Reinterpreting Economic Growth: Parables and Realities

Moses Abramovitz, Paul A. David

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INTERPRETATIONS OF ECONOMIC GROWTH

Reinterpreting Economic Growth: Parables and Realities

By MOSES ABRAMOVITZ AND PAUL A. DAVID*

"History," said Voltaire, "is a fable agreed upon." In these days, when the concept of an aggregate production function has become so widely accepted, we might well be moved by the truth of this aphorism. Surely any history of an economy's growth will today be no more, and no less than a *parable* agreed upon.[1] This, however, does not require turning a wholly blind eye to the perils of reification. One need not imply—and in this paper we do not mean to suggest—that the production function has an independent existence which would warrant literally regarding "it" as a causal determinant of the temporal path traced by the economy. Instead, an hypothesized set of stable or regularly changing aggregate supply relationships may be viewed as an historical summation of growth processes which in reality were played out at the microeconomic level.[2] And yet if the historian must occasionally pause and attempt to comprehend some unity in the diversity of the microeconomic experience of growth, how better than by essaying simple parables wherein there may appear this mythical, functional figure, endowed with properties and powers induced from, and so consistent with, the record of the past.

I

One may ask, then, by what style of growth fable should students of the *U.S.* economy be most persuaded? If pressed for a short answer to this rather metaphysical question, we should resist the temptation to respond with the sort of story that the modern theorists of growth find especially enchanting. To subscribe to that vision, we would have to depict the establishment of a "modern" rate of increase of per capita product as the consequence of attaining a balanced-growth path along which capital accumulation keeps pace with output expansion, the real rate of return on capital and the savings rate remain constant, and steady (Harrod neutral) technological progress continues to raise the efficiency of labor—thereby carrying both the capital-labor ratio and the level of labor productivity ever upwards.[3]

* Professors of economics, Stanford University. The present paper has grown out of a long collaborative research project on economic growth in the United States, financial support for which was generously provided by the Social Science Research Council. A more detailed treatment of the first part of the story summarized here will be forthcoming in 1973 under the title "American Growth in the Nineteenth Century: Historical Realities and Neoclassical Parables." Full acknowledgement cannot be made here of the many who have helped in the course of this work. We must, however, express our gratitude to the following people for their suggestions, comments, and criticisms on an earlier version (1971) of this paper: Edward Denison, Stanley Engerman, Sol Fabricant, Zvi Griliches, Stanley Lebergott, Alan Manne, R. C. O. Matthews, M. M. Postan, Theodore Schultz, Robert Solow, and Peter Temin. We have not managed to absorb all this help, and they must not be held culpable simply by virtue of having offered it.

[1] The reference can only be to P. A. Samuelson (1962).

[2] In this we find ourselves in close agreement with the position stated recently by M. I. Nadiri, p. 1146.

[3] For a starkly explicit, elementary presentation of the steady-state conception of the history of growth in a

But general economic growth as we have known it is not a balanced, steady-state affair in essence any more than it has been such in its myriad realistic details. Rather, central features of the historical process of growth since the earliest years of the Republic may best be viewed as part of a sequence of *technologically induced traverses*, disequilibrium transitions between successive growth paths—each new path being characterized by higher wealth-output proportions and *a fortiori* by per capita output levels higher than the one left behind.

This broad historical conception is equally antithetic to the views now held by economists and economic historians who regard structural change as the central feature of economic development. Their orthodoxy nowadays disparages "the old-fashioned view that capital as narrowly defined is the critical factor"; for an understanding of the acceleration of per capita product growth to its characteristic modern pace of 1.5 to 2.0 percent per annum, we are told to look first not to conventional capital accumulation, but rather to the conditions causing a higher rate of increase of total factor-input efficiency.[4]

In the United States, however, over the course of the nineteenth century the pace of increase of the real gross domestic product was accounted for largely by that of the traditional, conventionally defined factors of production: labor, land, and tangible reproducible capital. The long-term growth rate of total factor productivity lay in a low range from 0.4 to 0.6 percent per annum! This was no more than a tenth to a seventh of the secularly persistent 4.0 percent annual rate of growth in the real gross domestic product; it represented less than two-fifths of the prevailing rate at which per capita output was rising.

