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Total Factor Productivity (TFP) as a fishery management indicator

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Introduction

Productivity indexes can be broadly expressed as either partial measures of productivity growth (relating a measure of output to a single measure of input) or Total Factor Productivity (relating a measure of output to all inputs). Total factor productivity is a measure of the productivity of all inputs, or factors of production, in terms of their combined effect on output and is often accounted for by technological change or more efficient methods of producing output. Technological change is the major determinant of long term economic growth and hence Total Factor Productivity growth serves as an indicator of the long term growth in an economy.

There are divergent views regarding what actually total factor productivity measure and the extent to which TFP can be taken as a measure of an economy's long-term technological change or technological dynamism. The conventional view is that TFP measure the rate of technical change (Law (2000) Krugman(1996)). In the long term, the new technologies transform the standards of living, economic, social and political ways of life, and even value systems of people. Much of the new technological knowledge is embodied in capital equipment whose accumulation is measured as gross investment. Hence technological change and investment are interrelated. Total factor productivity of an economy increases only if more output is produced from a given supply of inputs. Improvements in technology clearly increase total factor productivity. TFP measures all improvements in technology, including such things as the introduction of electricity, motorcar or technological progress leading to increased agricultural output or rapid technological shocks that are associated with information and communications technologies (ICTs).

The second argument suggests that TFP measures only externalities and other free gifts associated with economic growth. According to this view, the incomes generated by higher productivity are external to the economic activities that generate growth and these benefits spill over to income recipients not involved in these activities (Jorgenson, 1995).

The basics of total factor productivity measurement- The aggregate production function

Technological progress or the growth of total factor productivity is estimated as a residual from the aggregate production function. The aggregate productivity, mean the productivity of unique entities such as nations or entire industries.

Consider the simple Cobb-Douglas version of the aggregate function:

$$Y = AL^{\alpha}K^{\beta},\ \alpha + \beta = 1$$

Total aggregate output is measured as *Y*. *L* is an index of aggregate labour inputs. *K* is an index of aggregate capital. *Y*, *L* and *K* are independently measured while *A*, α and β are statistical estimations. *A* is an index of the aggregate state of technology called total factor productivity. But changes in the number indicate shifts in the relation between measured aggregate inputs and outputs and in this aggregate model these changes are assumed to be caused by changes in technology (or changes in efficiency and/or in the scale of operations of firms).

The geometric index version of TFP is calculated by dividing both sides of the production function by $L^{\alpha}K^{\beta}$ to produce a measure of TFP:

$$TFP = A = \frac{Y}{L^{\alpha}K^{\beta}}$$

The growth rate measure of TFP is then calculated as an arithmetic index generated by taking time derivatives of both sides of the TFP expression w and r are the shares of output/income accruing to labour and capital.

$$a = \frac{wL}{Y}$$

$$b = \frac{rK}{Y}$$

Where w is wages paid to labour, and r is the real rental rate of capital.

$$\frac{wL}{Y} + \frac{rK}{Y} = 1$$

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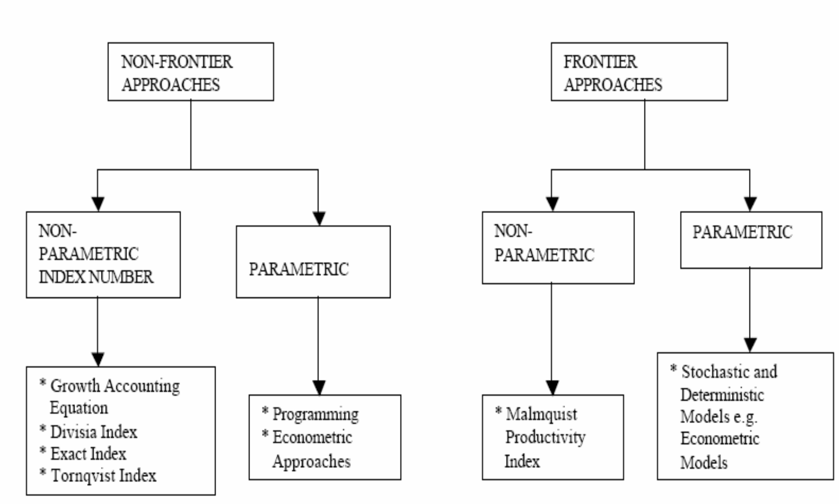
There are some conceptual and empirical problems concerning the measurement of TFP. These relate to the following issues: (1) a relevant concept of capital, (2) measurement of output, (3) measurement of inputs, (4) the place of R&D and public infrastructure, (5) missing or inappropriate data, (6) weights for indices. (7) theoretical specifications of relations between inputs, technology and aggregate production functions, (8) aggregation over heterogeneity.

