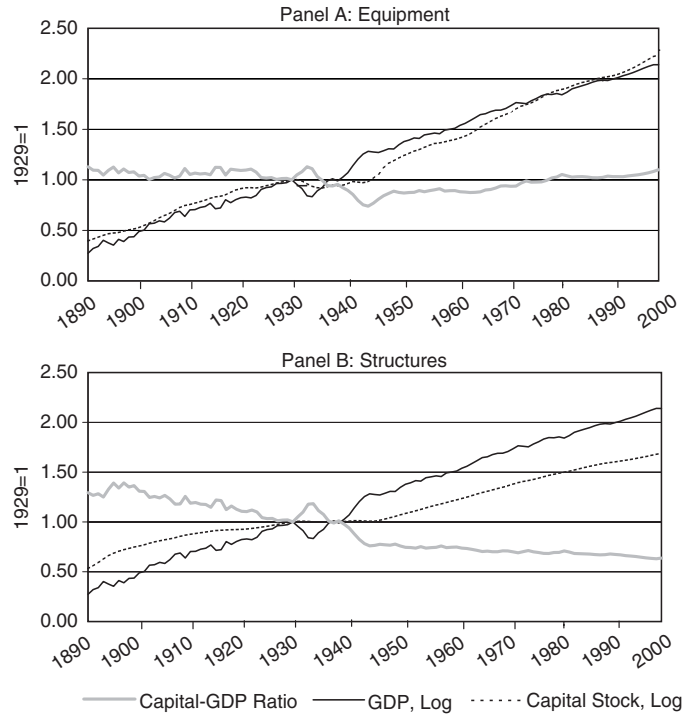
The fact that the relative price of equipment capital declined substantially, whereas the relative price of structures increased somewhat, suggests a differential productivity growth rate in the two broadly defined capital goods-producing sectors. An economy with productivity growth rates that are constant but different across capital goods-producing sectors can still achieve a BGP. Note that, however, on the BGP, the capital-output value ratios remain constant but that the capital-output quantity ratios do not. I now argue that there is no evidence for balanced growth in the United States economy at this more disaggregate level. Over the long run, capital-output quantity ratios do not appear to be stationary, and, for the post-WWII period, the equipment capital-output value ratio does not appear to be stationary either. Finally, I argue that one of the conditioning assumptions for balanced growth at the aggregate level—namely, constant depreciation rates—also does not hold for the late 20th century. Some of the changes in depreciation rates have to be attributed to the changing composition of the aggregate capital stock.

The structure of the U.S. economy changed drastically over the time period I consider. For example, government accounted for between 4 and 5 percent of GDP in the late 1800s, but since the 1930s, government's share in GDP has increased to about 10 percent. Within the private business sector, the share of value added that originated in agriculture declined from 30 percent in 1889 to 10 percent in 1930. It then stayed there until the mid-1940s and since then has declined to less than 1 percent.¹¹ These changes in GDP shares are also reflected in the changed employment shares of government and agriculture, but they are not the focus of this article.¹² In an attempt to limit the potential impact of this structural change on the BGP properties of capital-output ratios, I limit my analysis to output and capital in the nonfarm private business sector.

¹¹The shares for the pre-1929 period are calculated from Kendrick's (1961) constant dollar estimates, and the shares for the post-1929 period are from BEA's current dollar estimates. In 1930, the shares based on constant and current dollar estimates are both roughly the same.

¹²See, for example, Kuznets (1971).

