Abstract.– This study develops and demonstrates a framework for measuring changes in the total-factor productivity of fishing fleets operating in common-property, open-access fisheries. This approach is distinguished from previous efforts to measure productivity growth in fisheries by our explicit treatment of the fishery resource as a constraint on production and by the incorporation of recent advances in productivity measurement that take into account variations in the degree of capacity utilization in an industry. The approach is developed in sufficient detail for the non-economist fishery analyst to follow and implement. The empirical analysis of total-factor productivity growth in the U.S. tropical tuna fleet reveals that this approach eliminates a significant amount of bias in fleet productivity measures which is otherwise introduced when using traditional methods of productivity analysis.

On Measuring Fishing Fleet Productivity: Development and Demonstration of an Analytical Framework

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Measuring changes in productivity has long been an important component in evaluating an industry's economic performance. Such measures in fishing industries can signal the need for, as well as indicate the success of, policy or management actions. Measurement of productivity growth or technical progress in marine fishing industries has received attention by Bell and Kinoshita (1973), Davis et al. (1987), Duncan (n.d.), Kirkley (1984), and Norton et al. (1985).

Two considerations not addressed by previous researchers are important for evaluating productivity growth in fishing industries. First, traditional measures of productivity implicitly assume that a fishing industry's capital stock is being utilized, in an economic sense, at its long-run equilibrium or capacity output level. Thus, traditional measures fail to adjust for variations in the degree of utilization of the industry's productive capacity. Second, the effect of changes in abundance of the fish stock on productivity growth in fishing industries has not been specifically accounted for in the traditional analysis. As a result, changes in resource abundance are not disentangled from changes in productivity.

In this study we develop a nonparametric framework utilizing the method of growth accounting and economic index numbers to analyze the productivity growth of fishing fleets operating in common-property, open-access fisheries. The framework is then demonstrated by analyzing productivity growth in the U.S. tropical tuna purse seine fleet over the years 1981–1985.[1] We also demonstrate a method for deriving implicit aggregate output and input price indices for the purse seine fleet.

In developing the productivity assessment framework, we introduce further refinements to the standard procedure described by Denny et al. (1981) and Cowing et al. (1981)—which has seen continual improvement since the pioneering work of Solow (1957)—by adjusting for variations in capacity utilization and changes in resource abundance. The exposition includes the technical detail necessary to provide the non-economist fishery analyst with a comprehensible and useful means of tracking and analyzing productivity growth and performance in fisheries.

[1]The method is non-parametric because parameters of the production technology or production function are not econometrically estimated. The method of growth accounting and economic index numbers is discussed in a later section of the text. Econometric estimation of productivity growth does not impose the conditions of a constant-returns-to-scale production technology and Hicks-neutral technical change. However, this comes at the expense of more demanding data requirements: either a longer time-series of aggregate data or more vessel-level observations in any given year. In addition, some fairly sophisticated econometrics and economics are required to estimate and interpret the results.

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In the following section we introduce the methodology used to analyze total factor productivity in fishing fleets. The potential bias from failing to account for variation in economic capacity utilization is investigated in the third section. We discuss the data, empirical issues, and the construction of index numbers for the U.S. tropical tuna purse-seine fleet in the fourth section, and then we develop the implicit price indices and report and interpret results of the empirical analyses in the fifth section.

Total-factor productivity

The standard procedure for estimating total-factor productivity is derived from the economic theory of production. In common-property natural resource industries, the production function expresses a stock-flow relationship between the resource stock and the flow of resource extraction or output from the production activity in any given time-period. An important consideration when measuring productivity growth in fishing industries is defining the role of the common-property resource stock in the production technology.

Rather than treating the common-property resource as a conventional input (Scott 1954, Clark 1976, Dasgupta and Heal 1979), it is more appropriately specified as a constraint to the production technology. The fish stock is a biological constraint on the production technology because its abundance affects the production environment within which fishing firms operate, but it is beyond the control of any individual firm. That is, the use of conventional inputs such as capital, labor, and energy is conditional upon expected resource-abundance levels. Changes in resource abundance shift the production technology. McFadden (1978) develops this approach by treating environmental parameters (such as resource abundance) in a manner similar to disembodied technical change; i.e., technological progress due to more efficient use of existing inputs. Finally, resource abundance is a technological constraint because the total catch cannot exceed the abundance available, and an increase (decrease) in resource abundance allows an increase (decrease) in catch for any given level of input usage and state of technology.[2]

When the fish stock is treated as a technological constraint, the production function, F, relates the maximum flow of output in time t (such as tons of fish extracted), $Y(t)$, to the flow of $N+1$ inputs, $X_1(t)$, $X_2(t),\ldots,X_{N+1}$, the state of technology represented by $A(t)$,[3] and abundance of the fish stock indexed by $B(t)$:

$$Y(t) = F[X_1(t), X_2(t),\ldots,X_{N+1}(t); A(t), B(t)]. \quad (1)$$

Growth-accounting framework

Total-factor productivity measures are derived from equation (1) using the growth-accounting framework and economic index numbers.[4] This approach accounts for the growth in output flow over time by partitioning this output growth among the growth in inputs, technical progress, and changes in resource stock abundance. Total-factor productivity is then measured as the residual in the growth of output flow after accounting for all of the measurable sources of growth.