Between the first and second halves of the century (the trend periods 1800–1855 and 1855–1905 in Table 1, to be precise) the long-term per capita output growth rate underwent acceleration, increasing by roughly 0.5 percentage points to the 1.7–1.9 percent per annum level which has been maintained in the *U.S.* economy throughout the last one hundred years. This acceleration was entirely attributable to the quickened growth of real product per manhour. Yet the movement initially owed little to the rise of the residual; the trend rate of total factor-productivity growth was not appreciably increased between the consecutive periods 1800–1855 and 1855–1890. (See Table 2.)

Indeed, between the antebellum era (1800–1855) and the half century that followed, there occurred a decline in the *relative* contribution made by total factor-productivity growth to the growth rate of labor productivity—a fall from 60 percent to 45 percent, with a corresponding rise in the relative contribution of the growth of land and reproducible capital in relation to labor inputs. Over an extended transitional period stretching from around 1835 to 1890, the average growth rate of labor productivity was approximately 0.75 percent per annum, of which at least six-tenths (more than 0.4 percentage points) must be assigned to the effects of the near doubling of the reproducible capital-gross product ratio.[5] Thus we may say that virtually all

capitalist economy, specifically the United States, see Samuelson 1970, ch. 36. Further along in the same vein, see R. M. Solow.

[4] The quotation is from D. C. North (1966b, p. 88) who dismisses W. W. Rostow's concept of an American "take off" as ascribing undue significance to increases in the net capital formation rate. See also North (1965). On the contribution of faster factor-productivity increase to "modern economic growth" in general, see S. S. Kuznets (1971, ch. 2) and the appreciative review by C. Clark (p. 816).

[5] The calculation is not explicitly reported in the accompanying tables, but the result may be obtained from the data in Table 2 as the ratio of $\theta_K(\mathbf{K}-\mathbf{Y})$ to the sum: $\mathbf{E}+\theta_K(\mathbf{K}-\mathbf{Y})+\theta_R(\mathbf{R}-\mathbf{Y})$. In the constant returns case, the latter magnitude equals $\theta_L(\mathbf{Y}-\mathbf{L})$. Boldface denotes proportional rate of change in the respective variables.

TABLE 1—GROWTH IN THE U.S. PRIVATE DOMESTIC ECONOMY
Average Annual Growth Rates
(Percentages)

Conventional Factor Input Measures	1800–55 "Crude"	1855–1905 "Crude"	1905–27 "Crude"	1927–67 "Crude"	1927–67 "Refined"[a]
Real Gross Product[b]	4.2	3.9	3.3	3.2	3.2
Per Capita Real Output	1.1	1.6	1.7	1.8	1.8
Labor Input per Capita	0.6	0.5	−0.3	−0.9	0.2
Output per unit of Labor Input[c]	0.5	1.1	2.0	2.7	1.6
Total Conventional Factor Productivity[c]	0.3	0.5	1.52	1.9	1.3

[a] Growth rates refer to the 1929–67 period, rather than to the 1925/29–1965/69 interval—denoted as "1927–1967." See Table 2 for exact dating of terminal observations underlying the periods referred to here.

[b] The output measures for the 1800–1905 period refer to *GDP* inclusive of land improvements and home manufacturing; "crude" measures for 1905–67 relate to *GDP* in the private economy (Commerce Department definition); "refined" measures refer to gross private domestic product inclusive of services of durables owned by households and institutions, after Christensen and Jorgenson, Table 12.

[c] The "crude" factor input measures are manhours and the net capital stock (Divisia index distinguishing unimproved land and all reproducible capital for 1800–1905, simple aggregation of all capital for 1905–1967). The "refined" input measures accept the work of Christensen and Jorgenson, Table 7, as far as concerns their corrections for aggregation biases in undifferentiated manhours and simple aggregate capital estimates.

"Crude" residual factor-productivity growth rates have been computed for 1800–55, and 1855–1905, from the estimates made for shorter trend intervals, e.g., 1853/57–1869/73, 1869/73–1889/92, 1889/92–1903/07, using the estimated factor shares (in gross product) as the weights appropriate to each shorter period. The "Refined" productivity calculation has been made using the input and output growth rates, and average factor share weights from Christensen and Jorgenson, Tables 2, 7, 12.

of the 0.5 percentage point trend acceleration of the per capita product-growth rate recorded in the nineteenth century was purchased in a conventional costly "Grand Traverse" to a higher growth path.