Figure 3 Real Capital and Output in the Nonfarm Private Business Sector, 1889-2001



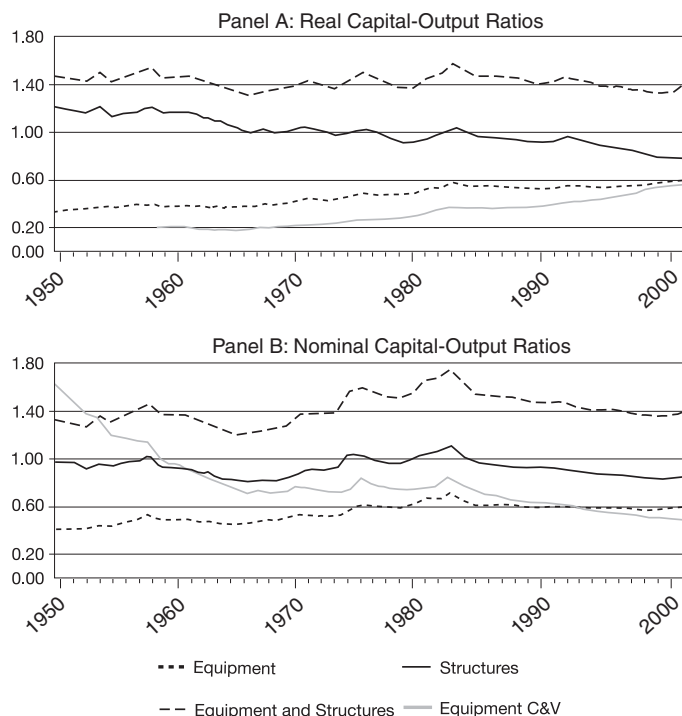
Notes: A detailed description of the data is in the Appendix.

Capital-Output Ratios for Equipment and Structures

Over the long run, capital-output quantity ratios for either equipment or structures do not appear to be stable. Figure 3 displays real nonfarm private GDP, nonfarm private equipment and structures, and the relevant capital-output ratios from 1889 to 2001. The stock of structures includes residential structures. There is a clear downward trend in the capital-output ratio for structures—the ratio has been falling steadily since the late 1800s, from 1.4 to 0.6 today. The behavior of the equipment capital-output ratio is more ambiguous. This ratio appears to be quite stable before 1929, then declines substantially until the 1950s and from then on shows a clear upward trend.

We now study the capital-output quantity and value ratios for the nonfarm private business sector, excluding housing. A big component of the housing sector output in National Income and Product Accounts (NIPA) consists of

Figure 4 Capital-Output Ratios in the Nonfarm Private Business Sector Excluding Housing, 1950–2001



Notes: A detailed description of the data is in the Appendix.

imputed rental income for owner-occupied housing. One could argue that NIPA data that includes residential housing is less reliable and that one should therefore focus on the non-residential business sector. Figure 4 graphs the capital-output quantity and value ratios for this sector. Even though residential structures are now excluded, the structures-output quantity ratio continues to decline for the period from 1.3 in 1950 to 0.8 in 2000. The structures-output value ratio, however, remains relatively stable over this time period. For equipment capital, we see that both the quantity and the value capital-output ratio increase from 0.4 in 1950 to 0.6 in 2000.

Figure 4 also includes real and nominal equipment-output ratios based on updated data from Cummins and Violante (2003). Cummins and Violante (2003) argue that the official NIPA figures overestimate the inflation rate for equipment capital because they do not appropriately account for quality change. Based on Cummins and Violante (2003), the real equipment-output ratio increased drastically from 0.2 in 1960 to 0.7 in 2000. On the other hand,

according to their numbers, the nominal equipment-output ratio actually fell from 1.6 to 0.5.¹³

