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Introduction

Charles R. Hulten

The Japanese "miracle" is one of the remarkable economic events of the last 50 years. Emerging from the ruins of World War II, the Japanese economy grew at double-digit rates through the 1950s and 1960s and, when the oil crises of the 1970s slowed growth throughout the industrialized world, Japanese growth rates continued to be relatively strong. Japan has emerged as the second largest economy in the noncommunist world and one of the most formidable trade competitors.

There have been many attempts to explain this remarkable history. A wide variety of hypotheses, which range over a number of academic disciplines, have been offered about the Japanese experience. Some explanations stress cultural factors (the Japanese have always been a frugal and industrious people), while some are essentially historical (the destruction of World War II provided an opportunity to "catch up" to the United States by building a new capital stock and by importing the best-practice technology). Other explanations are institutional in nature (the war reduced the power of special interest groups like labor unions and trade cartels, which tend to impede growth), or organizational (Japanese managers keep their eye on long-run growth while their American counterparts stress short-run profitability), or fiscal (Japanese tax policy was more conducive to saving and investment than that of the United States).

Some of these explanations are surely correct, if only in part and in combination with other factors. The problem is to assign the correct weight to the various alternatives. This is not an easy task, since there is no accepted model that encompasses the full range of cultural, political, and economic factors. Without such a model, it is virtually impossible to sort out the true causal factors from those that correlate well with the phenomenon of rapid growth, but are not true explanatory variables, or those that are truly causal but of limited significance.

Quantitative analyses of economic growth have tended to explore the more limited, but also more tractable, question of *how* Japan was able to grow so rapidly. Any sustained increase in real gross national product (GNP) must be due either to an increase in the quantity of capital and labor used in production or to the more efficient use of these inputs (e.g., technical and organizational progress). Empirical models have been developed that sort out the separate contribution of each factor and that indicate the weight of each in the process of output growth. This, in turn, provides a limited explanation of how growth was achieved but falls short of a complete explanation since the factors causing the growth of capital, labor, and technology are not explained.

The papers presented in this volume belong to this tradition of growth analysis and range over a variety of topics related to the measurement of economic growth. Early versions were originally given at the 26–28 August 1985 meeting of the Conference on Research in Income and Wealth and are, for the most part, quite technical. However, the reader who is more interested in substantive issues rather than issues of technique will find much of interest. To facilitate reading this volume from that point of view, the following section provides an overview of the basic methods commonly used in empirical growth analysis. Those familiar with these methods may want to proceed directly to the "Summary of the Conference Proceedings" below.

Introduction to the Measurement of Economic Growth[1]

Theory

The neoclassical analysis of aggregate economic growth starts with the assumption of a stable relationship between output, $Q(t)$, and inputs of capital, $K(t)$, and labor, $L(t)$:

$$Q(t) = F[K(t),L(t),t]. \tag{1}$$

The production function $F(\cdot)$ represents the technological possibilities open to an economy at any point in time; a time trend t is included to allow for the changes in the function due to improvements in technology or in managerial efficiency. If an economy remains on its technological frontier, the production function is a constraint on the rate of economic growth, and any hypothesis about the fundamental causes of growth must be consistent with this constraint.

The analysis of growth can proceed directly from equation (1). The early work used a parametric form for (1)—the famous Cobb-Douglas production function, $Q(t) = e^{\lambda t}K(t)^{\alpha}L(t)^{\beta}$—which characterized the production possibility set in terms of three parameters: the rate of change of technical efficiency (λ) and the elasticities of output with respect to capital (α) and labor (β).

Estimation of the parameters (α,β,λ) yields complete information about the technology and permits a decomposition of the growth rate of output into

$$\text{(2)} \qquad \dot{q}(t) = \hat{\alpha}\dot{k}(t) + \hat{\beta}\dot{\ell}(t) + \hat{\lambda}.$$

This equation indicates that the growth rate of output, $\dot{q}(t)$, must be equal to the growth rate of capital, $k(t)$, weighted by its estimated output elasticity, plus the growth rate of labor input, $\dot{\ell}(t)$, also weighted by its elasticity of output, plus the estimated rate of technical change, $\hat{\lambda}$. This decomposition highlights the relative importance of each factor in explaining the growth of output and thus provides clues about the underlying mechanisms of economic growth.

An alternative approach assumes a competitive equilibrium in which prices are related to the marginal products. This assumption, along with a more general and flexible parametric representation of technology (typically the translog functional form), is used to estimate the production function. The resulting parameter estimates can be used to decompose the growth rate of output into its components in a manner analogous to (2), but without the restriction that the capital and labor weights are constant. Another variant of this approach allows for even more flexibility by dropping the assumption that the economy adjusts to price changes instantaneously. In this variant, costs of adjustment are assumed to prevent capital from varying by the extent necessary to equate marginal products to relative factor prices at each point in time.

The assumption of competitive equilibrium is also used to characterize technology (1) in terms of its minimum cost function. The minimum cost of producing a given level of output $Q(t)$ when the prices of capital and labor services are $P_K(t)$ and $P_L(t)$ is denoted by

$$\text{(3)} \qquad C(t) = C(P_K(t),P_L(t),Q(t),t).$$

Since technical change in the sense of equation (1) is equivalent to a reduction in the quantity of inputs needed to produce a given level of output, technical change can equally be represented as a reduction in the minimum cost of producing that output, given input prices. The t in (3) is thus analogous to the t in (1), and the rate of technical change, along with other characteristics of technology, can be estimated by specifying a parametric representation of (3)—the translog cost function, for example. A decomposition of the change of minimum cost into its components, along the lines of (2), is also possible, and adjustment costs can be taken into account.

Estimation of (1) or (3) is termed the *parametric* approach to measuring the sources of economic growth. An alternative model, which does not involve parametric representation of the technology or econometric analysis, has been developed from *index number* theory. This model starts with the "adding-up" identity between the value of output and the value of input:

$$(4) \qquad P_Q(t)Q(t) = P_K(t)K(t) + P_L(t)L(t),$$

where $P_Q(t)$ represents the price of output. Differentiation of the prices and quantities in (4) yields, with some manipulation, the following expression for the growth rates of prices and quantities:

$$(5) \quad \dot{q}(t) - s_K(t)\dot{k}(t) - s_L(t)\dot{\ell}(t) = \dot{p}_Q(t) - s_K(t)\dot{p}_K(t) - s_L(t)\dot{p}_L(t) = \dot{a}(t),$$

where $s_K(t)$ and $s_L(t)$ are the shares of capital and labor in the value of output, that is $s_K(t) = P_K(t)K(t)/P_Q(t)Q(t)$ and $s_L(t) = P_L(t)L(t)/P_Q(t)Q(t)$. The far left-hand side of (5) defines the residual growth rate of output not explained by the share-weighted growth rates of inputs, and is interpreted as the growth rate of output per unit input. This index, termed "total factor productivity" and denoted by $\dot{a}(t)$, is also seen to be equal to the (negative) growth rate of output *price* not explained by the share-weighted growth rates of the input prices.[2] This is the "dual" form of the growth accounting model.

The estimate of total factor productivity derived from (5) is based only on prices and quantities and is thus a pure index number—nothing is said about the parameters of an underlying technology or even the existence of such a technology. However, it was demonstrated by Solow (1957) and Diewert (1976) that, under the conditions assumed above, there is a fundamental unity between the parametric and index number approaches, in the sense that both are derived from the production function (1).[3] The share-weighted growth rates of the inputs are interpreted, by Solow, as a movement along the aggregate production function, while the TFP residual is interpreted as a shift in that function.

