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Productivity change in commercial fisheries: An introduction to the special issue

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ABSTRACT

Productivity is a key economic indicator that measures the relationship between inputs used to produce a product, and the amount of product produced. Productivity change measures how productivity has changed through time. In traditional land based industries, these two economic metrics have been extensively measured and studied. Until recently, this has not been true for commercial fishing fleets. This article provides an overview of productivity as an economic performance metric, and highlights specific studies of productivity change in commercial fisheries during the past 50 years. It concludes with an introduction to the articles contained in this special edition.

1. Introduction

Fishing power is often used by fisheries biologists to describe what economists refer to as productivity. In traditional land based industries, the measurement of productivity and productivity change is important for understanding the economic condition of firms, industries, and sectors of an economy. Productivity change is often used as a reason for differences in the condition of national economies and is a key economic indicator. Productivity is an important driver of both economic growth, and firm profitability [1], and there is an extensive literature on the subject.

Productivity measures the relationship between the quantity of outputs produced and the quantity of inputs used to produce those outputs. Simply put, productivity $=Y/X$, where Y is the quantity of output and X is the quantity of input. Productivity is the quantity component of firm profits, and if a firm can increase the quantity of output (Y) using a given quantity of input (X), (ceteris paribus), the firm can increase its profit. Firms may also increase profitability through higher output prices, lower input prices, or some combination of increased productivity and price changes [2]. Although productivity may be explained in terms of an individual firm, this same concept can be used to explain productivity at the industry, sector of the economy, or national level. That is, productivity is the ratio of output(s) produced to input(s) used for a given productive unit.

Productivity change is simply the change in productivity levels between time periods. Measurement of productivity change yields insight into how firms, industries or sectors of the economy are performing through time, or in response to a specific policy change. It may also be important to look further into productivity change to explain its underlying causes. Thus, productivity change can be further broken down into changes in efficiency and technical change. Efficiency change is about whether the firms, or unit of interest, become better about organizing their inputs to produce a given output bundle. Technical change is about whether the firm can produce more with a given bundle of inputs and involves a shifting of the production possibilities frontier. Although both efficiency change and technical change can be further broken down these additional measures are not further elaborated herein.

In a natural resource industry, such as a fishery, measurement of productivity change is often confounded because the stock of fish changes over time. Generally, what are of interest in a fishery is how vessels change their input use in response to a policy change, and how their outputs change. But, these changes have to be isolated from the influence of the fish stock. The stock effect interacts with the vessel production technology in the same way as disembodied technical change, which is technological change that is not associated or "embodied" in an input, notably the physical capital stock [3]. Disentangling the stock effect from the other components of productivity change is not a trivial task. A similar problem also occurs in stock assessment models with the key difference being that stock assessment scientists want to consider changes in biomass using data where the influence of

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productivity change has been removed [4].

Productivity is a key policy metric. Productivity indices can be constructed under a wide range of data availabilities. In the U.S. policy makers are charged with managing fisheries to maximize benefits to the nation. As an indicator of net direct benefits of the fishing industry, productivity indices can play a key role in tracking the economic health of this sector. Furthermore, productivity indices track the health of the industry using the variables, namely inputs and outputs, over which managers have historically exercised regulatory control (for better or worse). More generally, regulations can intentionally or unintentionally impose constraints on inputs or outputs. Tracking productivity over periods of policy implementation can provide insight into the realized effect of a given policy. A classic example in fisheries is the input/effort leakage that can result from effort control policies (e.g., ship length) as fishermen substitute inputs that are not regulated for inputs that are.

The purpose of this article is to provide an overview of productivity analysis and to review some of the key applications to fisheries. First, productivity analysis and how it has evolved is reviewed. Then, the main methods used to measure productivity change are discussed, followed by a review of past productivity studies in fisheries. This is followed by a brief synopsis of the papers included in this special issue.

2. Productivity analysis

Productivity and productivity change have been a topic of interest for economists for well over 80 years leading to a voluminous literature that would not be possible to fully cover here. The focus herein is on the economics literature pertinent to the development and application of productivity studies to fisheries. Most nations have government run statistics agencies, and produce reports, yearly or more often, on productivity trends for their respective economies. From a national reporting perspective, the question becomes how to take various data streams concerning inputs and outputs by numerous firms and generate productivity metrics?