By contrast, the subsequent maintenance of the higher modern per capita output growth rate thereby achieved appears to have involved an elevation of the rate of improvement in the overall *efficiency* of the same three factors of production. So long as the accounting is restricted to noticing only these conventional inputs it is apparent that around the turn of this century there commenced a marked acceleration of the factor productivity growth rate.[6] Starting from 0.3 percent per annum in the period 1855–1890—a level no higher than that maintained over the first fifty-five years of the century—the conventional residual rose to 0.8 percent per annum in the brief *fin du siecle* interval 1890–1905; it then took a second step up to reach the 1.5 percent per annum level during the period 1905–1927. (The dating here corresponds to the subperiods distinguished in Table 2.)

The facts pertaining to the crude productivity residual in the *U.S.* private domestic economy in more recent times are too familiar to bear much repetition. Over the years "1927–1967" the average rate of growth in the productivity of the conven-

[6] Some, albeit less dramatic, intimations of this secular acceleration are found in the published work of J. W. Kendrick (1961) and Robert E. Gallman (1972), upon whose researches we have drawn in fashioning the estimates presented here.

TABLE 2—SELECTED GROWTH RATES AND FACTOR SHARES

Trend Intervals	Average Gross Factor Shares θ_R	θ_K	θ_L	Average Annual Percentage Rates of Growth **R**	**K**	$\mathbf{K}_T$	**C**	**Y**	**E**	
1800 –1834/36	.09	.23	.68	2.81	4.52	3.66	4.04	4.21	0.49	0.28
1834/36–1853/57	.11	.27	.62	3.41	5.54	4.80	4.92	4.15	−0.11	
1853/57–1869/73	.12	.34	.54	2.46	4.44	3.90	3.92	2.96	0.31	0.50
1869/73–1889/92	.10	.35	.55	3.62	5.57	5.16	5.14	4.90		
1888/92–1903/07	.09	.37	.54	1.95	3.94	3.60	3.55	3.78	0.84	
1903/07–1925/29	.46		.54	—	—	2.43	—	3.31	1.52	1.87
1925/29–1965/69	.43		.57	—	—	2.00	—	3.18	1.93	

Notes and Definitions: All observations for 1800–1903/07 refer to *U.S.* domestic economy; observations for 1903/07–1965/69 refer to *U.S.* private domestic economy. "Real" magnitudes for the pre-1903/07 era are expressed in constant 1840, 1860 prices; for the post-1903/07 era, in constant 1929, 1958 prices. Boldface denotes proportional rates of change in the respective variables.

R—Land exclusive of farm improvements.

K—Reproducible capital stock (net basis), including improvements made to farm land.

K_T—Net stock of reproducible and nonreproducible capital, i.e., $K_T = R + K$, by simple aggregation.

C—Divisia index of reproducible and nonreproducible capital stocks, i.e., $\mathbf{C} = (\theta_R\mathbf{R} + \theta_K\mathbf{K})/(1-\theta_L)$.

Y—For 1800–1903/07, real gross domestic product including improvements to farm-land and home-manufacturing output; after 1903/07, real gross private domestic product, Commerce Department concept.

E—Total factor productivity, "crude" residual measurements: for 1800–1903/07, $\mathbf{E} = \mathbf{Y} - [(1-\theta_L)\mathbf{C} + \theta_L\mathbf{L}]$; for 1903/07–1965/69, $\mathbf{E} = \mathbf{Y} - [(1-\theta_L)\mathbf{K}_T + \theta_L\mathbf{L}]$. The labor inputs are measured in (*L*) manhours, and the share weights employed are those indicated for the corresponding trend intervals. Growth rates for periods spanning more than one trend interval are computed as weighted averages of factor productivity growth rates within the constituent intervals.

L—Manhours of (full-time equivalent) labor service. **L** can be computed from the entries in the table for **E**, **Y**, **C**, and θ_L and $\mathbf{K}_T$.

tional factor inputs has represented well more than half the growth rate of real product and has exactly corresponded to the rate of increase of per capita product. When input measurements are made for this recent period on a more "refined" basis, following the work of L. R. Christensen and D. W. Jorgenson in allowing for costly alterations in the detailed quality-mix of the labor force and capital stock, the increase which is found to have occurred over the (crude) factor-productivity growth rates characteristic of the nineteenth century is still very substantial. For, on this refined basis, conventional factor productivity has been growing at 1.3 percent per annum (during 1929–67) and represents nearly three-fourths of the annual percentage increase in output per capita.

The quantitative foundations of this story are broadly displayed in Tables 1 and 2, but this is not the place to review the nature and sources of the underlying detail from which that summary picture has been composed. The full body of data we have assembled will be presented for examination in a later publication. We proceed here to consider only its most obtrusive implications for our thinking about the process of growth in the past and in the present.

II.