Under the growth-accounting framework, a constant-returns-to-scale production function is assumed, so that a proportional increase in inputs yields a proportional increase in output flow for any given level of resource stock abundance and state of technology. Movement in time t is assumed to lead to improvements in the state of technology, so that $\delta F/\delta A(t)>0$ (Solow 1957). Following conventional practice, we further assume a particular form of technological change, Hick's-neutral disembodied technical change.[5] Moreover, $\delta F/\delta B(t)>0$, so that increases (decreases) in resource stock-size allow an increase (decrease) in the flow rate of extraction for any given input bundle and state of technical progress. We assume a Schaefer (1957)-type production technology, and further assume that changes in resource stock-size are Hick's neutral, so that the

[2]Gordon (1954) similarly treated biological abundance as a technological constraint. Gordon (p. 136) states, "For each given level of population, a larger fishing effort will result in larger landings. Each population contour is, then, a production function for a given population level." Moreover, as Gordon noted, this approach does not preclude the impact that increases in catch typically have in reducing the resource stock. If resource abundance was instead another factor of production, like labor or capital, then changes in resource abundance would imply movements along the existing production function rather than shifts up or down the production function.

[3]The state of technology refers to the current level of technology or kind of production process utilized. For example, the current state of technology in the U.S. tuna fleet is represented by purse seining with some level of usage of vessel electronics.

[4]For a discussion of some of the limitations to the growth-accounting approach to measuring total-factor productivity, see Nelson (1981).

[5]Technological change or progress refers to the changes in a production process that come from the application of knowledge. These changes in the production process can be realized in various ways: through improved methods of utilizing existing resources, such that a higher catch-rate per unit of input ("effort") is obtained for a given level of resource stock abundance, often referred to as disembodied technological change; through changes in input quality, referred to as embodied technological change; or through the introduction of new processes and new inputs, which can be either (or both) disembodied and embodied technological change.

Hick's neutral technological change, whether disembodied or embodied, means that the technological advance does not change the proportions in which different inputs are used. Thus, for example, after technological change, capital, labor, energy, and any other inputs would be combined in the same proportions as before.

proportions with which all inputs are used remain constant for any given level of resource stock abundance.

The productivity growth-accounting measure is fully developed in the Appendix, while only its final form is presented here:

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \sum_{i=1}^{N+1} S_i \frac{\dot{X}_i}{X_i} - \frac{\dot{B}}{B}, \quad (2)$$

where the dots over variables represent time derivatives, $S_i(t) = P_i(t)X_i(t)/P(t)Y(t)$; i.e., the income or cost share of input X_i, where $P_i(t)$ is the price of input X_i in time t, and $P(t)$ is the price of output Y in time t. Productivity growth $\dot{A}/A$ is the residual of output growth $\dot{Y}/Y$ after accounting for aggregate input growth $\Sigma_i S_i(\dot{X}_i/X_i)$ and changes in resource abundance $\dot{B}/B$. This index of total-factor productivity growth is also called a Divisia index.

Tornqvist economic index numbers

A convenient discrete-time approximation to the continuous Divisia index is provided by Tornqvist (1936). The Tornqvist discrete approximation to the Divisia index of total-factor productivity growth (*TFP*) is expressed as:

$$\frac{TFP_t}{TFP_{t-1}} = \prod_{j=1}^{M} [Y_{jt}/Y_{j,t-1}]^{1/2(R_{jt}+R_{j,t-1})} - \prod_{i=1}^{N+1} [X_{it}/X_{i,t-1}]^{1/2(S_{it}+S_{i,t-1})} - \frac{B_t}{B_{t-1}}, \quad (3)$$

where the Y_j are outputs, the X_i are the $N+1$ inputs, B is the index of resource abundance, the $R_j = P_jY_j/\Sigma_j P_jY_j$ are output revenue shares, and the S_i are $N+1$ input cost shares.[6] As the interval between time-periods approaches zero, discrete-time Equation (3) approaches continuous-time Equation (2).