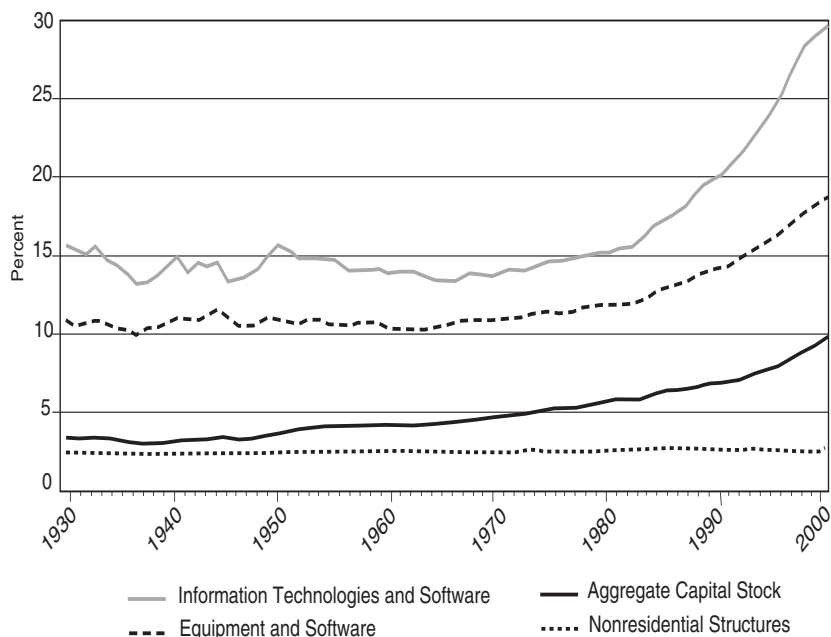
Other Related Work

Maddison (1991) also argues that real capital-output ratios are not stationary, in particular, that the ratio of nonresidential capital to GDP changed substantially for some countries other than the United States. According to Maddison (1991, 67), from 1890 to 1987 the capital-GDP ratio doubled for the UK (from 0.95 to 2.02) and almost tripled for Japan (from 0.9 to 2.8). Maddison (1991) also calculates big increases for France and Germany from 1913 to 1987. Finally for the 19th-century United States, Gallman (1986, 192) argues that the real equipment capital-GDP ratios actually increased from 0.15 in 1840 to 0.91 in 1900 and that the corresponding nominal capital-GDP ratios increased from 0.23 in 1840 to 0.40 in 1900. Related to the stability of capital-output ratios on a BGP is the stability of expenditure shares in GDP. Along these lines King, Plosser, Stock, and Watson (1991) argue that the behavior of real private GDP, consumption, and investment in the United States satisfies the balanced growth conditions from 1949 to 1988. Their statistical tests indicate that output and consumption, as well as output and investment, are cointegrated and that the consumption-output and investment-output ratios are stationary. Whelan (2003) reviews the evidence for balanced growth of two expenditure components: consumption and investment. He also emphasizes that in the face of drastically changing relative prices of investment in producer-durable equipment and investment in structures, one should not expect that the ratios of real consumption to real investment in either of the two types remain constant, but rather that the ratios of nominal expenditures remain constant. Whelan shows that for an extended sample—the United States from 1949 to 2000—one can reject the null hypothesis of cointegration for real investment and real consumption, but one cannot reject the null hypothesis of cointegration for nominal consumption and nominal investment.

Depreciation

Depreciation rates for equipment capital have been increasing significantly since the 1980s (see Figure 5). This increase reflects mainly an aggregation

¹³ At first, one might be surprised that the capital-output value ratios for Cummins and Violante (2003) are so different from the corresponding NIPA ratios. After all, we usually observe values, and the problem is one of obtaining a quantity index by deflating values with an appropriate price index. The problem with capital is that most capital is not traded, so we do not observe values. The NIPA procedure to obtain current values of the capital stock is to evaluate the estimated real capital stock at the current prices of capital stocks. I have used the same procedure to obtain capital stock values for Cummins and Violante (2003), and there is no reason to expect that the two estimates should agree on their values.

Figure 5 Depreciation Rates, 1926–2001

Notes: A detailed description of the data is in the Appendix.

effect since information technology (IT) equipment has higher depreciation rates than other equipment capital types, and the relative share of IT in total equipment has been increasing as part of the IT revolution. Assuming a stable real rate of return on capital, higher depreciation rates require a higher rental rate of capital to satisfy the optimal capital accumulation condition (1). This, in turn, implies that the aggregate capital-output ratio should have declined significantly, since the capital income share has remained stable for this time period. Thus, the stability of the aggregate capital-output ratio since the 1980s suggests that the behavior of the U.S. economy has not been well approximated by a BGP.