Approaches to measure TFP

The approaches to total factor productivity measurement are generally classified into frontier and non-frontier approaches. The non- frontier approaches consists of parametric and non- parametric methods. The growth accounting and indexing procedure comes under the non -parametric approach. Programming and econometric approaches are included under the under the parametric methods



There are different indexing methods for calculating the total factor productivity. Some of the most common of these are the Laspeyres index, the Paasche index, the Fisher index and the Tornqvist index. Most work on TFP uses a Tornqvist index, which is basically a percentage change index that averages base and given years weighted indexes. The Tornqvist quantity index is defined as the product across all goods of the ratio of current quantities divided by base year quantities weighted by the average of the base year and current year prices. The Tornqvist index is considered 'superlative' because of its capacity to approximate general functional forms of the production function. Tornqvist index is a discrete approximation to a continuous Divisia index. A Divisia index is a weighted sum of the growth rates of the various components, where the weights are the component's shares in total value. For a Törnqvist index, the growth rates are defined as the difference in natural logarithms of successive observations of the components and the weights are equal to the mean of the factor shares of the components in the corresponding pair of periods. The Törnqvist index represents an improvement over constant base-year weighted indexes, because as relative prices of inputs change, the Törnqvist index allows both quantities purchased of the inputs to vary and the weights used in summing the inputs to vary, reflecting the relative price changes (Lipsey and Carlaw, 2001).

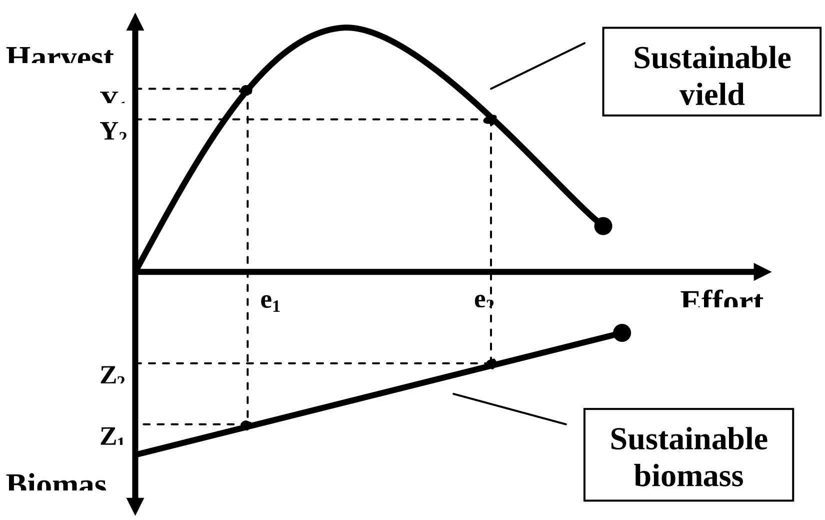
When TFP is calculated from a macro production function, the quantities used are the aggregate capital stock and the aggregate labour supply; when it is calculated from industry data, they will be industry capital and industry labour; similarly for firms, it will be each firm's capital stock and its employed labour. To get the basic quantities without any prior aggregation, extremely detailed micro data would be needed with a separate quantity input for each capital service. Thus, no matter how disaggregated are the physical quantities that are used for any calculation of a TFP index, they are typically aggregated over some group of heterogeneous capital goods (or capital services) by converting them to values. National productivity estimates are of special importance because they are an integral part in public policy making. However at this level of aggregation, the data available are limited to fairly short time series, which limits the scope for econometric estimation. As a consequence, index number methods are most commonly employed for measuring TFP. Most studies have used the index number approach to measure productivity growth due to its easiness and less data requirements when compared to complicated econometric models.