[6]In practice, the logarithmic form of Equation (3) is computed, which gives the productivity growth between two periods. The exponent of this computation is then taken to obtain $TFP_{t,t-1}$. These period-to-period changes are then typically chained as in Equation (4) to form the Tornqvist bilateral chain index. The logarithmic form of the Tornqvist index is:

$$\ln(TFP_t/TFP_{t-1}) = 0.5\sum_{j=1}^{M}(R_{jt}+R_{j,t-1})\ln(Y_{jt}/Y_{j,t-1}) - 0.5\sum_{i=1}^{N+1}(S_{it}+S_{i,t-1})\ln(X_{it}/X_{i,t-1}) - \ln(B_t/B_{t-1}).$$

Chain indices

We use the method of chain indices to calculate the Tornqvist total-factor productivity index. Chain indices directly compare adjacent observations in a sequence of economic index numbers.[7] Nonadjacent observations are only indirectly compared, using the intervening observations as intermediaries, a practice resulting in transitive comparisons. The general form of the chain index can be written:

$$TFP_{t,t+N}^{\text{chain}} = TFP_{t,t+1} \cdot TFP_{t+1,t+2} \cdot \ldots \cdot TFP_{t+N-1,t+N}, \quad (4)$$

where each individual term of Equation (4), $TFP_{t,t+1}$, is computed by the bilateral Tornqvist formula given in Equation (3), and represents the change from time period t to time-period $t+1$; i.e., $TFP_{t,t+1} = TFP_{t+1}/TFP_t$.

Productivity and capacity utilization

If firms are in long-run equilibrium, quasi-fixed inputs are optimally utilized in that the total cost of production per unit of output is minimized. This long-run optimal utilization is called full economic capacity utilization. Under long-run equilibrium, the flow of services from a quasi-fixed input is assumed proportional to the stock of that input, so that the available services from each of the quasi-fixed inputs are fully utilized: the observed stocks replace unobserved service flows in Equation (2) (Berndt and Fuss 1986).

When quasi-fixed inputs are not optimally utilized, i.e., the firm is not in long-run equilibrium, the observed productivity growth is composed of both the true technical progress impact, captured by $\dot{A}/A$ in Equation (2), and the rate of change in capacity utilization. An additional source of output variation is added to Equation (3): variations in capacity utilization (*CU*). To develop this argument, suppose that the $N+1^{th}$ input is now a quasi-fixed input capital (K), while the first N inputs are variable inputs. Then growth in productivity is written as (Hulten 1986):

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \sum_{i=1}^{N} S_i \frac{\dot{X}_i}{X_i} - S_K\left[\frac{\dot{CU}}{CU} + \frac{\dot{K}}{K}\right] - \frac{\dot{B}}{B}, \quad (5)$$

where S_K is capital's cost share.

[7]The alternative approach is that of fixed-base indices in which *TFP* in any time t is directly compared with *TFP* in the initial or base period. See Squires (1988) for an extensive discussion within fisheries.

Failure to capture this additional source of variation creates a potential bias in the true productivity residual, $\dot{A}/A$, which varies with the rate of capacity utilization.

Methods of capacity utilization adjustment

When the firm is in temporary or short-run equilibrium rather than long-run equilibrium, the productivity residual formula can be adjusted for variations in CU in two different ways. The first relaxes the assumption that service flows are proportional to stocks by adjusting the stock of a quasi-fixed input to reflect its flow of services[8] (Berndt and Fuss 1986). Thus, rather than specifying capital as a stock (e.g., the number of vessels in the fleet), capital is measured by its flow of services or total time of utilization (e.g., as fleet vessel-days fished). Such a flow adjustment corresponds to an economic notion of CU, because we assume that a producer's decision to increase or decrease running and fishing time is the outcome of an economic optimization process.

The second approach to adjusting the productivity residual for CU variations uses engineering notions of the proportion of available productive capacity that is actually being utilized. Let capacity output Y^* represent the maximum possible output level corresponding to "normal" input usage, existing technology, and the stocks of quasi-fixed inputs. A measure of capacity utilization is then obtained by the identity: $CU \equiv Y/Y^*$, where Y is the observed output level.

Data and empirical issues

Tornqvist output indices for the U.S. tropical tuna purse-seine fleet were constructed using annual deliveries of skipjack and yellowfin tuna by the fleet to U.S. canneries and the corresponding dollar values of these deliveries. Weighted exvessel implicit prices for skipjack and yellowfin tuna were calculated by dividing the total dollar value of cannery receipts for each species by the total volume of cannery receipts. Revenue and cannery receipts data were obtained from the Southwest Region, National Marine Fisheries Service (NMFS). Dollar values were deflated by the GNP implicit price index.