The analysis of individual industries within the aggregate economy is also important for understanding the process of economic growth. The techniques for analyzing aggregate growth outlined above can also be applied on an industry-by-industry basis, with appropriate modification for interindustry flows of materials and services. This modification involves the use of real gross output rather than real value added as the measure of output and requires that the list of inputs in (5) be extended to include intermediate goods. The main complication arises when the resulting industry-based estimates of TFP growth are aggregated into an economywide measure of TFP. The appropriate weights for this aggregation sum to a quantity greater than one because of the magnifying effects of the intermediate inputs. The industry-level TFP estimates computed using gross output thus tend to be smaller than TFP estimates based on value added.[4]

We note, finally, that the analysis of equation (5) involves rates of growth. The study of the corresponding levels is also of interest, for at least two reasons. First, one of the major explanations of the high rate of Japanese economic growth emphasizes Japan's ability to grow by "catching up." In this view, the devastation of World War II put Japan far below her production possibility frontier, and the national effort to rebuild industry, along with the ability to import technology from abroad, created an opportunity for an abnormally high rate of growth. This opportunity has diminished over time as the level of technology in Japan has approached that of the best-practice countries.

The measurement of relative TFP levels is also important for explaining the pattern of international trade. The price competitiveness of U.S. and Japanese products depends, in part, on the relative efficiency with which these goods are produced. Other things equal, a relatively higher level of TFP in one country will result in a relatively lower product price.[5] When exchange rates adjust to balance trade flows, comparative advantage will be influenced by relative TFP levels.

A method of estimating relative TFP levels using index number procedures was developed by Jorgenson and Nishimizu (1978). For any industry, the index of relative TFP is defined as the difference in the natural logarithms of output in each country minus the share-weighted difference in the logs of the inputs, where the weights are the cost shares averaged across the two countries. As such, the Jorgenson-Nishimizu TFP index is a variant of the translog method of estimating the growth rate of TFP over time applied to the problem of estimating TFP differences across countries (with appropriate adjustment of prices to insure comparability).[6]

The Sources of Growth

A number of empirical studies have used the index-number approach to compare the sources of output growth in Japan to those in the United States. The paper by Nishimizu and Hulten (1978) compares the results of 12 studies undertaken prior to 1978, and more studies have been published since then. The results of several studies are shown in table 1, thereby providing a sample of the kinds of numbers generated by the sources of growth approach. These results are supplemented by table 2 below, which places Japanese economic growth in an international context. Table 1 shows the decomposition of the

Table 1 **The Sources of Aggregate Economic Growth in Japan (in percentages)**

	Denison & Chung (1976) for 1953–71	Nishimizu & Hulten (1978) for 1955–71	Christensen, Cummings, & Jorgenson (1976)	
			1952–60	1960–73
Growth rate of:				
Output	10.0	11.5	8.1	10.9
Capital[a]	2.2	5.9	1.6	4.8
Labor[a]	2.0	1.9	3.1	1.6
TFP	5.9	3.7	3.4	4.5

Note: TFP = Total factor productivity.
[a]Weighted by income share.

growth rate of output into its components: total factor productivity and the *share-weighted* growth rates of capital and labor. Table 2 presents similar estimates, but input growth rates are not weighted by cost shares.

It is readily apparent from these tables that the Japanese economy has performed very well. Japan grew rapidly (at or near double-digit rates) throughout much of the post–World War II period and still managed to outperform Europe and the United States even after the energy crisis slowed economic growth nearly everywhere. The sources of this superior performance are less readily apparent. The relative importance of each factor varies from study to study and from year to year but, for the period before 1973, a rough estimate would assign somewhat more than one-half of Japan's economic growth to TFP and most of the balance to capital input, with only a small fraction attributed to labor input. After 1973, growth slowed dramatically, and the importance of TFP growth declined while that of capital increased, a phenomenon that also occurred in a number of other countries listed in table 2. Japan experienced a more rapid rate of growth of output and capital input than other countries, while Canada and the United States experienced the strongest growth in labor input. However, while the magnitude of the Japanese numbers is large, the *pattern* of growth (i.e., the relative importance of each source of growth) is not all that different from the other countries of table 2.

These tables also provide some support for the catching-up hypothesis. Total factor productivity grew at a slower rate in the United States over the period 1960–73 than in any other country listed in Table 2. Englander and Mittelstadt (1988) report that these data show a steady process of catch-up and convergence. However, critics of the convergence hypothesis point to a breakdown of this hypothesis when more countries are added to the list.[7]

The study of relative labor productivity levels at the industry level of detail has also been quite active in recent years. Table 3 reports the results of one such study, by Dollar and Wolff (1988), which tracks the level of labor productivity in 13 countries for the years 1963, 1970, 1976, and 1982. They conclude that there has been a convergence in labor productivity over this period, both in aggregate manufacturing and in individual manufacturing industries. They also note that of all the countries in their study, Japan started with the lowest productivity level relative to the United States. However, they also note that convergence was stronger in the aggregate than in the separate industries, suggesting an added degree of complexity to the catching-up process.

In contrast to the Dollar-Wolff paper, which studies labor productivity in manufacturing industries, Jorgenson and Nishimizu (1978) present estimates of relative TFP levels in the aggregate economies of Japan and the United States. Using the translog method developed in that paper (described above), they find that the catching-up process was largely completed by 1973. However, a subsequent study by Christensen, Cummings, and Jorgenson (1981), using revised data, reported that, in 1973, Japanese technology still lagged behind that of the United States by about 20%.

Table 2 **Real Gross Product, Factor Inputs, and Productivities in the Business Economies of Nine Countries, 1960–1973 and 1973–1979 (average annual percentage rates of change)**

Country	Real Gross Business Product	Factor Inputs			Factor Productivities		
		Total	Labor[a]	Capital[a]	Total	Labor	Capital
United States:							
1960–73	3.8	2.3	1.7	3.5	1.5	2.2	.3
1973–79	2.8	2.9	2.5	3.7	−.1	.3	−.9
1979–86	2.2	2.2	1.6	3.3	.0	.6	−1.0
Canada:							
1962–73	5.7	3.5	2.8	4.6	2.2	2.9	1.1
1973–79	4.9	3.7	2.9	5.2	1.1	2.0	−.3
1979–86	2.5	2.9	1.5	5.2	−.3	1.1	−2.6
Japan:							
1967–73	9.7	3.5	1.0	12.1	6.1	8.6	−2.4
1973–79	3.8	2.0	.6	6.8	1.8	3.2	−3.0
1979–86	3.8	2.1	1.0	5.8	1.7	2.8	−2.0
United Kingdom:							
1960–73	3.2	1.2	−.1	3.9	2.0	3.3	−.7
1973–79	1.1	.9	−.1	3.0	.2	1.3	−1.9
1979–86	1.4	.3	−.6	2.1	1.1	1.9	−.8
France:							
1965–73	6.4	2.1	.5	5.7	4.3	5.9	.6
1973–79	3.5	1.4	.0	4.7	2.1	3.5	−1.2
1979–86	1.5	.2	−1.0	3.0	1.3	2.5	−1.4
West Germany:							
1961–73	4.6	1.8	−.3	5.6	2.8	4.9	−1.1
1973–79	2.4	.6	−1.0	3.5	1.8	3.4	−1.1
1979–86	1.6	.8	−.4	2.9	.8	2.0	−1.3
Italy:							
1961–73	5.6	.9	−.9	5.2	4.7	6.5	.4
1973–79	2.9	1.3	.5	3.4	1.6	2.4	−.4
1979–86	1.9	1.1	.6	2.5	.7	1.2	−.7
OECD average:							
1960–73	5.2	2.4	1.1	5.6	2.8	4.1	−.4
1973–79	2.9	2.2	1.3	4.4	.7	1.6	−1.4
1979–86	2.3	1.7	.9	3.6	.6	1.4	−1.3

Source: Englander and Mittelstadt (1988), based on the national source data and Organization for Economic Cooperation and Development estimates.
Note: Errors due to rounding.