Total factor productivity measurement in natural resources

Productivity growth in a fishery can generally be attributed to several factors. Improvement in technology (innovations) and adoption of technologies help to produce greater amounts of output for their inputs. Structural adjustment of a fishery's fleet towards more productive vessels (through exit and entry) will positively affect productivity- either through market forces or through government funded adjustment assistance. Change in the fishery resource stock- An increase in the abundance of fish stock leads to an increase in estimated productivity as fish can more easily be caught with relatively fewer inputs. Analysis of productivity trends for a fishery increases understanding of the fishery's ability to convert inputs into outputs and is also useful for assessing a fishery's overall economic performance. Availability of productivity estimates over a number of years enables trend analysis to determine key drivers of vessel level productivity growth-changes in the technology mix used in fishing, seasonal conditions and any changes in the regulatory environment.

Importance of fish stock in TFP measurement in marine fisheries

Several fisheries economists consider changes in a fishery's stock biomass as an important factor of productivity growth in marine fisheries. Adjusting for changes in the stock allows for a distinction between productivity changes due to fluctuations in the stock and productivity changes by changes in economic performance (Samuel Herrick and Dale Squires, 1990, Arnason, 2000, Hannesson *et al*, 2005).



Stock / biomas and sustainable yield

The curve in the upper half of the diagram represents the sustainable yield function which traces out the relationship between sustainable effort and the harvest. The line in the lower half of the diagram is the sustainable biomass curve which traces out the relationship between sustainable fishing effort and biomass. The effort level e_2 corresponds to output y_2 and biomass z_2. Reducing the effort to e_1 will lead to an increase in the sustainable harvest to y_1 which shows an increase in productivity. But this is not true as the other input, biomass has increased to z_1. There has been no shift in the production function and both production points lie on the same production possibility frontier (Arnason, 2000).

Hannesson(2005) studied the development of productivity in the Norwegian fisheries during the period 1961-2002 using data on catches at constant fish prices, capital stock, labour input and fish stocks. The total factor productivity has increased rapidly in the mid 60s which was proved to be due to technological progress.

Stephan (2013) analyzed the total factor productivity indexes of five key Commonwealth fisheries using the Fisher index. The TFP indexes were adjusted for changes in fish stocks where fish stock biomass information is available. The productivity increased over the last decade in most Commonwealth fisheries analyzed. These increases reflect a mix of government induced structural adjustments and management changes as well as autonomous adjustment responses to market conditions. Fishery management measures like the vessel buyback is expected to have increased industry level productivity as the least profitable (and therefore, least efficient) vessels exited the fishery-remaining vessels share a similar sized resource, with less crowding and competition, operated more efficiently and productively.

Total factor productivity- an application to the marine fisheries sector in India

Technological advancements took place in marine and aquaculture sectors in the form of improved mechanized fishing crafts and gears, seed, feed, and advances in marine and aqua farming technologies paved the way for increased fish production in the country. Analyzing the impact of productivity growth and quantification of factors leading to productivity growth occupies a significant role in developing a sustainable development plan for the marine fisheries sector in the country. The total factor productivity of marine fisheries in India was anlaysed for the period 2000-10. Gear wise and species wise catch - effort data and species wise average marine fish prices in different states of India obtained from Central Marine Fisheries Research Institute (Government of India) for the period 2000-10 were used for the analysis. TFP index was worked out using Divisia-Tornquist indexing method.

$$\text{TFP index} - \frac{\text{Output index}}{\text{Input index}}$$

$$\text{Input index} = \Pi_i (X_{it}/X_{it-1})^{(S_{it}+S_{it-1})1/2} \quad (1)$$

Where Xit and Xit-1 are the quantities of input i at time t and t-1

Sit and Sit-1 are the shares of input i in total cost at time t and t-1

Similarly output index was workout as follows:

$$\text{Output index} = \Pi_j (Q_{jt}/Q_{jt-1})^{(R_{jt}+R_{jt-1})1/2} \quad (2)$$

Where Q_{jt} and Q_{jt-1} are the quantities of resource j at time t and t-1

R_{jt} and R_{jt-1} are the shares of resource j in total revenue at time t and t-1 t is the number of years (Kumar and Jha,2005).