To construct the input indices, four major categories of factors used in owning and operating a tropical tuna purse seiner were identified: labor, capital, fuel, and other intermediate inputs (transshipment services, repairs, gear, insurance, helicopter services, travel, and other). Constant-dollar unit prices for these inputs were estimated based on purse-seine expenditure data reported by the U.S. International Trade Commission (ITC 1986).

The labor index incorporates the flow of labor services derived by multiplying estimated total days absent (at sea or absent from port) per vessel per year by 19 crew members, which is the assumed average crew size in each year of the period. The unit price of labor, cost per crew-day-absent, was estimated by dividing the sum of the ITC's reported annual crew-related expenditures per vessel by a measure of annual crew-days-absent per vessel.

Three different capital indices were constructed for the total-factor productivity analysis of the U.S. tropical tuna fleet. The first two capital indices both assumed that firms were in long-run equilibrium and that the flow of capital services was proportional to the capital stock. The first capital index specified capital as the annual number of vessels in the fleet. The second capital index captured the effect of different vessel sizes (where size is a measure of the vessel's hold or carrying capacity) upon catch rates by measuring capital as the annual carrying capacity of the fleet.

The third capital index not only captured the effects of different-sized vessels, but also accounted for actual changes in the flow of services from this size-differentiated capital stock. In this third case, the flow of capital services was measured in annual ton-days-absent, an aggregation of each vessel's carrying capacity multiplied by the number of days it spent at sea during the year. Measures of annual ton-days-absent were derived from purse-seine-fleet activity data compiled by NMFS. The cost share for capital used in construction of all the capital indices was its market rental price, the sum of the annual interest expense and reported annual depreciation per vessel from the ITC sample.

The fuel index was constructed by dividing the annual fuel expenditure per vessel (from the ITC sample) by average fuel prices provided by the American Tuna Boat Association. Fuel consumption per vessel was then multiplied by the number of vessels in the fleet resulting in the aggregate annual fuel consumption.

The index of other intermediate inputs was derived by deflating the fleet's nominal expenditure on this category of inputs by the producer price index for industrial commodities. This approach represents the collective use of these inputs in real terms. The nominal expenditure for this category of inputs divided by the corresponding deflated expenditure was used as a proxy for the unit price of other intermediate inputs.

[8]An alternative approach to accounting for variations in economic capacity utilization adjusts the cost or income shares rather than the flows of capital services. Berndt and Fuss (1986) and Hulten (1986) develop this approach, and Squires and Herrick (1988) provide a fisheries application. This approach is well suited when accurate and detailed data on running and fishing time are unavailable.

Table 1
Total-factor productivity growth in the U.S. tropical tuna fleet, 1981–85.

	No biomass adjustment				Biomass adjusted
	Capital input alternatives				
Period	No. of vessels[1]	Fleet carrying capacity[2]	Ton-days-absent[3]	Engineering-*CU*-adjusted carrying capacity[4]	Ton-days-absent; biomass adjustment[5]
1981–82	-0.1037	-0.1241	-0.0863	-0.1159	0.1006
1982–83	0.3739	0.3643	0.3378	0.1753	0.2120
1983–84	0.0298	0.0278	0.0767	0.1056	-0.4330
1984–85	0.0619	0.0499	0.0452	0.0932	0.0192
Mean	0.0905	0.0795	0.0933	0.0645	-0.0253

[1]Long-run equilibrium in capital, capital represented by the number of vessels; no biomass adjustment.
[2]Long-run equilibrium in capital, capital represented by fleet carrying capacity; no biomass adjustment.
[3]Capital input represented by the actual flow of capital services, ton-days-absent; no biomass adjustment.
[4]Capital represented by carrying capacity corrected for variations in capacity utilization (*CU*); no biomass adjustment.
[5]Capital represented by ton-days-absent; biomass adjusted.
Note: Calculated as Tornqvist bilateral indices using the logarithmic form of Equation (3) given in Footnote 6.

Because the U.S. tropical tuna purse-seine fleet operates almost exclusively in the Pacific Ocean, resource abundance measures relied on the extensive biological database that has been compiled by the Inter-American Tropical Tuna Commission (IATTC, La Jolla, CA 92038). From the IATTC database, we obtained estimates of annual yellowfin tuna biomass and estimates of catchability coefficients for yellowfin in the Commission's eastern tropical Pacific yellowfin regulatory area (CYRA). The CYRA was the only region of the Pacific for which such data were available. Moreover, there were no such data for skipjack tuna from any area of the Pacific. Because of these circumstances, it was not possible to explicitly account for fluctuations in biomass over the full range of the fishery and across all species harvested. Therefore, only the annual yellowfin biomass in the CYRA weighted by the catchability coefficient was used to adjust fleet productivity for changes in resource abundance.