[a]Unweighted.

Finally, it should be noted that the results summarized in these tables contain an important lesson for "consumers" of growth analysis. There is substantial variation across studies, and the reader should be careful to note the following characteristics of any study: the time period covered, the scope of the economic activity covered, the methods used, and the definitions of output

Table 3 **Value Added per Workhour in Manufacturing in 12 Industrial Countries Relative to the United States, 1963–1982 (index numbers, United States = 100)[a]**

	1963	1970	1976	1982
United States	100	100	100	100
United Kingdom	52[b]	60	94	88
Italy	45[c]	50	58	88
Sweden	52	68	72	78
Canada	77	80	77	76
Germany	54[d]	68	70	68
France	53	64	59	67
Japan	26	49	50	61
Denmark	41	54	54	59
Australia	47	53	55	56
Finland	34	48	45	51
Austria	37	47	45	49
Norway	46	58	54	49
Coefficient of variation	.36	.24	.26	.23
Unweighted average (excluding United States)	47	58	61	66

Source: Dollar and Wolff (1988).
[a]Calculated from aggregate data for all manufacturing.
[b]1968 data
[c]1967 data
[d]1965 data

and input. Denison (1962), for example, uses national income as the definition of output, while the other studies use gross product. When combined with a measure of capital stock that is heavily weighted to gross stock, a national income measure of real product tends to reduce the apparent importance of capital as a source of growth. On the other hand, studies that include the residential and household sectors of the economy tend to increase the apparent importance of capital and reduce the importance of TFP.

Summary of the Conference Proceedings

Overview

The papers included in this volume cover a variety of subjects and techniques. To facilitate reading, they are grouped into two general categories. The first contains papers dealing with the measurement of productivity in Japan and the United States. The first two papers in this group present results based on the conventional index-number and econometric approaches to estimating the structure of production. The next four papers introduce capacity utilization and adjustment costs into the analysis: some treat some inputs—principally capital—as being fixed in the short run, while the fourth investigates the complementarity of capital and energy and its impact on measured TFP growth. The last paper discusses the measurement of TFP in an open-economy context.

The second category of papers discusses various issues in the measurement of, or market for, capital and labor. The first set of four papers range over the application of the perpetual inventory method to Japanese investment data, the taxation of income from capital in Japan, the measurement and interpretation of Tobin's *Q*, and the relationship between R&D capital and productivity growth. The last three papers deal with labor input and include a discussion of quality change in the Japanese labor force, investment in firm-specific labor skills, and the effects of work attitudes on production costs in the two countries. Comments that were prepared by conference discussants are included when available.

The Structure of Production in Japan and the U.S.

The paper by Jorgenson and Kuroda presents estimates of the relative levels of TFP in a variety of industries in Japan and the United States that are based on the translog index method developed by Jorgenson and Nishimizu (1978). This paper is an updated version of the original paper presented at the 1985 conference—Jorgenson, Kuroda, and Nishimizu (1987), which covered the period 1960–79—and extends the estimates of relative TFP levels to the period 1960–85. Since the comparison of relative TFP levels sheds light on the "catching-up" hypothesis (the idea that Japan was able to grow rapidly by importing foreign technology) and provides partial insight into the pattern of comparative advantage in bilateral trade, the extension of the original study to these additional years is particularly important.

The authors reported in the original conference paper that the level of TFP in Japan had passed or reached that of the United States in nine of the 28 industries studied, and that Japan was expected to close the gap in six others. In the revised and updated version of this paper, Japan has reached or surpassed the United States in 12 industries and is expected to close the TFP gap in three others. Thus, in both 1979 and 1985, Japan has or is expected to have technological leadership in half of the industries studied. The United States is expected to have an efficiency advantage in the remaining half.

These results suggest that catching up is an uneven process, if it is operative at all. Some industries seem to catch up and others do not, and the catch-up pattern appears to change from period to period. This may reflect industry-level differences in the ability to "play catch-up," or it may reflect differences in measurement procedures or measurement difficulties during periods of macroeconomic turbulence, such as occurred after 1973. Or it may reveal that the notion of catching up is too simplistic or that the catch-up effect had worked itself out by the mid-1970s. In any event, there is little evidence in this paper to complement the Dollar-Wolff (1988) finding of a general convergence of labor productivity at the industry level in Japan and the United States. That is, the convergence of labor productivity was apparently not caused by a convergence in one of the factors explaining the growth rate of labor productivity, that is, total factor productivity.[8]

Jorgenson and Kuroda also present estimates of relative product prices, adjusted for purchasing power parity. They report that, by 1985, the relative price of labor input in Japan was only 50% of the U.S. level, the relative cost of capital was 75% of the U.S. level, and that relative product prices in Japan were only 83% of those of the United States. They also find that a lower product price in one country is generally associated with a higher level of TFP in that country, suggesting that the TFP level is an important determinant of relative product price.

The paper by Jorgenson, Sakuramoto, Yoshioka, and Kuroda is a companion piece to the original TFP-level comparison paper presented at the conference. This second paper presents econometric estimates of the parameters of a translog production function and thus represents the second of the two major approaches to analyzing the structure of production (the index-number approach of the first paper is the other). The translog production function is parameterized so as to jointly estimate the structure of production in the United States and Japan for each of the 28 industries included in the study. Parameter estimates for each industry are presented for the time period 1960–79, but partial elasticities of substitution are not presented.

The principal results can be summarized briefly. The factor substitution parameters and biases in technical change are distributed rather heterogeneously across industries, implying diversity in the structure of production. Production in Japan is also shown to differ from production in the United States with Japanese industry generally found to be more capital intensive and material-input intensive and U.S. industry more labor intensive. That is, if input prices were the same in both countries, Japanese industries would tend to have higher capital-labor and materials-labor ratios (though actual ratios depend on differences in input prices). It is interesting to note, in this regard, that Japan had a significantly higher savings rate during the period in question while the United States had a higher growth rate of labor input. However, it must also be noted that the authors report that technical change was predominantly capital saving *and* laborsaving, but materials using, in both countries.

The next group of papers extend the conventional framework for measuring productivity change to allow for the possibility that some factors cannot adjust rapidly or costlessly to shifts in relative prices. This possibility introduces a variety of potential biases into conventional analyses of economic growth, which uses relative price ratios as a surrogate for the corresponding marginal rate of substitution.[9] And, even when bias is not present, the short-run fixity of some factors (termed "quasi-fixed" factors) leads to a distinction between changes in TFP due to improvements in technology and changes due to variation in the degree of utilization of these factors.