The aggregate depreciation rate on private nonfarm capital increased from about 4 percent before the 1970s to about 10 percent in the year 2000 (see Figure 5). Based on the neoclassical growth model, this increase in the depreciation rate should have resulted in a significant decline of the capital-output ratio. Before 1970, the capital-output ratio for the nonfarm private business sector was about 2.5 (1.5, excluding housing), and the capital income share was about 0.33 (0.25, excluding housing) (cf. footnote 2). Assuming a con-

stant price index for the aggregate capital stock and use of the optimal capital accumulation condition (1) implies a 9.3 (12.5, excluding housing) percent rate of return on capital.¹⁴ An increase of the depreciation rate to 10 percent would then imply that the capital-output ratio should decline to 1.7 (1.1, excluding housing), conditional on a constant return on capital and a constant capital income share. We have not observed such a decline in the capital-output ratios.¹⁵

I interpret the depreciation rates constructed from the BEA depreciation and capital stock series as physical depreciation of the capital stock. Whelan (2002) argues that this is not a valid interpretation of the BEA depreciation rates since the BEA frequently applies depreciation schedules in its procedures that include both physical and economic depreciation. While this is a valid concern, it does not necessarily affect our conclusions. First, to the extent that the BEA data overestimate the depreciation of the capital stock, they also underestimate the size of the capital stock. This means that the equipment capital-GDP ratio should have increased even faster over the last 20 years, implying that the aggregate capital-output ratio would have increased rather than remained stable. Second, it is not clear that the higher depreciation rate observed for the BEA data can only be attributed to faster economic depreciation. IT equipment depreciates at a rate of more than 20 percent, which is substantially higher than the 10 to 20 percent rates of other equipment capital.¹⁶ Thus, the composition effect induced by an increase of the relative share of IT equipment alone increases the aggregate depreciation rate.

3. CONCLUSION

Does it matter whether the time path of the economy is characterized by balanced growth? Yes. Observed empirical regularities are important for the development of our understanding of how the economy works, and a breakdown in one of these empirical regularities might be viewed as a setback. The perceived stylized facts of growth certainly stimulated research on growth, and the neoclassical growth theory provided a simple interpretation of the facts that added to the appeal of that theory. On the other hand, since the behavior of the capital-output ratio over the last 20 years apparently no longer conforms

¹⁴ Note that these estimates for the return on capital are significantly higher than other estimates, such as Siegel's (1998) estimate of 7 percent for the long-run rate of return on equity.

¹⁵ One can argue that it takes some time for the economy to converge to the new BGP, given the new higher depreciation rates. Note, however, that for the observed capital income shares and depreciation rates, convergence—as predicted by the growth model—tends to be fast, and a higher depreciation rate speeds up the convergence process.

¹⁶ In a recent reevaluation of the BEA depreciation scheme for PCs, Doms et al. (2003) have found annual depreciation rates of up to 35 percent, even accounting for quality change and economic depreciation. The work of Doms et al. (2003) has already been incorporated in the 2003 NIPA revisions.

to the stylized facts, it may just point to some structural break. After all, there was also a structural break in the aggregate capital-output ratio between 1930 and 1950, and the ratio was quite stable before 1930 and after 1950. We would then have to come up with some explanation for this structural break. The behavior of the aggregate capital-output ratio is also of some interest for the evaluation of monetary policy. Some observers have argued that the investment boom in the late 1990s was in part due to monetary policy that did not raise interest rates fast enough. The collapse of the investment boom and the ensuing 2001 recession are then attributed to having too much capital around, that is, overcapacities. In order to talk about whether the capital stock is too high, one needs an estimate of the “normal” capital stock. If the long-run capital-output ratio is quite stable, we might use this ratio to construct a good first indicator of the “normal” capital stock. Since the aggregate capital-output ratio at the end of the 1990s was not much out of line with its long-run average, we would therefore conclude that the investment boom of the 1990s did not result in any overcapacities. Thus, it did not contribute to the 2001 recession. On the other hand, taking into account the substantial increase of aggregate depreciation rates, we should conclude that the “normal” capital-output ratio was much lower than the observed capital-output ratio. Thus, the investment boom did result in “excess” capital.