Fuel, labour and fixed capital were used as the input variables for working out the input index. Fuel used in the marine fisheries sector of India consists of diesel and kerosene. The fuel used in the fishing industry was estimated based on average fuel consumption per hour of operation for all the fishing units. The data was validated by using total diesel sales data from the different diesel pumps, data from fishermen societies and information on diesel subsidy given by various state departments of fisheries. The data on kerosene was estimated based on the number of motorized units operated per year and average kerosene consumption per fishing trip. Labour employed in the marine fishing industry (Mechanized/motorized/Non-mechanized sectors) was estimated in terms of labour days. The fixed capital was estimated from the number of boats and investment details on each category of fishing unit.

The total factor productivity indices were developed based on the input and output indices calculated for the period 2000 to 2010. Fuel, labour and fixed capital used in the fishery were used for developing the input index. The average fuel consumption in the fishing industry varied from 1000 million litres and on an average every tonne of fuel produced 3.5 tonnes of fish. Mechanized trawlers are the prominent fishing units in the country and 76 percent of the fuel requirement in the fishing industry goes to the trawl sector followed by dolnetters(12 per cent), gillnetters (9 per cent) and others(3 per cent). State wise diesel consumption showed that the maximum diesel consumption is in the state of Gujarat where the maximum number of mechanized boats operates.

Labour used in marine fishing industry was estimated in terms of number of days employed per worker per annum. The labour consists of three categories- mechanized, motorized and non-motorized. The mechanized category included vessels of less than 20 m OAL, which used mechanization both for propulsion as well as for fishing operations. The motorized category consisted of outboard motor fitted boats and non- mechanized category consisted of the traditional wooden canoes without any engine. The labour cost included both wages and crew shares received by the fishermen. The average quantum of labour stood at 105 million days during 2000-10 and nearly 70 percent of which is contributed by the mechanized sector. The labour cost in the marine fishing sector was Rs.62 billion and the diesel cost was Rs.36 billion in 2010 at current prices.

The marine fish production increased from 2.65 million tonnes to 3.32 million tonnes during 2000 to 2010. Species wise analysis showed that the quantity of clupeids increased from 6.37 lakh tonnes in 2000 to 9.29 lakh tonnes in 2010. The quantity of other low value pelagics consisting of Bombay duck, half and full beaks, flying fishes, ribbon fishes, bill fishes and barracudas stood at around 3 lakh tonnes. The quantity of mackerels almost doubled from 1.34 lakh tonnes to 2.67 lakh tonnes. The resource wise average share in the gross revenue earned at landing centres during 2000-10 showed that the maximum share was contributed by crustaceans (40 per cent) followed by clupeids (11 per cent), low value demersals(9 per cent), cephalopods(8 per cent), seer fishes(6 per cent) and pomfrets(5 per cent). The output indices calculated from the quantities and revenue shares of the different resources during 2000 to 2010 period showed a growth rate of 3.4 percent.

The total factor productivity showed a positive growth of 1.65 percent during 2000-10 at all India level. The state wise analysis indicated that the total factor productivity growth was positive in the east coast with a growth rate of 8.16 percent whereas in the west coast the total factor productivity growth was negative in the states of Kerala (-3.69%) and Maharashtra(-5.83%).

Table 1 : Total factor productivity growth of marine fisheries in different coastal states in India (2000-2010)

States	TFP growth (%)
West Bengal	6.42
Orissa	18.06
Andhra Pradesh	5.80
Tamil Nadu	4.18
Puducherry	13.75
East coast	**8.16**
Kerala	-3.69
Karnataka	2.88
Goa	4.52
Maharshtra	-5.83
Gujarat	3.15
West coast	**-0.17**
All India	**1.65**

The marine fish production in the major fish producing states of Maharashtra and Kerala showed declining catch trends of high value resources like shrimps and increase in the catches of low value fishes. Deshmukh (2006) reported that among 20 commercially important resources, Bombayduck, silver pomfret, elasmobranches and lobster resources have declined significantly in Maharashtra. Evnethough there was substantial increase in marine fish prices in the past decade, the reduction in catches of high value fishes like crustaceans, high cost of fuel and labour led to reduced economic efficiency of fishing operations in Maharashtra and Kerala. The reduction in profit levels of fishing units may lead to reduced fishing effort in the long run with the characteristic boom and bust game of open access common property marine fishery resources. However efforts are necessary to manage the fishery based on some community based measures to improve the profitability of operations of fishing units and development and promotion of fuel efficient fishing methods.

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