This distinction is central to the paper by Fuss and Waverman, who present a translog cost function analysis of the Canadian, Japanese, and U.S. auto industries over the period 1970–84. In the Fuss-Waverman framework, the growth in unit production costs is decomposed into the weighted growth rates of input prices and the growth rate of TFP (this is the economic dual of the decomposition of output into the weighted growth rates of input and TFP). The growth rate of TFP is then decomposed into three further components: technical change, capacity utilization, and scale economies, thus adding structure to the conventional TFP residual.

The empirical results reveal the role of TFP growth, and its individual components, in the evolution of unit costs and price competition in this important industry. Measured in yen, the average cost of producing autos grew at an average annual rate of 2.5% over the period 1970–84.[10] This rate is the sum of two effects: an increase in input prices drove costs up to 5.5%, and TFP growth offset 3% of this increase. Most of the increase in TFP was due to technical change (over four-fifths), while scale economies accounted for the rest of TFP growth. Changes in capacity utilization accounted for almost nothing.

In contrast, the average cost of auto production in the United States grew at an average annual rate of 6.3% over this period, measured in dollars. The growth of input prices increased cost by 7.4%, and this was offset by TFP growth of 1.3%. Technical change accounted for 0.8% of the TFP number, while scale economies accounted for 0.2% and capacity utilization for 0.3%. However, variations in capacity utilization are seen to be far more important when subperiods are considered: from 1970 to 1980, technical change proceeded at an annual rate of 1.1%, but this was offset by deteriorating utilization of 0.7% a year; this turned around during the 1980–84 period, with technical change proceeding at only 0.2% while increases in capacity utilization reduced costs at a rate of 2.7% per year. This effect was so strong that overall average cost did not grow at all during the 1980–84, and the U.S. auto industry actually outperformed the Japanese auto industry in this dimension of competitiveness over this period.

However, for the 15-year period as a whole, the average cost of producing autos in Japan grew at a significantly slower rate than in the United States (the differential was 3.8% a year), and the source of this advantage was split equally between a slower growth of input prices and improvement in efficiency due to scale economies and technical change.[11] This cost advantage was largely offset, however, by an appreciation in the value of the yen relative to U.S. and Canadian dollars. When this appreciation is taken into account, the authors find that the Japanese cost advantage grew at only 0.7% per year, as measured in Canadian dollars.

The paper by Nadiri and Prucha analyzes productivity change in another important industrial sector: the electrical machinery industries of Japan and the United States. This industry is a major success story in both countries. In the United States, the electrical machinery industry outperformed the manufacturing sector as a whole by growing at 4.2% a year from 1968 to 1973, and 4.9% from 1973 to 1979. In Japan, output grew at 16.9% during the first period, and then fell to 6.4% during the second period. However, despite this drop-off in output growth, Japan managed to increase its share of free-world exports in electrical machinery from 22% in 1971 to 48% in 1981.

Nadiri and Prucha develop a dynamic factor demand model of the electrical machinery industry in which capital and R&D are treated as quasi-fixed inputs. The technology is modeled in terms of a restricted cost function that explicitly incorporates dynamic costs of adjustment, and that is fitted to annual U.S. data for the period 1960–80 and Japanese data for the period 1968–80. Parameter estimates are presented, as are price and output elasticities distinguished by the short run, intermediate run, and long run. The short-run estimates are found to be significantly more inelastic than the longer-run counterparts and, while this is not surprising, it does suggest that the quasi fixity of some inputs is of economic importance and that short-run adjustments to price changes may be very different than long-run adjustments. The authors also note that the pattern of elasticities is quite similar in the two countries, with the own-price elasticities of capital and R&D somewhat larger in Japan and the own-price elasticities of labor and materials somewhat larger in the United States. The cost shares of each are also very similar in the two countries.

The estimated cost function is then used to decompose the growth rate of output into the contributions of inputs (capital, R&D, labor, materials), the direct effect of adjustment costs, technical change, and a residual. The bulk of U.S. and Japanese growth over the periods 1968–73 and 1973–79 is accounted for by the contribution of the inputs. For the United States, the average rate of technical change over the two periods is 0.73% and 0.86%, and for Japan the corresponding figures are 1.55% and 2.55%. Furthermore, the direct adjustment cost effect is small, except for the higher growth era before 1973 in Japan. However, this does not imply that the adjustment cost model is largely irrelevant, since adjustment costs also affect the weights assigned to the various inputs.

Of the input effects, the materials effect is shown to be the most important source of growth in the electrical machinery industries of both countries. Capital formation is seen to play a more important role in Japan than in the United States, but R&D is somewhat more significant in the United States over the period 1968–73. It is perhaps relevant to note that the authors show that the ratio of tangible capital investment to gross output is higher in Japan, but the ratio of R&D spending to gross output is higher in the United States.[12]

The authors also present an analysis of the conventionally measured TFP residual similar to the one carried out by Fuss and Waverman, although the latter is done with respect to the cost "dual" and does not model adjustment costs explicitly. The growth rate of TFP is decomposed into a scale effect, technical change, temporary equilibrium and adjustment cost effects, and an unexplained residual. The scale effect is shown to predominate, and, combined with the technical change effect, it explains most of the conventional TFP residual (a somewhat different pattern than observed in the auto industry). There is no simple relationship between this decomposition and the previous decomposition of the pseudo–TFP residual.

The paper by Morrison continues the analysis of quasi-fixed inputs in U.S. and Japanese manufacturing industries. In this paper, however, both capital and labor are treated as fixed in the short run, and energy and materials inputs are treated as variable. The parameters of a generalized Leontief cost function are estimated using annual data for total manufacturing over the period 1952–81 for the United States and 1957–81 for Japan.

The results of this analysis are similar to those of the preceding two papers. The parameters characterizing production in the two countries are, with a few exceptions, quite similar. Also, the short-run price elasticities tend to be significantly less elastic than their long-run counterparts, suggesting that production plans are less flexible in the short run (and that the extension of the conventional analysis to allow for the quasi fixity of some inputs is empirically important). The author also reports that capital and energy appear to be even stronger complements in Japan than in the United States, in contrast to some previous studies, and that labor and energy were less substitutable. This, in turn, suggests that Japanese manufacturing industries were not necessarily in a better position to absorb the energy price shocks of the 1970s.

Morrison also presents estimates of capacity utilization and corrected TFP. The trends in capacity utilization are similar in the two countries, but with Japan displaying a larger decline after 1970. The implied adjustment to the TFP residual is, however, rather small. For the United States, TFP growth is found to average 0.77% per year for the period 1956–81 using the author's "quantity variant," and this is adjusted downward to an average annual rate of 0.74%. For Japan, the corresponding figures are 1.30% and 1.00%, implying that the adjustment for capacity utilization is somewhat more significant, but nonetheless of a second order of importance. This finding is also generally valid for the year-to-year changes in TFP.

The study by Berndt, Mori, Sawa, and Wood also examines the implications of capital-energy complementarity for the measurement of capital and TFP growth. Although energy's share of total cost (and thus its weight in the sources of growth equation) is small, the close link between energy use and capital utilization could result in a situation in which an increase in energy prices would render energy-inefficient capital obsolete and thereby reduce the effective amount of capital input obtained from a given stock of capital.[13] In order to examine this effect, the authors develop a putty-clay model in which each vintage of capital is built with a particular energy intensity based on the relative energy-capital prices prevailing at the date the capital was placed in service. Each vintage can be operated at a different intensity by switching labor from one vintage to another. Since energy and capital are "bundled," a rise in the cost of energy will cause those vintages designed under the assumption of lower energy prices to be operated less intensively.