Recognition of "the rise of the conventional residual" as an historical development, and as a concomitant of the process of modern economic growth in the United States rather than in any sense a prerequisite for it, should compel, in turn, more general acknowledgement of the restricted temporal relevance of the stress now being given to the growth of *unconventional* capital inputs. In the earlier phases of our development the direct productive impact of investments made in process and product innovation, in health, in labor mobility, and in raising minimum levels of formal education and worker training, must *in toto* have been of very limited quantitative import—certainly far smaller than one would be led to believe by the prominent place accorded these subjects in treatments of American growth by the "new" economic history books.[7]

A search for the origins of activities and institutional arrangements that were eventually to emerge as obtrusive features of modern economic life is, no doubt, of much interest. And it would surely be a mistake to simply dismiss the significant historical part played by human capital formation in promoting and more generally in facilitating the exploitation of technological innovations. The comparatively high level of the educational attainments of the American people, even at the mid-point of the nineteenth century, must have underlaid this society's peculiar receptivity to—nay, restless questing after—novel ways of doing things (Fishlow, 1966a). A generally educated population was surely better prepared both as workers and as consumers to adapt to, and so to adopt, the new products and services, the altered work routines, and the changed locations which technical and organizational progress entailed.[8] But if educational and kindred human investment expenditures in the nineteenth century are to be assigned a role analogous to that of replacement investment in vintage models of the conventional, inanimate capital stock, historians ought not to proceed to do so under any illusion that rapid conventional factor productivity gains resulted from the new "technology" thereby embodied in the work force.[9] After all, there is simply not that much of a crude residual left for sophisticated historical growth accountants to struggle with.

All this is not to say that the Progress of Invention—to revive the phrase used by nineteenth century writers in referring to the broad sweep of technical and institutional innovation—was formerly less important to the process of growth than it is now taken to be. Quite the contrary. A proper interpretation of these findings requires that we first discard the constricting exclusive identification of technological progress with such shifts in the aggregate production function as will have been completely reflected in measured changes of total input efficiency. The issue so raised does not concern the refinement with which the inputs are measured in growth-accounting exercises or the validity of the standard assumption of constant returns to scale. Our point is that there may be more to technological change than the residual can capture, rather than less.

The prevailing quantitative treatment of savings and technological progress as capable of contributing independent, orthogonal components to the labor productivity growth rate has been extremely fruitful in the development of systems of empirical growth accounting and in the formal analysis of the steady-state equilibrium solutions of dynamic models. But the laudable impulse to isolate and unambiguously quantify the effects of technological progress unfortunately has also tended to promote a misleading concep-

[7] On human capital themes, see Bruchey, pp. 178–93; North, 1966a, pp. 172–76, and 1965. R. W. Fogel and S. L. Engerman features Engerman's paper, "Capital, Education and Economic Growth," and versions of Albert Fishlow, 1966b, and Shultz, 1960. S. Lebergott, pp. 124–26, attempts to restore some perspective to the treatment of the subject historically.

[8] Compare the general statement of the relationship between educational and technological progress in Abramovitz, 1972.

[9] See Nelson, 1964, for a formal representation of the symmetry between technological progress being embodied in physical capital and in human beings and its present applicability to the *U.S.* economy.

tion of its character and consequently a misperception of its historical role in the process of economic growth. For the entire conception rests upon the unsupported presupposition that technological change has been "neutral" in its potential impact upon factor supply—typically either Hicks-neutral, as in the former growth-accounting connection, or Harrod-neutral, as in the standard growth-theoretic context.[10]

In reality, it is quite incorrect to blithely assume either form of neutrality at the level of aggregation at which this discussion is pitched; there is good reason to believe, instead, that technological innovation has exhibited significant systematic *bias*, repeatedly disturbing the relative and absolute rates of factor remuneration under the prevailing proportions between capital, labor, and output; that between the past and the present century there has occurred an important change in the nature and extent of those biases in the alteration of input efficiencies; and that the forces which have underlaid the rise of total factor productivity, therefore, are neither immediately identifiable with even the most refined measures of the residual, nor are they able to be so neatly disentangled as we might like from the growth of the various productive inputs, conventional and unconventional.