APPENDIX

Economic time series are usually reported in current prices—nominal terms. For much of our analysis, we want to eliminate the effect of price level changes and use time series in “real” terms. These real time series are supposed to reflect quantity rather than price movements. Given the level of aggregation we usually deal with, the construction of aggregate quantity indexes is neither easy nor unambiguous. Most data on historical “real” series calculate constant-dollar base period quantity indexes. That is, aggregate quantities are constructed by weighting individual quantity series with a fixed set of base period prices. For the most part, aggregation procedures are a matter of convention, but based on economic theory, some indexes are better than others. One can make an argument that quantity indexes from constant base period prices are not very reliable indicators for quantity movements when large changes of relative prices occur during the period of interest. In response to these concerns, the Bureau of Economic Analysis (BEA), which provides the National Income Accounts for the United States, has shifted from quantity indexes that are based on constant base period prices to chain-weighted quantity indexes that deal better with relative price changes. The BEA constructs Fisher-Ideal quantity indexes that, for most applications, are well approxi-

mated by Divisia-quantity indexes. For a more detailed description of the BEA procedures, see Seskin and Parker (1998) or USBEA (1997).

Output

The GDP series used in this article are from Kendrick (1961) and the official NIPA series published by the BEA. Output in Figure 1 is real private business GDP; in Figure 3, output is real nonfarm private business GDP, and in Figure 4, output is real (nominal) nonfarm private business GDP, excluding the contributions of the housing sector. For the long-time series in Figures 1 and 3, I splice the constant 1929 dollar GDP series from Kendrick (1961) with the chained 1996 dollar GDP series from the BEA in 1929 at the level of 1929 BEA GDP. Obviously, there are potential problems since the two series use different methods to obtain estimates of real activity. Nevertheless the average growth rates of real private business GDP for the pre-1929 and post-1929 periods are remarkably similar—3.8 percent before 1929 and 3.7 percent after 1929. For the time series in Panel A of Figure 4, I construct real nonfarm private business GDP excluding housing as a Divisia index using the series on nonfarm private business GDP and housing GDP.

In this article I rely on the work of Kendrick (1961) for the time period before 1929. Balke and Gordon (1989) provide a useful survey on the different sources for GNP data in the United States before 1929, the most important source being Kuznets (1961). Kendrick (1961) essentially restates Kuznets' estimates of GNP for the definitions used by the Department of Commerce in its construction of the NIPAs. Balke and Gordon (1989) update this early work, but their concern is with the relative volatility of GNP in the period before and after WWII. Since they consider the work of Kuznets (1961) and Kendrick (1961) as providing acceptable estimates of trends, they construct their own GNP estimates around the Kuznets and Kendrick trend estimates. Thus Balke and Gordon's (1989) updates do not affect the information in Kendrick (1961) that is relevant for this article.

Cummins and Violante (2002), discussed below, have recently provided alternative estimates of the price deflator for producer-durable equipment investment. Using this alternative deflator affects the measure of real investment and, in turn, the measure of the real capital stock and real GDP. In Figure 4, Panel A, I also display an equipment capital-GDP ratio that is based on Cummins and Violante's (2002) measure of real nonfarm private business GDP, excluding housing, and their estimate of the real capital stock.