In this framework, utilization is defined as the ratio of effective capital input to the stock of capital. Utilization is then shown to depend on the relative prices of capital services and energy expected to prevail in the future and on the ex ante elasticity of substitution between capital and energy. Changes in the rate of utilization are shown to introduce biases in the measurement of total factor productivity: the TFP measured by conventional procedures for estimating capital input is equal to the "true" TFP measure plus the rate of change of utilization weighted by capital's cost share.

This model is simulated for different values of the elasticity of substitution between energy and capital, using data on Japanese and U.S. manufacturing for the years 1958–81. The authors find that their index of utilization is roughly constant in both countries up to 1973 and that a large reduction occurs thereafter (for the largest value of the elasticity, the reduction is 25% for the United States and 22% for Japan). This result leads to an increase in the "true" TFP residual of up to 0.13% per year for the U.S. for the period 1973–81, and a corresponding annual increase of up to 0.48% for Japan. The U.S. figure is too small to account for much of the decline in TFP occurring after 1973, but the number for Japan is substantially larger and does explain about a third of the growth slowdown in TFP after 1973.

The paper by Morrison and Diewert shifts direction and offers a novel extension of the standard productivity model. A distinction is made in the standard model between movements along a production function and shifts in that function. Since the shift in the function implies an increase in output from given inputs, the shift effect represents a way for an economy to increase its welfare from a given resource base. Morrison and Diewert point to two additional ways that welfare in any given year can be improved in an open economy: an improvement in the economy's terms of trade (a fall in the price of imported goods relative to exports) and an increase in the trade deficit. As with a shift in the production function, these two mechanisms allow for increased domestic consumption and investment from a given amount of resources (albeit a transitory increase).

Morrison and Diewert develop a model, in which the trade effects are embedded in the standard sources-of-growth model, and present estimates of the three effects for Japan and the U.S. for the years 1967–82. They report that the annual growth rate of TFP averaged 3% for Japan and 0% for the United States (which is not surprising or necessarily inconsistent with other studies, since the starting year of the analysis was near a peak in the business cycle and the end year near a trough). The terms-of-trade effect for Japan is found to be rather small over the entire period (0.5% per year) but shows considerable year-to-year variation. The trade effect is found to be far less important for the United States, presumably reflecting the greater importance of foreign trade in the Japanese economy. The deficit effect also appears to be more important for Japan, although it appears to be highly transitory. However, while the terms of trade and deficit effects are rather small during the 1967–82 period, the recent changes in the value of the dollar and the massive U.S. trade deficit might well enhance the importance of the these effects in an updated version of this paper.

Capital and Labor

The paper by Dean, Darrough, and Neef considers one of the most important issues in empirical growth analysis: the problem of measuring capital stocks. While almost all economic measurement is problematic, the measurement of capital is especially subject to ambiguities and difficulties. A stock of capital provides a flow of services over a number of years, and this flow is, for the most part, not directly observable because capital is largely owner utilized. For the same reason, the price of capital services—the implicit rent that the owner must charge himself for the use of the asset—is also not observed directly. The measurement of this key variable must therefore proceed by indirect procedures, like the perpetual inventory method (PIM) and the Hall-Jorgenson user cost formula.

These procedures start with an estimate of the nominal value of investment spending in each year, $P_I(t)I(t)$. An estimate of the price of investment goods—the "investment deflator" $P_I(t)$—is then used to split nominal investment spending into price and quantity components. The quantity of investment is then cumulated into an estimate of capital stock using the PIM: with a constant rate of depreciation δ, this can be written as

$$K(t) = I(t) + (1-\delta)K(t-1), \tag{6}$$

which states that capital stock in period t is the sum of investment in period t and the undepreciated amount of capital carried forward from the preceding period. This approach requires a benchmark value for $K(t)$ or a sufficiently long time series on $I(t)$ that the initial level of $K(t)$ can be ignored.[14]

The price of capital services can be imputed using the formula developed by Jorgenson (1963) and Hall and Jorgenson (1967). With perfect foresight and no taxation, this formula is written as

$$P_K(t) = (r(t) + \delta)P_I(t) - \Delta P_I(t), \tag{7}$$

which states that the implicit rent charged on owner-utilized capital must cover the opportunity cost of capital (the discount rate r times the investment deflator) and depreciation (the rate of depreciation δ times the deflator) less any revaluation of the asset. Given data on the δ used in the PIM, the investment deflator, and an estimate of the discount rate r, this equation can be used to impute a value for the service price.

The paper by Dean, Darrough, and Neef describes how this framework can be implemented for Japanese manufacturing industry. Data on nominal investment from four sources—the Census of Manufactures, the Economic Planning Agency, the Annual Report on the Corporate Sector, and the Report on the Corporate Industry Investment Survey—are described and compared (their Table 5 provides a detailed comparison of these sources). A procedure for estimating the rate of depreciation, δ, from these sources and from capital benchmarks derived from the National Wealth Surveys is then described, and estimates of δ are reported for several types of assets. Deflators, user costs, and aggregation procedures are also discussed.

The authors conclude that the Census of Manufactures is the most reliable source of investment data. More important, they demonstrate that there is considerable variation in estimated capital stocks and depreciation rates calculated from the different data sets: estimates of the growth rate of capital stock based on census data average 3.9% per year over the period 1973–81, while Economic Planning Agency data yielded an estimate of 2.3% and Annual Report data implied a growth rate of 4.2%. These are significant differences considering that they represent growth rates compounded over eight years. Such a finding serves to reinforce the crucial point that different data sources and procedures can lead to very different results.

The paper by Kikutani and Tachibanaki examines the impact of the Japanese tax code on taxation of income from capital. This is an important problem for Japan-U.S. productivity comparisons, which attempt to apply a common analytical framework (e.g., the user cost of capital—eq. [7]) to the different institutional settings of two countries. The accurate specification and modeling of the relevant institutions in each country is often the most difficult part of such international comparisons. The tax codes of Japan and the United States bear witness to this problem: not only are the tax codes of both countries exceedingly complex, the resulting tax treatment of capital income is also very different in the two countries.

Kikutani and Tachibanaki present estimates of the marginal effective tax rate on income from capital, building on earlier work by Shoven and Tachibanaki (1988) and King and Fullerton (1984). The current paper extends the coverage of the Shoven and Tachibanaki paper from 1980 to the trio of years 1961, 1971, and 1980 and also takes into account additional features of the tax code like the "special depreciation" and "tax-free reserve" provisions. The tax treatment of the banking sector is also discussed in detail. Marginal effective tax rates are calculated at various rates of inflation and presented by class of asset, industry, source of finance, and owner. It is shown that the overall effective tax rate decreased from 24.7% in 1961 to 15.0% in 1970, and finally to 9.6% in 1980. The comparable U.S. figures are 48.4%, 47.2%, and 37.2%, respectively.