Empirical results

Table 1 reports changes in annual total-factor productivity growth for the U.S. tropical tuna fleet over the period 1981–85 using Tornqvist bilateral-chain indices. Each of the total-factor productivity growth rates presented in Table 1 is distinguished by its specification of the capital input and adjustments for changes in resource abundance. Treatment of outputs and the other inputs is the same in all cases. To anticipate our results, we find that adjusting the traditional productivity measures for variations in economic capacity utilization and changes in resource abundance pares away sources of output growth that are not due to technical progress, giving a more accurate measure of productivity.

Productivity measures under full equilibrium

Columns (1) and (2) of Table 1 provide productivity growth measures assuming long-run equilibrium—economic capacity is fully utilized—without accounting for changes in resource abundance. The total factor productivity growth rates in column (1) use the first capital index: capital is represented by the number of vessels included in the fleet. The growth rates reported in column (2) are based on the second capital index: capital is represented by the carrying capacity of the fleet. Because vessels leaving the fleet during the period tended to be older and in the smaller size-categories, capital expressed in number of vessels decreased at a greater rate than capital measured in aggregate carrying capacity (columns [2] and [3] of Table 2). Hence, total-factor productivity growth based on the second capital index is lower than that based on the first capital index for those years in which the fleet declined.[9]

[9]It might be argued that technical progress is embodied in the capital stock, so that different ages of vessels, embodying different advances in technical progress, should be explicitly considered. This is referred to as vintage effects, and is certainly the case for some types of technical progress such as purse seining versus pole-and-line harvesting. However, in recent years, much of the technical progress has been in the form of vessel electronics. While this type of technological change in a narrow sense, represents embodied technical change, so that vintage effects could theoretically be important, the volume of investment is negligible in comparison with the vessel's value, and much of the technical change is fundamentally related to the managerial function, information, and learning-by-doing: Hick's-neutral technical change.

Table 2
Annual growth in output, capital, CYRA* yellowfin tuna biomass, and capital stock capacity utilization rates, 1981–85.

Period	Output[1]	No. of vessels[2]	Fleet carrying capacity[3]	Ton-days-absent[4]	CYRA yellowfin tuna biomass[5]	Rate of capacity utilization[6]
1981–82	−0.0090	0.0947	0.1151	0.0773	−0.1869	−0.0327
1982–83	0.1869	−0.1870	−0.1774	−0.1508	0.1258	0.3898
1983–84	−0.0165	−0.0464	−0.0444	−0.0932	0.5096	−0.0244
1984–85	−0.0800	−0.1420	−0.1299	−0.1252	0.3167	−0.0125
Mean	0.0204	−0.0702	−0.0592	−0.0730	0.1913	0.0801

*Eastern tropical Pacific yellowfin regulatory area, IATTC.
[1]Annual change in deliveries of U.S.-caught yellowfin and skipjack tuna to U.S. canneries.
[2]Annual change in number of vessels comprising U.S. tropical tuna purse-seine fleet.
[3]Annual change in U.S. tropical tuna purse-seine fleet's hold capacity.
[4]Annual change in the fleetwide flow of capital services for the U.S. tropical tuna purse-seine fleet.
[5]Change in IATTC estimates of the annual CYRA yellowfin biomass.
[6]Annual change in ratio of actual U.S. tropical tuna purse-seine fleet output to fleet engineering capacity.
Note: In natural log form (cf. footnote 6).

Productivity measures adjusted for capacity utilization

The total-factor productivity growth rates presented in column (3) of Table 1 incorporate the third capital index: the annual flow of capital services from the size-differentiated capital stock, ton-days-absent. Since the number of ton-days-absent directly reflects the degree to which economic capacity is utilized, resulting measures of total-factor productivity growth are not subject to a capacity-utilization bias as are the growth rates shown in columns (1) and (2) of Table 1.

The effects of adjusting for *CU* are revealed in Table 2 by comparing the rates of change in the fleet's capital stock and the fleet's flow of capital services: fleet carrying capacity and ton-days-absent reported in columns (3) and (4), respectively. Between 1982 and 1983, fleet carrying capacity decreased 18%, while ton-days-absent decreased 15%. This means that the reduced fleet was fishing more intensively, and that a measure of productivity growth based on the stock of capital or fleet carrying capacity, without correcting for the degree of capacity utilization, will be biased upwards. Similarly, comparing growth in fleet carrying capacity and ton-days-absent between 1983 and 1984 reveals a greater decline in the latter relative to the former. Therefore, a smaller fleet capital stock is utilized (fished) proportionately less, and productivity growth based simply on the capital stock (carrying capacity) will be understated.