When describing as "conventional" the forms of accumulation which spearheaded the capital-deepening traverse during the nineteenth century, it is helpful to remember that contemporary commentators regarded the mounting stocks of productive structures and equipment as novel departures, epitomizing the spirit of the modern age. The growing preoccupation of nineteenth century America with capital in the shape of canals, railroads, mines, mills, and machines, like twentieth century America's increasing devotion to health, skills, knowledge, and such intangible human assets, reflects more than a process of passive adjustment to increased thrift. These continuing alterations of the modes in which it becomes attractive to deploy savings, along with the impetus such shifts impart to further capital-deepening, in our view are most plausibly traced to the changing direction of actual capital-deepening biases within the broad array of technical and social innovations which have continually reshaped the United States' economy.

III.

There is scant room here for more than brief allusion to the several lines of argument we should advance in support of these propositions. Perforce there will be no space whatsoever for the many appropriate qualifications.

The view that material progress in the West was intimately bound up with what we would describe as Harrod labor-saving or conventional capital-deepening innovations—innovations permitting the efficiency of labor to be raised only by recourse to more roundabout modes of production—is not new. It was firmly held by E. Böhm-Bawerk, H. Sidgwick, F. W. Taussig, and others among the generation of economists who wrote from the vantage point afforded by the late nineteenth century.[11] A cursory glance at Table 2 suggests that this is a view which has to be taken seriously as far as the American experience is concerned. At the *fin du siecle* (1890–1905), the total gross share of property (i.e., $\theta_{TK}=\theta_K+\theta_R$, reproducible capital and land) in gross domestic product stood at (0.45), a level half again larger than it had been when the century was new, *despite* the intervening rise of the ratio of total capital, K_T, to gross product, V. If

[10] W. W. Chang gives a recent review of alternative taxonomies of innovations and their interrelationships.

[11] Cf. Sidgwick, especially p. 133; Taussig, pp. 7–10; Böhm-Bawerk, *passim*.

we postulate a well-behaved *CES* production function which is first degree homogeneous in the arguments labor, L, and the simple aggregate of all land and conventional reproducible capital, K_T, it becomes necessary to accept one of the two following conditions as true: either (1) the constant elasticity of substitution between labor and all capital exceeded unity, so that over the course of the century the share of the factor that had increased in relative abundance was *enlarged*, or (2) the elasticity of substitution was less than unity but capital-deepening technological change lowered the ratio of capital to labor when both are measured in efficiency units, rendering capital services the increasingly scarce input reckoned on an efficiency basis.

Both theory and fact urge us to embrace the second of these possibilities: theory, because an elasticity of substitution exceeding unity wreaks havoc with the processes of adjustment envisaged in many growth parables; familiar facts throw their weight in the same direction. Empirical studies repeatedly yield less-than-unity estimates of the elasticity of substitution for the *U.S.* domestic economy in the twentieth century—when the same two-factor specification of an aggregate production function is employed.[12]

Yet, as said, it is dangerous to project very recent structures of production upon the distant past. We therefore hasten to mention also certain corroborative indications gleaned from the wretchedly sparse and undoubtedly less reliable data pertaining to the nineteenth century itself. The general line of the approach we have employed may be indicated by sticking with the two-factor model of production for the moment. We shall denote the proportional rate of change in a variable X by boldface, thus $\mathbf{X}$. By regressing the rate of change of the total capital-labor ratio $(\mathbf{K}_T-\mathbf{L})$ on the rate of change of the corresponding relative factor shares $(\boldsymbol{\theta}_L-\boldsymbol{\theta}_{TK})$, taking observations for these variables from the five nineteenth century subperiods distinguished in Table 2, we may obtain joint estimates of the hypothetically constant elasticity of substitution and of the relative labor-augmenting bias of efficiency growth.[13] The former turns out to be $(\hat{\sigma}=.20)$ significantly below unity, and the latter $(\hat{\xi}''=\mathbf{E}_L-\mathbf{E}_{TK}=.017$ per annum) is consequently sufficiently large in relation to the total factor-efficiency growth rate to imply that capital-deepening technological change $(\mathbf{E}_{TK}<0)$ was tending to raise the rate of return to all conventional property. A somewhat more complex specification of an aggregate production function distinguishing two types of nonlabor inputs—reproducible capital and raw (unimproved) land—enables us to carry through a more sophisticated analysis for the nineteenth century, from which we extract the following conclusion: up to the 1890's the same complex of economic and technological transformations that brought greater efficiency of ordinary labor, and similarly "augmented" unimproved land, simultaneously must have been operating so as to raise the desired ratio of reproducible tangible assets to output corresponding to any specified real rate of return.