Several conclusions emerge from these results. The combined effects of the corporate and individual incomes taxes imply a heavier burden on capital income in the United States than in Japan over the period 1961–80, and effective tax rates fell in both countries over this period.[15] The authors show that this can be attributed in large part to the greater use of debt finance in Japan and the lower effective tax rate on interest income. Indeed, it is interesting to note that the effective tax rate associated with debt finance is −55% in 1980, while the tax rate on equity-financed capital is around 70%. The average of the two is 9.6%, so it is apparent that the debt-equity ratio is a critical determinant of the average rate. Furthermore, the authors present a simulation for the year 1980 in which they replace the Japanese debt-equity ratio with the U.S. figure and show that the overall Japanese tax rate rises from 9.6% to 29.0% (furthermore, if Japanese interest income is subjected to U.S. tax treatment, the overall Japanese tax rate rises from 9.6% to 40.3%, which is larger than the overall U.S. tax rate of 37.2%).

The authors also explore the impact of inflation on effective tax rates in both countries. They show that effective rates rise with inflation in the United States, but fall with inflation in Japan. This curiosity is attributed to the greater use of debt finance in Japan and to the lower effective tax rate on interest income.

The next paper, by Fumio Hayashi, continues the analysis of the Japanese tax code within the framework of Tobin's Q analysis. Tobin's marginal Q is conventionally defined as the present value of the income accruing to an additional unit of capital (as reflected by the financial value of the firm or industry) divided by the cost of purchasing that unit. With competitive markets and the absence of adjustment costs and taxes, a value of Q greater than one indicates that an additional unit of capital is worth more than it costs, implying that the capital stock should be expanded. Conversely, a Q less than one signals that the capital stock is too large; equilibrium occurs when Q equals one. This is equivalent to the neoclassical condition that the user cost (eq. [7]) should be equal to the value of the marginal product of capital.

When adjustment costs are present, a variant of this optimal investment rule must be used. Adjustment costs introduce a gap between the value of the marginal product of capital and the user cost, and Hayashi derives a version of Q that is shown to be equivalent to the present value of this gap. This version is adjusted for various features of the Japanese tax code, including the special depreciation and tax-free reserve provisions discussed by Kikutani and Tachibanaki.

Hayashi describes the steps necessary to implement his model, including the problem of using average Q to measure the marginal value of Q. He presents estimates for the years 1956–81, and shows that Q is a significant factor in explaining Japanese investment up to 1974. He also notes that Q fails to provide a good explanation of investment behavior after this time, that is, after the OPEC oil crisis, and speculates that the failure may be due to mismeasurement or omitted variables. It may be noted, however, that a similar pattern occurs in the U.S. data: Q theory explains U.S. investment behavior fairly well up to the energy crisis, and does poorly for the rest of the 1970s. Thus, while mismeasurement of key variables in both countries cannot be ruled out, it seems more likely that omitted variables or specification errors are the source of the problem.

While the preceding papers have dealt primarily with the accumulation of tangible capital, the paper by Griliches and Mairesse examines the role of another type of capital: intangible "knowledge" capital. The concept of a "stock of technical knowledge" is a departure from the conventional Solow (1957) dichotomy, since advances in technical knowledge are associated with systematic changes in a measured input (the accumulated stock of R&D investment) and not with residual shifts in the production function. Indeed, the attempt to estimate a stock of knowledge may be regarded as an attempt to build additional structure into the sources of growth model.[16]

Griliches and Mairesse begin by comparing aggregate data on R&D spending in Japan and the United States. They observe that there is little difference in the level or sectoral distribution of company-financed R&D investment in the two countries (although there is a larger difference in government-financed R&D spending). They also note that most of the company-financed R&D is done in three industries—electrical equipment, transportation, and chemicals—and that large firms account for almost all of the U.S. R&D spending but only three-quarters of Japanese R&D. These data are then compared with the firm-level data used in the subsequent analysis. The authors find that the U.S. company data are roughly consistent with the aggregate data but report that the Japanese data appear to under report R&D spending.

These data, which cover the years 1973–80, are used to estimate the parameters of a Cobb-Douglas production function expressed in growth rate form (recall eq. [2]). The authors find that the estimated R&D coefficients are of similar size in both countries and statistically significant (except for Japan when industry dummy variables are introduced). They also report that estimated coefficients imply that R&D contributed around 0.5% per year to the growth of labor productivity in both countries. The principal finding, however, is that R&D investment cannot account for the mean difference in the growth rates of Japan and the United States. That is, the generally superior performance of labor productivity and TFP in Japan cannot be attributed either to the intensity or "fecundity" of R&D expenditures. While this may be due to the measurement problems described by the authors, it nevertheless casts doubt on one possible explanation of U.S.-Japan productivity growth differentials.

The last three papers deal with the measurement of labor input. The first of the three, by Hajime Imamura, presents an analysis of the sources of "quality" change using the Divisia index framework. As noted above, the growth rate of output can be decomposed into the growth rates of capital and labor, weighted by their cost shares, plus the growth rate of total factor productivity. This decomposition can be taken a step further by allocating the growth rate of labor input into a component due to the growth rate of total hours worked and a component due to the shift in the composition of the work force.

The nature of the compositional changes can be seen by the following example. Suppose that there are two types of worker, Y (young) and O (old), that the growth rate of hours worked by young and old is $\dot{\ell}_Y$ and $\dot{\ell}_O$ percent a year, respectively, and that the corresponding wage-shares are s_Y and s_O. The Divisia index of labor input is defined as the share-weighted average of these two growth rates:

$$(8) \qquad \dot{\ell} = s_Y \dot{\ell}_Y + s_O \dot{\ell}_O.$$

This expression can be modified to account for shifts in the composition of the work force by simultaneously adding and subtracting the (unweighted) growth rate of total hours worked, $\dot{h}$, in the right-hand side of this equation (it can be introduced in this way because the wage-shares sum to one):

$$(9) \qquad \dot{\ell} = \dot{h} + s_Y(\dot{\ell}_Y - \dot{h}) + s_O(\dot{\ell}_O - \dot{h}).$$

In this form, the growth rate of the Divisia index of labor input is the sum of the growth rate of total hours plus the share-weighted sum of the shifting fraction of total hours worked by each type of worker. The latter measures the impact on output growth if the composition of the work force shifts toward the category with the smallest output elasticity (as measured by the cost shares).[17] For this reason, the composition effect is termed "quality change."

Imamura applies a more complex version of this framework to Japanese labor-force data and compares his results to corresponding results for the United States. Japanese workers are classified according to gender, age, education, and occupation, and the Divisia index of quality change is for the period 1960–79 by major industry. The principal findings include: (1) quality change was an increasingly important source of growth in Japanese labor input and, after 1970, served as an offset to the negative growth rate of hours worked; (2) the age category had by far the most important direct effect of quality change, with education and occupation sharing a distant second and the gender category in the last place; (3) quality change was a more important source of economic growth in Japan than in the United States, according to a comparison with the study by Chinloy (1980); (4) where age was the most important quality dimension in Japan, education was the most important dimension in the United States.

The importance of the age dimension in Japan is hardly a major surprise, in view of the tendency toward seniority-based labor compensation in that country. If wage differentials are interpreted as wholly due to productivity differences (as they are in the Divisia framework), a seniority-based wage system combined with an aging work force will necessarily produce a strong labor-quality effect. One must therefore question whether wages are based entirely on current productivity or whether they reflect other factors like implicit contracts, in which wages are back loaded in order to attract workers with low quit rates and to reduce incentives to shirk. Or, are the seniority-based wages largely due to a cultural respect for age and seniority?