Column (4) of Table 1 reports growth in total factor productivity for the U.S. tropical tuna fleet, where changes in fleet carrying capacity—changes in the stock of capital—are corrected for variations in the rate of capacity-utilization. In this case, the capacity utilization adjustment is based on vessel design or engineering characteristics which act to establish an upper limit on fleet output in a physical sense. To estimate fleet engineering capacity, we assumed that each vessel was capable of making three fishing trips annually, filling its hold on each trip. Thus, maximum fleet output in each year is three times the fleet's carrying capacity. The ratio of actual fleet output (the total quantity of tuna delivered to canneries) to maximum potential fleet output estimates the degree of capacity utilization.

Changes in the rate of capacity utilization using the engineering adjustment are shown in column (6) of Table 2. These capacity-utilization rates were then used to derive the engineering-adjusted total-factor productivity growth rates presented in Table 1, column (4). Comparing the total-factor productivity growth rates in columns (2) and (4) of Table 1 discloses the extent of the bias introduced by failing to account for variations in the degree of capacity utilization.

The capacity-utilization adjustment is made to approximate the actual flow of services from the quasi-fixed factor, the capital stock. Therefore, one might expect the total-factor productivity growth rates using ton-days-absent (Table 1, column [3]) to closely correspond to those based on correcting for capacity utilization using the engineering approach (Table 1, column [4]). The fact that they do not points out that, in an economic sense, capacity-utilization adjustments explicitly recognize that quasi-fixed factors are not always utilized at the long-run equilibrium or full economic-capacity-output level, the level of output which minimizes the per-unit-cost of production. Under these circumstances, engineering-capacity output, as we have

Table 3
Implicit aggregate output and input price and total-factor-productivity chain indices.

Year	Total-factor productivity	Implicit aggregate output price	Implicit aggregate input price
1981	1.0000	1.0000	1.0000
1982	1.1058	0.9504	1.0221
1983	1.3669	0.8833	0.9016
1984	0.8865	0.7961	1.1941
1985	0.9037	0.7049	1.1099

Note: Implicit price indices formed by Fisher's weak factor-reversal relationship. See text for details. Total-factor productivity, calculated as Tornqvist bilaterial chain indices, adjusted for variations in biomass and capacity utilization (using ton-days-absent).

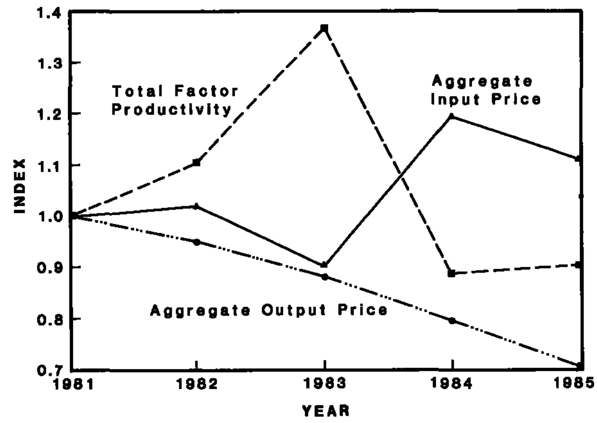

Figure 1
Total-factor productivity and implicit price indices.

defined it, should be greater than full economic-capacity output. Thus, the engineering capacity-utilization rates should be biased downward, and the corresponding productivity growth rates will inherit this bias. The preferred capacity-utilization correction, consistent with economic theory, should adjust the capital stock by its time in use to provide a flow measure of capital services.

Productivity measures adjusted for biological abundance

The total-factor productivity growth rates presented in column (5) of Table 1 are based on the actual flow of capital services and the growth of the yellowfin biomass in the CYRA (Table 2, column [5]). Comparing columns (3) and (5) of Table 1 indicates that the increase in the CYRA yellowfin biomass during most of the period acts to partially offset gains in total-factor productivity otherwise attributable to technical progress. The resource and capacity utilization adjusted total-factor productivity growth rates from Table 1, column (5) are used to compute the index of total factor productivity for the U.S. tropical tuna fleet shown in Table 3 and in Figure 1.[10]

Implicit output and input price indices

Fleet economic performance depends upon the real prices of outputs and inputs in addition to total-factor productivity. Corresponding to the aggregate output and input quantity indices are implicit aggregate output and input prices. These are calculated by a relationship due to Fisher (1922), which states that the product of the price index times the quantity index equals the expenditure ratio between the two time-periods. The implicit price index for an output (or input) can be interpreted as the ratio of the price level in period $t+1$ to the price level t. Fisher's relationship for the price (PI) and quantity (QI) indices for aggregate output Y can be written as:

$$PI(P_t, P_{t+1}, Y_t, Y_{t+1})\ QI(P_t, P_{t+1}, Y_t, Y_{t+1}) = \textstyle\sum_i P_{it+1} Y_{it+1} / \sum_i P_{it} Y_{it}. \qquad (6)$$

Given either a price index or quantity index, the other function can be defined implicitly by Equation (6).