National statistical agencies use several different approaches to measure productivity change, but most are centered on index numbers. Index numbers can be based on a ratio of two index numbers in different years, or the difference between two index numbers, which is known as an indicator. In the fisheries literature, index numbers based on prices, and index numbers constructed using distance functions have both been used to measure productivity change. A third method called growth accounting has also been used. More explanation of the growth accounting framework can be found in the works by Squires and Hannesson [5,6]. The remainder of this section will focus on the "index number problem" [7]. That is, techniques which are used to construct productivity indices.

Returning to the earlier definition of productivity as the ratio of outputs to inputs (Y/X), the obvious question is how to construct an aggregate value for Y and X given multiple inputs and outputs? In reality most firms, including fishing vessels, are multi-output, multi-input firms. This multi-input, multi-output notion of productivity is referred to as total factor productivity (TFP), or multifactor productivity (MFP). Because inputs and outputs need to be aggregated into a single number for each set of quantities, an index number problem results [7]. In other words, how does one construct a number representing the aggregate value of outputs and inputs? Generally, there are two methods used to do this. The first uses prices to aggregate quantities leading to well known index numbers such as Fisher, Törnqvist and Lowe. Productivity indices based on prices often follow the KLEMS-Y format [8]. For inputs this means including capital (K), labor (L), energy (E), materials (M) and services (S) in the input index, with Y representing the output. Often, data on inputs such as energy, materials and services are not available, nor are the prices paid for these inputs. A second approach which does not require prices constructs indices based on a theoretic representation of the production technology and uses distance functions as aggregators. Some examples of these indices include the Malmquist, Hicks-Moorsteen, Lowe, and Färe-Primont [9]. In studies of commercial fishing fleets, the distance function approach is attractive because only a minimal number of inputs may be required, which are generally readily available. For example, studies have used fishing effort, crew size, vessel length, horsepower and tonnage, along with landings to construct productivity indices [10].

There is no "best" approach to use when constructing index numbers. The distance function approach is appealing because it does not need prices. However, constructing distance functions may be computationally difficult and may require some restrictive assumptions about the underlying technology. Using prices to aggregate quantities can be easily done in a spreadsheet program, but may not be able to yield the same amount of information as methods using distance functions. There is an extensive literature that has evolved around decomposing measures of productivity based on distance functions, notably the popular Malmquist index [1]. In some regards, the approach chosen will depend on the question to be answered and the level of detail one needs for final results.

2.1. TFP indices using prices

TFP indices can be constructed using prices to weight, and then aggregate quantities of outputs and inputs into a value aggregate for outputs $Q(Y)$ and a value aggregate for inputs $Q(X)$. Productivity is the ratio of the output value aggregate $Q(Y)$ to the input value aggregate $Q(X)$; i.e. $\text{TFP}=Q(Y)/Q(X)$. Productivity change is the ratio of the productivity value aggregate in one time period to the productivity value in a base time period, and is referred to as a TFP index. The quantity indices of a TFP index typically use prices from a base and/or a reference period to weight the significance of the input and output quantities. There are several different types of common quantity indices which differ by the period(s) from which prices are chosen and how they are used to construct the weights on quantity. An extensive review of indices in general can be found in Balk [11] or Coelli et al. [4]. The two most basic indices are the Laspeyers index and the Paasche index. These indices differ by the period from which weights are constructed (base and reference, respectively) and provide theoretical bounds for the "ideal" index [12].

The Fisher index presents a middle ground and is the geometric mean of the Laspeyeres and the Paasche index. Although, the Fisher index is nonlinear it is approximately linear with weights that are an average of the base and reference periods [13]. The Fisher index has a number of desirable theoretical properties and provides a second-order approximation to an arbitrary twice-differentiable linearly-homogenous production function, a property known as being superlative [14]. The Fisher index has been widely used to measure productivity change in numerous industries. Recently, the Australian government used the Fisher index to measure productivity change for important Australian fisheries [15].

The Törnqvist index is another popular quantity index which weights quantities by value shares from two time periods through a geometric mean. The Törnqvist index is also both nonlinear and superlative, and is the exact index implied by the popular translog production function. Examples of some fisheries productivity studies using the Törnqvist index include [3,16,17].

In spite of being one of the older indices, the Lowe index has enjoyed a recent revival and uses fixed prices to weight outputs and inputs [2,11,18]. The critical feature that differentiates the Lowe index from others is that the prices used as weights in the index are fixed over time. Conveniently, the price weights may be from the base or reference time period or from a time period outside of either the base or reference period. This means that the indices are transitive, which simplifies temporal comparisons of productivity. The recent study of productivity change for U.S. catch share fisheries used a Lowe index [8]. Furthermore, the Lowe index permits a decomposition of the TFP index into technical, environmental, and scale-mix components [2,19].