The paper by Hong Tan investigates some of these issues. Tan hypothesizes that a higher rate of technical change induces firms to want workers with firm-specific skills, which in turn increases the incentive to induce low quit rates by rewarding job tenure. In this model, workers and firms share training costs through low initial wages; training results in higher productivity, and thus wages will rise with job tenure. Tan then compares his model with the competing model of implicit contract theory, in which workers initially accept wages that are less than their marginal product in order to obtain job tenure and higher wages in the future.

The paper presents evidence on these competing models, using U.S. data from the May 1979 Current Population Survey and Japan's 1977 Employment Status Survey. These data show that American workers tend to have shorter job tenure (8.1 years) than their Japanese counterparts (12.2 years) but more schooling (12.9 vs. 11.0 years). The wage in each country (in logarithmic form) is regressed on age (a surrogate for experience), tenure, schooling, total factor productivity growth, and output growth. Wage-experience and wage-tenure profiles are found to rise more rapidly in Japan than in the United States, and the latter is found to be steeper than the former. The difference between the return to experience is interpreted as a return to firm-specific training, and the author concludes that Japanese firms invest more in firm-specific skills than do American firms.

The hypothesis that the observed difference in firm-specific skills is positively related to the difference in TFP growth rates is clearly supported by aggregate data on the growth of the U.S. and Japanese economies. However, the hypothesis is not confirmed when interindustry variations in TFP are linked to variations in skill investment within the United States and Japan. While there is a positive association between the two variables among U.S. industries, the Japanese data do not reveal a significant association. Since this finding leaves room for other explanations, Tan compares his explanation of seniority-based wages with a leading competitor, the implicit contract explanation. Using U.S. data from the National Longitudinal Survey, he finds a correlation between a direct measure of training and TFP growth and concludes that the evidence favors his hypothesis. In sum, these results suggest a link between wage differentials and differences in worker productivity, and thus they tend to support the use of the Divisia labor-quality adjustments.

Differences in age, experience, education, and training of the labor force are not the only source of difference between workers in Japan and the United States. There is a widespread view that the Japanese simply work harder and more diligently than their American counterparts. While this view may be supported largely by casual empiricism, it is amusing to note that the Japanese government has recently proposed a new holiday, "Happy Couple Day," in an effort to reduce the perceived workaholic tendencies of the Japanese labor force.

The paper by Lam, Norsworthy, and Zabala attempts to probe this issue by examining differences in worker attitudes in the United States and Japan. Although attitude and effort are not necessarily the same thing, differences in attitude may serve as a proxy for differences in the intensity of work effort and commitment to product quality. With this in mind, Lam et al. collected data on strikes, labor disputes, and quit rates in both countries, with the rationale that labor unrest is related to worker attitude. These variables are added to a conventional translog cost function analysis of the manufacturing sectors of both countries. The authors find that strikes and grievances have a larger impact on costs in the United States than in Japan. In the United States, these factors increased the cost of production by around 8% in the 1950s and 1960s, and this increased to 12% in 1980. On the other hand, production costs in Japanese manufacturing were higher by only 7% in 1965 and this fell to about 3% in 1978. These results suggest that a significant cost advantage accrues to Japanese manufactured goods as a result of conditions in the workplace.

Conclusions

The last two decades have been a steady advance in the methods of empirical productivity analysis: the development of flexible functional forms, like the translog, for use in estimating the structure of production; the introduction of duality theory into empirical analyses of production and growth; the extension of conventional models to allow for the possibility that capital cannot adjust immediately or costlessly to changes in input prices or desired output levels; and, the elaboration of the index-number approach to measuring economic growth and the linkage of this approach to the corresponding parametric procedures. The papers in this volume may be regarded as an application of these new developments to the comparison of U.S. and Japanese economic growth.

The results presented in the various papers generally confirm the conventional view that Japan experienced an extraordinary surge of growth, from the mid-1950s through 1973, that far exceeded the rate of U.S. growth, which was itself quite strong. After 1973, growth slowed in both countries and the relative growth rates narrowed. However, while there is widespread acceptance of this pattern, there is no agreement about its cause. No single causal factor—no "smoking gun"—emerges from these papers to explain why Japan was able to grow so fast. Indeed, several authors comment on the similarity of the structure of production in the countries. By the same token, there is little agreement about the factors causing the post-1973 slowdown in Japan and the United States. There is similarly a lack of agreement about "catching up" as an explanation of comparative growth trends. This notion is intuitively appealing and, in light of recent analyses of labor-productivity growth, is surely part of the answer. However, several papers in this volume suggest that the process is more complex than the simple convergence of labor productivity at the industry level. According to Jorgenson and Kuroda, the total factor productivity levels in some U.S. industries are increasing relative to the corresponding Japanese levels, while Japan has already surpassed the U.S. in other industries. And, while they do not examine the time trends in comparative TFP levels, the Nadiri and Prucha industry study finds little evidence of convergence in TFP growth rates after the 1973 dropoff.

That there remain many puzzles and unresolved issues is hardly surprising. The papers in this volume are essentially limited to the analysis of one subset of equations governing the economic system: that is, the production function and associated equilibrium conditions. Even complete knowledge of this subsystem could not lead to a complete understanding of the growth process, and our knowledge of the production subsystem is far from complete. Much more work needs to be done on the data used to test the structure of production, with particular emphasis on the development of better measures of capital in all its forms—tangible, intangible, and human. The formal modeling of production also needs attention. It would be, for example, desirable to move away from the paradigm of pure competition that underlies much of the conventional analysis of growth and move toward models that incorporate a more realistic description of market structure, account for uncertainty and expectation-formation, and allow for differences in institutions across countries and regions. Further progress in the modeling of productivity change is also desirable, since the residuals and time trends of many, if not most, conventional analyses are poor substitutes for direct measures of technical and organizational progress. Finally, our understanding of the process of economic growth at the level of plants and firms needs to be integrated with our analyses of growth (and fluctuations) at the industry and economywide level of aggregation.

Work on this agenda is underway, and the papers in this volume are part of this trend. They present many interesting facts and ideas (far more than have been reviewed in this introduction), but they also remind us that, while much progress has been made, there is much still to learn about the processes of economic growth.

Appendix

Logarithmic differentiation of production function (1) yields

$$\dot{q}(t) = \varepsilon_K(t)\dot{k}(t) + \varepsilon_L(t)\dot{l}(t) + \dot{a}(t), \quad (1')$$

where $\dot{a}(t)$ is the rate of change of the production function $F(\cdot)$ with respect to time, holding capital and labor constant: $[\partial F/\partial t)/F]$. It is evident that (1′) is a generalization of (2) where $\dot{a}(t) = \lambda$, $\varepsilon_K(t) = \alpha$, and $\varepsilon_L(t) = \beta$. It is also true that if input prices are equated to marginal products, the output elasticities, $\varepsilon_K(t)$ and $\varepsilon_L(t)$, are equivalent to the value shares, $s_K(t)$ and $s_L(t)$, since the conditions $P_Q(\partial Q/\partial K) = P_K$ and $P_Q(\partial Q/\partial L) = P_L$ imply

$$\varepsilon_K = \frac{\partial Q}{\partial K}\frac{K}{Q} = \frac{P_K K}{P_Q Q} = s_K,$$

and

$$\varepsilon_L = \frac{\partial Q}{\partial L}\frac{L}{Q} = \frac{P_L L}{P_Q Q} = s_L.$$

This being true, it follows immediately that the total factor productivity index defined on the right-hand side of (1′) is equivalent to $\dot{a}(t)$, leading to a geometric interpretation of the total factor productivity index as the shift in the production function (1), and the index $s_K(t)\dot{k}(t) + s_L(t)\dot{\ell}(t)$ as a movement along the production function. Note the right-hand side of (4) is related to the cost function (3) when price equals marginal cost.