Implicit Tornqvist bilateral-aggregate output-price and input-price chain indices for the U.S. tropical tuna purse-seine fleet, along with the resource-abundance adjusted total-factor productivity index, are presented in Table 3 and in Figure 1. Increases in total-factor productivity or output prices, or both, improve the fleet's economic performance, while increases in input prices worsen the fleet's economic performance.

Taken together, the changes in total-factor productivity, aggregate input-price, and aggregate output-price indices shown in Figure 1 and Table 3 indicate that the 1981–85 period was highly unstable with regard to the fleet's economic performance. Herrick and Koplin (1986, 1987) point out that this was a time of massive restructuring in the U.S. tuna industry, during which the U.S. fleet began a significant shift of its operations from the eastern to the western Pacific

[10]These period-to-period changes in total-factor productivity, i.e., productivity growth, were computed following footnote 6. Next, the exponent is taken of each value in column (5) of Table 1, giving $TFP_{t,t-1}$. The Tornqvist bilateral-chain index is then formed following Equation (4), to give the first column of Table 3. Note that the value 1.000 for 1981 is the exponent of zero, where zero refers to the zero change for the first period.

Ocean, and the U.S. canned tuna market was inundated by imports. These events undoubtedly contributed to the unstable pattern of productivity growth, and would have introduced additional, unmeasurable disturbance into the system which we are unable to disentangle from the productivity residual in the growth-accounting framework.[11]

Concluding remarks

We have shown how the nonparametric growth-accounting framework can be modified to measure the growth in total-factor productivity or technical progress of fishing fleets. This framework can provide useful information for tracking and analyzing economic growth and its causal factors in a fishing industry, particularly where short time-series of aggregate data are all that is available. Our approach can be readily implemented in fishing industries in both developed and developing countries, even by non-economist fishery analysts. Unique to our approach is the treatment of the fishery resource, not as a conventional input, but as a technological constraint on production. Our empirical analysis of total-factor productivity growth in the U.S. tropical tuna fleet demonstrates that disentangling the productivity residual from changes in resource abundance provides markedly different results.

We consider capital the most important component of aggregate input because it is represented by the basic unit of production, the fishing vessel. The capital stock—the fishing fleet—determines capacity output in both an economic and engineering sense. Theoretically, it is the flow of services from the capital stock that should serve as the capital input when measuring total-factor productivity. In practice, however, one may not have measures of the flow of capital services, in which case proper specification of the capital input, and accounting for temporary equilibrium effects such as variations in the degree of capacity utilization, becomes extremely important.

[11]Because our biomass adjustment is based only on changes in yellowfin tuna resource abundance in the CYRA, the variation in total-factor productivity should become more pronounced as the fleet moved from the eastern to the western Pacific Ocean during the 1981–85 period. Furthermore, there were likely to have been some initial technical inefficiencies as the fleet began fishing in the relatively unfamiliar western Pacific.

New investment and industry restructurings can have very real detrimental effects upon the time-path of productivity growth. Therefore, we would expect to see unstable productivity growth as firms adapt over time to changing industrial conditions. Under such circumstances, the assumptions underlying our model—constant-returns-to-scale, disembodied Hick's-neutral technical change conditions, and technical efficiency—may not fully apply. Nonetheless, these are limitations of virtually any application using the growth-accounting framework.

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Appendix

The growth-accounting framework is developed by differentiating Equation (1) with respect to time t:

$$\frac{dY(t)}{dt} = \sum_{i=1}^{N+1} \frac{\delta F}{\delta X_i(t)} \cdot \frac{dX_i(t)}{dt} + \frac{\delta F}{\delta A(t)} \cdot \frac{dA(t)}{dt} + \frac{\delta F}{\delta B(t)} \cdot \frac{dB(t)}{dt}, \tag{A.1}$$

where $dY(t)/dt$ represents the growth rate of output (i.e., extraction rate) due to technical progress. Putting the left side of Equation (A.1) into percentage terms (and suppressing the notation for each time period t) gives:

$$\frac{dY}{dt}\frac{1}{Y} = \frac{1}{F}\left[\sum_{i=1}^{N+1} \frac{\delta F}{\delta X_i}\frac{dX_i}{dt} + \frac{\delta F}{\delta A}\frac{dA}{dt} + \frac{\delta F}{\delta B}\frac{dB}{dt}\right]. \tag{A.2}$$