Turning to more recent history, it would appear that far too little notice has been given the impact of the emerging pace and character of twentieth century technological innovations upon the marginal effi-

[12] Cf. P. A. David and Th. van de Klundert and the earlier findings of I. P. Kravis, K. J. Arrow et al., and J. W. Kendrick and R. Sato, discussed therein. On the ambiguity of tests purporting to confirm the Cobb-Douglas alternative, cf. Herbert A. Simon and Ferdinand K. Levy.

[13] This adaptation of the approach followed by David and van de Klundert is explicitly described in our earlier paper: Abramovitz and David, 1971, pp. 22–23.

ciency of investment in human beings. One has but to stop for a moment to ask how it came about that persons having comparatively extensive formal schooling continue to command attractively large earnings premiums, indeed, premiums that are perhaps large by historical standards, despite the very great increase that has occurred since the beginning of the century in the relative supply of such people in the United States labor force. In our view, the offsetting relative shifts in the demand for more highly educated people derive from heightened needs for reliable performance of communication, coordination, and control functions in an urban society within which the organizational scale and degree of specialization have been steadily pushed upward to take advantage of technical innovations in commodity production. Such derived demand shifts, and the lengthening of the life expectancy of youngsters as a result of advances in medical technology, come most quickly to mind among the array of forces tending to maintain the real rate of return to educational investment in the face of a relatively growing stock—and so have been responsible for prolonging the secular boom in education.[14]

Quite separate from, but paralleling, these influences are the effects flowing from the increasing frequency and regularity of change in production and distribution arrangements. The need for, and more significantly the rate of return on, investments that educate people in general—and not just research and development personnel—to function creatively as problem-solvers depends in good part upon the *actual* pace of technical and organizational innovation, as well as upon the desired rate of efficiency improvement which technological progress is expected to confer (R. R. Nelson, 1964, pp. 591–92).

We contend further that the expansion of systematic investment in research and development activities owes much to the nature of advances in scientific knowledge during the present century—although it is the opposite debt which has lately been more widely proclaimed by economists. So regarded, the fact that contemporary company-financed *R&D* outlays devoted largely to new product development have been especially high in relation to revenues in "science-based" industries, such as chemicals, electrical equipment, and scientific instruments, appears not so much as the cause as it is the consequence of the present configuration of the body of scientific knowledge.[15] The latter, by making it easier to generate saleable new products in these industries, has rendered it profitable to turn over the whole product line more frequently there than in other branches of manufacturing.

At the aggregate level of analysis, however, we have gone no further than to ascertain the quantitative plausibility of the hypothesis that a *global* bias towards unconventional capital-deepening has been manifested by technological progress in the United States during the twentieth century. The approach employed for this purpose broadly resembles that sketched by the preceding resumé of our arguments in regard to the nineteenth century, but there are some differences owing to the absence of any direct comprehensive measures of the unconventional capital stock. As the relevant abstraction we again propose a constant returns production function with generalized factor-augmenting technical change

[14] On this view, the other forces that undoubtedly contributed to the extension of the average period of schooling prior to labor force entry—from the democratization of politics and society, to the improved access of households to sources of external finance—would, by themselves, have been of no avail.

[15] Nelson, Peck, and Kalachek, pp. 77–79, however, advance just the opposite interpretation of the same body of cross-section data.

$$(1) \quad Y = F(G[L'E_{L'}, K'_T E_{TK'}], HE_H).$$

The arguments of this function are conventional labor, total conventional capital, and unconventional, or heterodox, capital inputs, each entering the function measured in efficiency units—the product of a natural unit measure and an efficiency index; as equation (1) indicates, the form of the function is restricted to satisfy the Leontief conditions for separability in the unconventional capital inputs. Letting $(\theta_L - \epsilon_1)$, $(\theta_{TK} - \epsilon_2)$, and $\epsilon = \epsilon_1 + \epsilon_2$ stand for the output elasticities with respect to the three factors of production, it is straightforward to obtain a variation on the familiar relationship between the output growth rate, the input growth rates, and the rates of change of the individual input efficiency indexes:

$$(2) \quad \mathbf{Y} = \theta_L \mathbf{L}' + \theta_{TK}\mathbf{K}'_T + \epsilon_1(\mathbf{H} - \mathbf{L}') + \epsilon_2(\mathbf{H} - \mathbf{K}'_T) + (\theta_L - \epsilon_1)\mathbf{E}_{L'} + (\theta_{TK} - \epsilon_2)\mathbf{E}_{TK'} + (\epsilon_1 + \epsilon_2)\mathbf{E}_H.$$