2.2. TFP indices using distance functions

TFP indices may also be constructed through econometric techniques or math programming methods using distance functions as aggregators [1]. These methods construct a production frontier based on observed values of inputs and outputs in different time periods. An advantage of this approach is that the change in productivity can be broken down into different components, such as efficiency change and technical change. Efficiency change measures how much closer a firm moves to a constructed production frontier in each period, while technical change measures how that frontier shifts between time periods. Some of the different indices that can be constructed include the Malmquist, Hicks-Moorsteen and the Lowe [1,2]. These indices are constructed using either the stochastic production frontier approach (SPF), or data envelopment analysis (DEA). The SPF approach incorporates random variability which tends to be an important issue in fisheries. DEA methods generally make minimal assumptions about the underlying technology, but do not include random variability. However, DEA models can be bootstrapped, which can help with noisy data.

Measuring productivity change in commercial fisheries is perhaps more challenging than in traditional industries, because the role of biomass in the estimate needs to be disentangled from the effects of changing input use and outputs produced. In other words, productivity change needs to be normalized by the change in biomass in some way so that the productivity metric reflects only changing inputs and outputs. This is not a simple task, but failure to do so can lead to erroneous conclusions about the direction of productivity change. Studies which used index numbers generally constructed a separate biomass index and then "peel away" the biomass change from the productivity metric [3,5,6,8,16]. This may be problematic because there is an assumed one-to-one correspondence between biomass change and productivity change, which may not hold. Several studies have incorporated biomass change using an adjustment factor based on species' specific elasticity of output, which measures the change in output given a change in stock size [3,5,6,20,21]. However, a measure of the elasticity of output may not always be available. Studies using distance functions usually incorporate biomass as part of the distance function estimation[10,22]. In the context of distance functions, incorporating the biomass directly in the estimate may be problematic if the biomass change does not influence the position of the production frontier between time periods. Incorporating biomass change in frontier models is a subject ripe for future research.

3. Fishery productivity studies

Studies of productivity change in commercial fisheries have not occurred as frequently as some might think, particularly given the connection between productivity change and profitability change. However, this is beginning to change as fishery management agencies and others are becoming interested in economic performance measures and how they change in response to management changes [8,15]. Regulators are interested in both developing long-term trends in fishing fleet performance [23], and looking at productivity change after policy changes have been implemented [10]. Ultimately, what is likely to become more important is measures of profitability change, which can be produced with increased collection of cost data [24]. However, in the absence of cost data, productivity metrics can be constructed with basic data on inputs and outputs and can give managers important information about how their fleets are faring [25].

Examination of past productivity articles in the fisheries literature could loosely fit the studies into one of three categories. Overlap occurs between all three categories, but there seems to be three distinct threads. The first would be papers that presented methodology for calculating productivity in fisheries, or explained productivity using tools from the economic productivity literature. Secondly, there are a group of papers that measured productivity change over a long time period, and attempted to match productivity change with policy changes. Finally, a third group looked at productivity change given a specific change in policy. This last group of studies differs from the second group in that the study of productivity change stopped within a short time interval after the policy change. Often, studies falling into the second and third group also introduced different methodologies, so there are now a wide variety of techniques that have been introduced to model productivity change.

3.1. Studies emphasizing methods

The difference between methodological works and more applied studies is often very narrow. One of the earliest methodological studies was published in 1967 and used a Cobb-Douglas production model to estimate a production function for North Pacific halibut vessels. Productivity change was estimated by incorporating a time variable in the production model, and was estimated for the time period 1958–64 [26]. Surprisingly, the next significant study which examined productivity change was not published until 1985 when Norton, Miller and Kenney published productivity estimates for a multi-species fishery in the northwest Atlantic as part of a larger study which developed an "economic health Index" [27]. In this work, the authors used an index number approach to measure productivity change. While index numbers were regularly used outside of fisheries, they were rarely used in fishery economic studies at that time. This was shortly followed in 1992 by Squires who used a Törnqvist index to examine productivity change in the U.S. pacific trawl fleet [3]. This work was particularly notable because it used a modern index number approach to measure productivity change, and also focused attention on the issue of separating the impact of biomass change from the productivity measure. Squires called the productivity metric with biomass included "biased", as opposed to the metric with the influence of biomass removed being called "unbiased." This paper also introduced accounting for variations in capacity utilization and adjusting for stock effects by assigning different exponents or output elasticities to the different species' measures of biomass. The theme of accounting for biomass change in productivity measurement has been part of every productivity study of commercial fishing fleets since that time. In 2003, a study by Arnason [20] introduced the notion of "three factor" TFP (3TFP) which included biomass change, as opposed to "two factor" TFP (2TFP) which excluded biomass. This study clearly showed differences in outcomes between the two approaches and emphasized the importance of including biomass in studies of productivity change. The concept of accounting for biomass change has evolved further, and it is now generally recognized that stocks impact technological change in the same manner as disembodied technical change [22].