To obtain proportionate growth rates for all variables, substitute $[dY/dt][1/Y] = \dot{Y}/Y$, $[dX_i/dt][1/X_i] = \dot{X}_i/X_i$, $[dA/dt][1/A] = \dot{A}/A$, and $[dB/dt][1/B] = \dot{B}/B$ into Equation (A.2) to give:

$$\frac{\dot{Y}}{Y} = \sum_{i=1}^{N+1}\left[\frac{\delta F}{\delta X_i}\frac{X_i}{F}\right]\frac{\dot{X}_i}{X_i} + \left[\frac{\delta F}{\delta A}\frac{A}{F}\right]\frac{\dot{A}}{A} + \left[\frac{\delta F}{\delta B}\frac{B}{F}\right]\frac{\dot{B}}{B}. \tag{A.3}$$

In equation (A.3), by convention (Denny et al. 1981, Solow 1957) the term $[\delta F/\delta A][A/F]$ is the proportional shift in the production function with time and is set equal to unity. Thus a 1% increase in the index of technical progress increases the flow rate of output by 1%. This shifting of the production function through time is called technical change or the time rate of growth of technical progress. The term $[\delta F/\delta B][B/F]$ is set to unity because it is a technology-shift parameter for a Schaefer (1957)-type production technology in which catch rates are proportional to resource abundance for any given vector of inputs.[12]

Define $E_i = [\delta F/\delta X_i]\ [X_i/F]$. This is the output elasticity of input X_i, representing the proportional change in output flow for a given change in X_i within some level of resource stock abundance and state of technological progress. Substituting the output elasticity expression into (A.3) gives the long-run rate of output growth as:

$$\frac{\dot{Y}}{Y} = \sum_{i=1}^{N+1} E_i\frac{\dot{X}_i}{X_i} + \frac{\dot{A}}{A} + \frac{\dot{B}}{B}, \tag{A.4}$$

[12]This corresponds to the production function specified by Schaefer (1957), $Y = F(E,B) = qEB$, where q denotes the catchability coefficient and E represents effort or an aggregate input index so that $E = g(X_i, \ldots, X_{N+1})$, where g is a linearly homogeneous aggregator function and the $N+1$ X_i are the inputs. Thus, $\delta Y/\delta B = 1$. We are grateful to Jim Kirkley who pointed this out to us. Moreover, the Schaefer production function implicitly assumes constant-returns-to-scale in inputs, because $\delta Y/\delta E = 1$, so that a proportionate increase in E generates an equal proportionate increase in Y. In addition, changes in the resource stock affect the production function in a Hick's-neutral manner, similar to technical progress.

or after rearranging:

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \sum_{i=1}^{N+1} E_i \frac{\dot{X}_i}{X_i} - \frac{\dot{B}}{B}, \tag{A.5}$$

where the dots over the variables represent time derivatives.

Equation (A.5) is the fundamental equation of growth accounting in its continuous time form. Thus full, long-run equilibrium total-factor productivity growth, $\dot{A}/A$, identified with technical progress, is a residual after the sources of output growth have been allocated among intertemporal changes in inputs and resource abundance for a constant-returns-to-scale production technology.

Equation (A.5) allocates the growth rate of $Y(t)$ among $A(t)$, $X(t)$, and $B(t)$ as required, but because the E_i are not observable, two additional steps are required for empirical analysis. Assuming that all inputs are paid the value of their marginal product, then $\delta F/\delta X_i(t) = P_i(t)/P(t)$, where $P(t)$ and $P_i(t)$ are the full equilibrium prices of output and inputs, respectively. This implies that: $S_i(t) = E_i(t) = P_i(t)X_i(t)/P(t)Y(t)$, where $S_i(t)$ is the income or cost share of input X_i. Under constant returns to scale, total costs equal total revenue; i.e., $\Sigma_i P_i(t)X_i(t) = P(t)Y(t)$, and $\Sigma_i S_i(t) = 1$.

The final step is to substitute $E_i(t) = S_i(t)$ into equation (A.5), which gives an equation in which all variables are measurable except $\dot{A}/A$, which is calculated as a residual:

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \sum_{i=1}^{N+1} S_i \frac{\dot{X}_i}{X_i} - \frac{\dot{B}}{B}, \tag{A.6}$$

where the notation for time-period t is again suppressed and $\Sigma_i S_i(\dot{X}_i/X_i)$ represents aggregate input growth. Productivity growth equals the rate of change of output flow minus a share-weighted index of rates of change of inputs minus the rate of change of the resource stock. The index of productivity growth in Equation (A.6) is also called a Divisia index (Hulten 1974).