Notes

1. There are numerous sources that provide a more detailed description of the procedures used in growth analysis. Solow (1957), Kendrick (1961), Denison (1962), and Jorgenson and Griliches (1967) set forth the basic sources of growth framework. The surveys by Nadiri (1970), Hulten (1986), Maddison (1987), and Griliches (1987) provide more recent descriptions of the relevant issues and methods, as does the material presented in the Bureau of Labor Statistics publication *Trends in Multifactor Productivity* (U.S. Department of labor 1983). However, this list hardly exhausts the relevant literature. *Asia's New Giant* (Patrick and Rosovsky 1976) is a key source for comparative economic studies of the United States and Japan.

2. The term "total factor productivity" is used to denote the collective productivity of all inputs taken together and is synonymous with "multifactor productivity" and "joint productivity." This concept of productivity must be distinguished from single-factor measures like labor productivity. The latter is defined as rate of change of output per unit labor and, in the notation of equation (5), can be written as

$$\dot{q}(t) - \dot{\ell}(t) = s_K(t)(\dot{k}(t) - \dot{\ell}(t)) + \dot{a}(t), \quad (5')$$

under the assumption of constant returns to scale. In this form, the sources-of-growth equation states that the growth rate of labor productivity is equal to the share-weighted growth rate of the capital-labor ratio plus the growth rate of total factor productivity.

3. A derivation of this key result is given in the appendix below.

4. The issues involved in aggregation with intermediate goods are reviewed in Hulten (1978). It may be noted that industry-level estimates of TFP growth can be computed using a value-added measure of real output. However, the resulting estimates are theoretically correct only if the underlying production function exhibits the property of weak separability in the primary inputs. When this holds, aggregation can proceed with weights that sum to one.

5. Under constant returns to scale in production and Hicks-neutral technical change, eq. (3) can be written in such a way that the price of output is equal to a function of input prices (w) times the index of TFP (A), i.e., $p = A^{-1}\phi(w)$. Differences in product price, measured in domestic currency units, must therefore be due to differences in the relative level of TFP or due to differences in $\phi(w)$.

6. The nature of the relative TFP index can be illustrated in the following example. If a good is produced in the United States with a technology $Q_u = A_u F(X_u)$, where A_u is an index of TFP and X_u a vector of inputs, while the same good is produced in Japan with the technology $Q_J = A_J G(X_j)$, the translog index of relative TFP measures the ratio A_J/A_U. In actual applications, the technology is assumed to have the translog form and technical change is not restricted to Hicks neutrality.

7. See Baumol, Blackman, and Wolff (1989) for a detailed discussion of this issue and references to the relevant literature.

8. Recall, here, that the growth rate of labor productivity is equal to the growth rate of the capital-labor ratio, weighted by capital's share of total factor cost plus the materials-labor ratio and the energy-labor ratio, weighted by their cost shares, plus the growth rate of TFP. The time path of labor productivity can thus be quite different from the path of TFP. Moreover, Dollar and Wolff (1988) use a value added framework for estimating labor productivity, while Jorgenson and Kuroda (in this volume) use a gross output framework. One consequence of this difference is that the estimated growth rates of TFP are typically quite a bit smaller than the corresponding rates generated by the value-added approach.

9. First, capital is almost invariably measured as a stock and not a flow, so that variations in the latter may go undetected and be suppressed into the TFP residual. This problem is widely thought to account for the procyclical variation in TFP over the business cycle. However, Berndt and Fuss (1986) have shown that, in the absence of adjustment costs, the conventional framework does embody a degree of correction for factors that are fixed in the short run: if firms react along their short-run marginal cost curves, utilization is increased by the application of more variable input to the quasi-fixed input, and this increased utilization is accurately reflected in relative prices. If, on the other hand, firms shut down in response to changes in demand, or these changes are not expected, then the Berndt-Fuss approach does not solve the stock-flow problem. Furthermore, when adjustment costs are present, prices are not proportional to marginal products and the conventional productivity model yields biased results.

10. The TFP estimates of this paper are somewhat higher than those reported in the Jorgenson-Kuroda paper. This difference is not surprising given the difference in data, methodology, and time period. It does, however, highlight the problem noted at the beginning of this introduction that different procedures can yield very different conclusions about the process of economic growth.

11. It is interesting to note that the superior rate of technical change in Japan was apparently not associated with a greater degree of flexibility in production. The authors show that own-factor price elasticities were roughly similar in all three countries and rather inelastic. Partial elasticities of substitution showed less commonality, but not dramatically so.

12. It is also worth noting that R&D spending is subtracted from other inputs in order to avoid a double counting of inputs. This adjustment is not made in most studies, so the impact of R&D is either embodied in the weighted growth of the other inputs (e.g., labor or capital) or, if there are economic rents or if the social return to R&D exceeds the private return, suppressed into the conventional TFP residual.

13. Recall, again, that capital input is typically measured as a stock rather than as a flow (using, as we shall see, a perpetual inventory method that does not allow for an acceleration in the rate of retirement of old capital or for variations in the rate of utilization of existing stock). This method results in biased estimates in situations where an

increase in the price of a complementary input, like energy, reduces the demand for capital services when stocks cannot adjust rapidly.

14. This procedure yields an estimate of the *stock* of a given type of capital asset, but not the *flow* of services of that asset. Several of the preceding papers in this volume have dealt with this issue under the guise of quasi fixity and endogenous capacity utilization. Other procedures include the assumption that service flows are proportional to stocks and the use of an exogenous estimate of capital utilization.

15. Those who believe that differential tax burdens are a key determinant of relative economic performance may find some comfort in these numbers, given the lower effective tax rate on capital income in Japan and the more rapid rate of capital formation and economic growth. However, the time pattern of tax rates is not so favorable to this view. The percentage cut in the Japanese effective tax rate was roughly equal between the 1961–70 and 1970–80 eras, but the rate of capital formation fell dramatically in the second period. And, in the United States, the period of high growth came during the 1960s, when the fall in the effective tax rate was negligible, and not in the 1970s, when it was substantial.

16. In this view, the residual shift in the production function is due to unmeasured inputs like the stock of knowledge, and accurate measurement of all inputs should reduce the residual to zero (Jorgenson and Griliches 1967). This is, of course, very difficult to accomplish since unobserved variables like the stock of knowledge cannot be measured with complete accuracy. Knowledge, for example, can be accumulated systematically through R&D investment, or it can be the result of learning by doing, pure inspiration, or imitation. The TFP residual may thus incorporate advances in knowledge through spillovers and non-R&D generated increments to knowledge even when a separate R&D stock is included in the analysis.

17. Suppose, for example, total hours worked is growing at 3% a year, while the hours worked by the young and old are growing at 4% and 2% a year, respectively. If the wage-share of the young workers is .25 and the share of the older workers is .75, the Divisia index of labor input grows at 2.5% per year. The relative increase in younger workers has the effect of decreasing the effect of hours worked on output.

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