Now define the conventional factor-productivity growth rate as the "refined" residual measure—weighting the growth rates of Divisia index measures of the conventional labor and capital inputs by their observed shares in gross product, rather than by their (unobserved) "true" elasticity coefficients—

$$(3) \quad \mathbf{E} \equiv \mathbf{Y} - \theta_L \mathbf{L}' - \theta_K \mathbf{K}'_T.$$

Further, entertain the not implausible stipulation that the rates at which inputs of labor and conventional capital have been augmented correspond to the respective growth rates of unconventional capital per unit of labor, and per unit of conventional capital:[16]

$$(4) \quad \mathbf{E}_{L'} = \mathbf{H} - \mathbf{L}' \text{ and } \mathbf{E}_{TK'} = \mathbf{H} - \mathbf{K}'_T.$$

With these specifications we find that if the rate of conventional capital-augmenting advance can be said to have exceeded 0.9 percent per annum during the last four decades (the period 1927–1967), it is justifiable to infer that technological changes have also been tending to promote unconventional capital-deepening in the American economy.[17]

The relevant question, of course, is whether the predicate condition $(\mathbf{E}_{TK'} > .009)$ has in fact obtained; and, given the specification of the model (notably in (4)), this is equivalent to asking whether in the United States the stock of unconventional capital has been growing at least 0.9 percent per annum faster than the stock of conventional tangible assets. Caution is obviously warranted here, for we do not as yet have satisfactory comprehensive measures of the stock of unconventional capital. Caution nonetheless seems consistent with offering a tentative answer in the affirmative: Theodore Schultz's (1961, Table F) estimates of the constant dollar value of the stock of education of the labor force age fourteen and older in 1900 and 1957, taken by themselves, would suggest a long-term growth rate for H of 3.8 percent per annum, fully 1.5 percentage points above the growth rate of the Divisia

[16] This is at least supported by the following empirical agreement: $\mathbf{E}_{L'} - \mathbf{E}_{TK'} \equiv \xi = \mathbf{K}'_T - \mathbf{L}'$. For the period 1929–67 Christensen and Jorgenson's Table 7 gives "refined" estimates of the growth rate of the conventional inputs correcting for aggregation bias in both, from which it is found that $\mathbf{K}'_T - \mathbf{L}' = .007$, coinciding exactly with the trend estimate of $\mathbf{E}_L - \mathbf{E}_{TK}$ obtained for the *U.S.* Private Domestic Economy over the period 1899–1960 by David and van de Klundert. Note that no significant difference between the latter estimate and the conceptually appropriate magnitude $(\mathbf{E}_{L'} - \mathbf{E}_{TK'})$ arises, because for the period 1929–1967 it is found that $(\mathbf{K}'_T - \mathbf{K}_T) - (\mathbf{L}' - \mathbf{L}) = .0062 - .0067 \simeq 0$.

[17] This conditional statement $[\mathbf{E}_H < 0 | \mathbf{E}_{TK'} > .009]$ follows from (a) the familiar relationship which equations (1), (2) and (3) imply, namely $\epsilon\mathbf{E}_H = (\mathbf{E} - \theta_L\xi) - \mathbf{E}_{TK'}$; (b) the values for $\mathbf{E} = .0134$ and $\theta_L = .556$ drawn from Tables 1 and 2 for the period 1927–1967; and (c) the separability specification of the function (3), which permits us to make use of David and van de Klundert's estimate of the relative labor-augmenting bias of conventional factor efficiency growth in the twentieth century: $\xi = \mathbf{E}_{L'} - \mathbf{E}_{TK'} = .007$ per annum.

measures of the conventional capital inputs presented by Christensen and Jorgenson (Table 7).

IV.

In the terms of our parable of a single-sector economy, the long disequilibrium passage to higher wealth-income proportions which characterized the *U.S.* nineteenth century experience, therefore, is not properly regarded as the consequence of the greater exercise of Thrift. To be sure, the real gross savings rate (conventionally defined) did rise dramatically, from about 10 percent before 1840 to 16 to 20 percent in the decades immediately preceding the Civil War, and thence to the 25 to 30 percent level in the period 1869–1899 (R. E. Gallman and L. E. Davis). And without the entailed rise in the net capital formation proportion, the approximate doubling of the capital-output ratio could not have been achieved. Yet, to conceive of this grand traverse simply as an equilibrating adjustment to an autonomous, exclusively supply-driven rise of the savings rate in relation to the growth rate of population and the labor supply would overlook the very reason for its having had a potent effect in lifting the level of labor productivity instead of simply drastically depressing the real rate of return on capital.[18] The historical conventional capital-deepening bias of technological progress, by exerting upward pressure on the real rate of return, in our view must have played some direct part in eliciting and maintaining the higher real savings rates established over the course of the century.