While the earlier studies cited above introduced new methods and applied them to specific fisheries, a second group of studies took a broader view and discussed methodological issues when estimating productivity in fisheries [22,28,29]. The studies by Felthoven and Paul [28], and Felthoven, Paul and Torres [29] were particularly notable because they began with traditional methods found in the productivity literature, and then expanded those methods to incorporate external factors which influence fishing vessels, such as environmental conditions or policy changes, along with stock changes. Expansion of the factors which influence productivity, such as environmental impacts, is important because fishing vessel production can be influenced by both environmental conditions and policy change. Additionally, the regulatory environment is important, particularly when regulators are trying to limit productivity to rebuild fish stocks [16].

3.2. Productivity over long time periods

Both the Australian and U.S. Government have recently released productivity reports which examined productivity trends over long time periods for key fisheries [8,15]. These studies were notable because they examined productivity trends for a large number of fisheries over varying time periods using a standard methodology. Outside of studies produced by national fisheries agencies, relatively few studies examined productivity over a 20 year or more time horizon [6,16,21,30,31]. Generally, these studies attempted to match productivity change with policy changes which took place during the study years. It is also worth noting that all three studies used different methods, yet had similar conclusions.

The first study was of productivity change in the New England groundfish fishery over a 30 year time period using a Törnqvist index [16]. Results showed that productivity increased in spite of different regulatory policies, and declining biomass. Biomass change was calculated using revenue shares of landings for each species, and research vessel survey abundance indices for biomass. The resulting term was simply subtracted from the output and input portions of the overall productivity index. Failure to adjust for biomass change yielded a result where productivity declined 6.6%, while accounting for biomass change meant that TFP increased 4.4%. A second set of measures which adjusted the productivity metric for changes in capacity utilization showed the same trend. Under increasing regulatory constraints which were enacted to stop declines in fish stock abundance, the authors found that there were periods where productivity growth stagnated. They concluded that ultimately, regulators were unable to strike a balance between productivity growth and restoring resource abundance.

A second study published at virtually the same time as the work cited above also used a Törnqvist index to measure productivity change in Icelandic fisheries over a 20 year time period [20]. This study, previously mentioned above, used the phrase "three factor" productivity (3TFP) as a metric which included biomass, along with the inputs of capital and labor. In order to adjust for biomass, an elasticity of output of 0.1 was assumed for pelagic species, and 0.85 was assumed for other stocks. Results showed large gains in 3TFP over the period 1974–2004 for Icelandic fisheries. The gains were much larger than other sectors in the Icelandic economy and other fishing sectors abroad. It was speculated that much of the gain was driven by increased efficiency rather than technical change.

A third study measured productivity trends for capture fisheries in Norway between 1961 and 2004 using a growth accounting framework [6]. There were several important points made in the article, but one was the explicit link between capital, labor and the natural resource base in which the industry operates. In an industry which is limited by nature, such as the fishing industry, in order to for productivity to improve, technology must improve and capital replaces labor in order for a competitive rate of return on capital to be maintained. Again, the importance of correcting for capacity utilization was recognized in this study. Consistent with the New England groundfish study, results showed a virtual stagnation of productivity growth if changes in biomass are not considered. Incorporating fish stock biomass raised the annualized growth rate in productivity to 2–4%, but these results also depended on the output elasticity of stocks. Since the author was looking at multiple fisheries, various estimates of the stock output elasticity needed to be used in a sensitivity analysis of the results. Overall, productivity growth in the fishing sector was comparable to that found in other industries in Norway.

Two studies centered on Norwegian fisheries examined productivity trends in fisheries for time periods of 60 and 130 years [30,32]. Institutional factors played a role in productivity developments in both fisheries. In the herring fishery, which was examined for a 60-year time period, unregulated use of new technology, along with a lack of regulation, caused a decline in herring stocks. In the Lofoten cod fishery study, both labor productivity and total factor productivity were estimated for a 130-year time period. Because the fishery was maintained as a classic open-access resource that could provide "employment of last resort", there were long time periods of stagnant labor productivity. The fishery was also seasonal, and participants were active in other fisheries and occupations, such as agriculture, which occurred concurrently with rising total factor productivity. At one point, incumbents perceived technological improvements, notably purse seine gear, as a threat, and were banned. The authors speculate that total productivity gains may have occurred faster if more efficient technologies had not been banned, along with the development of access rights While the technology shocks in the herring fishery were found to have contributed to stock declines, the authors of this study found that cod biomass declines slowed technological change in this fishery. In both fisheries, lack of adequate regulations also hindered productivity gains [30].