Capital Stock

The capital stock series in this article is based on Kendrick (1961) and on the official fixed durable asset series published by the BEA. Capital in Figure 1 is real total private capital; in Figure 3, it is real nonfarm private capital; and

in Figure 4, it is real (nominal) nonfarm private capital excluding residential structures. From 1889 to 1953, Kendrick (1961) provides constant 1929 dollar estimates of farm structures and land, nonresidential structures and equipment, and residential structures.

Total capital is the sum of all these capital stocks. From 1929 to 2001, the BEA provides data on current and chained 1996 dollar estimates of capital stocks and depreciation for agricultural equipment (tractors and other farm machinery) and structures, nonresidential equipment (information technology and software, transportation equipment, etc.) and structures, and residential equipment and structures. The quantity index for individual asset classes is constructed based on the perpetual inventory method using deflated investment expenditures and estimates of the depreciation pattern for that class. The current dollar estimate is then calculated as the quantity index for the stock evaluated at current prices. To the extent that I have to construct quantity indexes from the BEA data, I construct them as Divisia indexes from the available current dollar and chained dollar estimates.

Real capital stock estimates by Kendrick (1961) and the BEA are quantity indexes of the real value of capital. That is, the components of the aggregate quantity index are weighted using their asset values. For the nominal capital-GDP ratios in Figure 4, Panel B, the nominal asset value series for capital are appropriate. From the point of view of production theory, one would prefer a quantity index that uses factor rental weights for the different assets in the aggregation procedure for the real capital-GDP ratios in Figures 1, 3, and 4 (Panel A).¹⁷ A capital stock index that is based on factor rentals better reflects the role of capital as an input to production and is used in total factor productivity studies (see, for example, Jorgenson, Gollop, and Fraumeni 1987). A problem with this approach is that we do not have observations on the average factor rentals of individual asset categories. The usual procedure is then to impute factor rentals based on required returns on capital using a version of equation (17) (Hall and Jorgenson 1967).

For the long time series in Figures 1 and 3, I splice the constant 1929 dollar capital stock series from Kendrick (1961) with the chained 1996 dollar capital stock series from the BEA in 1929 at the level of 1929 capital stock. From 1929 to 1954, the Kendrick and BEA series overlap and do not behave very differently.

I also display in Figure 4 the equipment capital-GDP ratio based on Cummins and Violante's (2002) estimates of the real equipment capital stock. For the nominal capital-GDP ratio in Figure 4, Panel B, I evaluate Cummins and Violante's (2003) estimate of the real equipment capital stock using their price deflator for new equipment capital.

¹⁷ For a discussion, see Whelan (2002).

Depreciation

The depreciation rates are based on official fixed durable asset series published by the BEA. The depreciation rates in Figure 5 are the ratio of nominal depreciation to nominal capital stock. The alternative calculation of depreciation rates as the ratio of constant-dollar depreciation to constant-dollar capital stocks yields slightly lower depreciation rates, but they are also increasing from the mid-1980s on.

Prices

For the period 1929 to 2001, the BEA provides current and chained 1996 estimates of personal consumption expenditures (PCE) for nondurable goods and services separately. I aggregate these to a nondurable goods and services index—consumption price index for short. For the same time period the BEA also provides price indexes for new investment in equipment and software and nonresidential structures. We can compare these price indexes with the capital price indexes implied by the current value and quantity indexes for the capital stock. Although the new investment price index and the implied capital price index are not the same, they follow each other closely, more so for structures than for equipment. The relative price of capital in Figure 1 is the implied capital price index for total private capital relative to the consumption price index. The relative capital prices in Figure 2 are the implied capital price indexes of nonfarm equipment and software and structures relative to the consumption price index. Figure 2 also displays an alternative relative price index for equipment and software constructed by Cummins and Violante (2002). Following the work of Greenwood, Hercowitz, and Krusell (1997), Cummins and Violante (2002) essentially extrapolate the quality adjustments of Gordon (1990) for producer-durable equipment prices from the time period 1947–1983 to the period 1983–2001.

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