Within the twentieth century, just the opposite sort of shifts in investment demands have played a dominant role in bringing about the decline in conventional capital formation rates recorded by Simon Kuznets (1961) and the U.S. Department of Commerce. The absence of any evidence of a secular rise in the real interest rate, if nothing else, indicates that it is the conventional capital-augmenting effects of technological progress during this century—rather than any *ex ante* reduction in the aggregate propensity to save—which is to be held responsible for the impression of a decline in real net and gross capital formation rates, along with the observed downward course of the conventional capital-output ratio in the private domestic economy.[19]

But there is another, less adequately recorded side to this story, inasmuch as concurrent and related technical and organizational changes have promoted unconventional capital-deepening. The frankly speculative set of calculations we have ventured, attempting to take into account the growth of these unconventional forms of capital, are quite consistent with the view that if all "capital" is considered together, then in the most recent era (since the late 1920's) a condition resembling steady-state growth may eventually have emerged: mutually offsetting technological biases—impinging in opposing directions upon the efficiency of conventional and unconventional capital—have perhaps left the real rate of return and the inducement to deferring consumption essentially undisturbed after all.[20]

The same line of speculation would also suggest that on a full and comprehensive reckoning of capital inputs, beyond any-

[18] Temin has offered a more traditional, neoclassical interpretation, in which the rise in the real (gross) savings rate which occurred over the course of the 1860's is taken to indicate that a substantial decline occurred in the real interest rate.

[19] Cf. David and van de Klundert. Here we find ourselves in agreement with the criticisms offered by Charles L. Schultze of the interpretation advanced by Kuznets 1961.

[20] If we thus assume $(\theta_K - \epsilon_2)\mathbf{E}_{TK'} = -(\epsilon_1 + \epsilon_2)\mathbf{E}_H$, we can solve this with the expression in footnote (17), and find the plausible value $(\theta_K - \epsilon_2) = .400$, i.e., $\epsilon_2 = .044$ for 1927–67.

thing yet to be seriously undertaken, the growth rate of total input efficiency in the recent period 1927–1967 might reasonably be placed in the neighborhood of 0.6 percent per annum.[21] This is a rate far below that indicated by familiar conventional calculations of the residual, even those which measure conventional factors on a "refined" basis by correcting for aggregation errors.[22] Indeed, it is a rate not substantially greater than the crude, conventional factor-productivity growth estimates presented here for the United States during the second half of the nineteenth century.

Is the role of the Progress of Invention revealed to have altered in the course of America's development by the historical rise of the conventional factor-productivity growth rate, or by the vanishing act we have just performed with the contemporary conventional residual? Obviously not. Insofar as technological change has not been neutral, we cannot gauge its full impact without considering its effects upon the changing quantities in which the various productive inputs have been supplied. In these circumstances it seems to us to be fundamentally misleading to persist in seeking to apportion the growth rate of per capita product between the exclusive "contributions" of Invention and Accumulation. Until we are able to articulate the reciprocal interactions between technical and social innovation and alterations in the availability of the factors of production, "the residual" as we have known it must remain at best a lower-bound measure of our ignorance of the process of economic growth.

[21] Under the condition specified in the previous footnote, we may write $\mathbf{E}' = (\theta_L - \epsilon_1)\mathbf{E}_{L'}$. Then, $\mathbf{E}_{L'} = \mathbf{H} - \mathbf{L}' = .038 - .0149 = .0231$. If we now take $\epsilon_1/\theta_L = .5$ as a plausible estimate of the contribution unconventional capital makes to the earnings of labor by raising the entire structure of marginal productivities, i.e., by changes other than those already caught in the Divisia measure L', for the period "1927–1967" $(\theta_L - \epsilon_1) = .278$ and $\mathbf{E}' = .0064$. We find some support in Z. Griliches for fixing the value of ϵ_1/θ_L at .5.

[22] Compare Table 1 for the "refined" residual estimate of Christensen and Jorgenson. A conceptually comparable estimate for the period 1950–1962 is put at 1.44 percent per annum by Jorgenson and Griliches Table 25, and even after further allowance for unmeasured, costly quality changes in the capital inputs and some minor adjustment for increased capital utilization, their "super-refined" residual stands at 1.03 percent per annum.

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