Finally, a recently published study examined productivity development in Icelandic, Swedish and Norwegian fisheries between 1973 and 2003 to test whether productivity between the three countries converged [21]. TFP growth was modeled using a value added approach in a Törnqvist index. The three inputs used in the model were capital, labor and fish stock size. The stock size index was constructed using output elasticities of 0.1 for pelagic species and 1.0 for all other species, which is consistent with previous studies. Once TFP was measured for each nation, further tests were conducted to see whether productivity between countries converged. Results did not support convergence in productivity between the three countries. The authors speculate that the failure for productivity to converge between countries may be due to slower adoption of rights-based fisheries by Sweden and Norway.

3.3. Productivity studies in response to regulatory reform

There have been a number of productivity studies that occurred after specific fisheries transitioned to output based management measures that adopt rights based fishing methods, such as individual transferable quotas (ITQs). This is because economic theory generally suggests that after adopting rights based systems with transferable quotas, there should be gains in productivity by the fleet that remains, as low productivity vessels exit. The remaining vessels will purchase quota from vessels which leave and increase their output levels. They also have further incentive to make changes in their input usage and become more efficient. However, there are still externalities which exist in these systems, and overall output is limited by the Government [10]. Researchers are interested in determining whether there were productivity changes post-ITQ, along with changes in output prices and fleet composition.

The evidence for improved productivity change seems mixed. A study of the British Columbia halibut fishery showed that the greatest benefit associated with a shift to individual harvesting rights was an increase in output prices, rather than productivity gains [25]. In this study, the authors used a Törnqvist index to measure productivity change as part of a fully decomposed profitability index which included price, productivity and capacity utilization indices. By fully decomposing a profitability index, it is possible to determine whether productivity changes or price changes were the largest influence behind profitability change. For this fishery, the authors found that profitability of the vessels post-ITQ was influenced more by improved price attributable to a longer fishing season rather than to productivity change. The importance of price changes post-ITQ, rather than productivity change, was also found in the Nova Scotian mobile gear fishery [33], which used the same profit index decomposition. A third study using this method found productivity gains and increased output prices in the southeast Australian trawl fishery after combining a vessel buyback scheme with quota trading [34].

In a study of the first U.S. ITQ system, it was found that vessel owners behaved strategically pre-ITQ in order to gain quota share, and increased their productivity. Post-ITQ productivity increased as less productive vessels exited the fishery [35]. The strategic behavior of vessel owners in order to gain more quota share was thought to be the major reason for productivity gains. This has interesting implications as the policy instrument was influencing productivity before the policy took place. A more recent study of the same fishery showed that those productivity gains were not sustained in later years [10]. This latest study was a fully decomposed Malmquist index, and showed that although overall productivity declined, technical change increased post-ITQ rapidly, and did not decline in subsequent years. The authors point out that an ITQ is not a complete property right, and additional restrictions placed on vessels post-ITQ may limit productivity gains.

4. Overview of articles in this special edition

There are eight articles which comprise this special edition. In the first article, an overview of productivity change in U.S. Catch Fisheries is presented by Eric Thunberg and his colleagues at the National Marine Fisheries Service. The second article features a case study of a shared stock fishery focusing on the Hawaii Longline fishery by Minling Pan and John Walden. Dale Squires and Niel Vestergaard focus on productivity growth and optimum renewable resource use, and show the relationship between optimal harvests and productivity. They also consider issues of identifying the difference between productivity and the resource stock and the relationship between productivity and time-varying catchability. Rolf Färe, Shawna Grosskopf and John Walden look at fleet restructuring after a transition to individual transferable quotas using a relatively new approach called the Färe-Primont index. Aaron Mamula and Trevor Collier examine productivity growth of a heterogeneous fishing fleet in the face of changing harvest conditions. Ben Fissel, Chris O'Donnell, Ron Felthoven and Steve Kasperski look at changes in productivity on the Alaskan head and gut factory trawl fleet. The issue concludes with work by Daniel Solis and Juan Agar on productivity change after an IFQ was implemented in the Gulf of Mexico red snapper fishery.

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