Measuring Fishery Productivity Growth in the Northeastern United States 2007-2018

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Abstract

Fishing vessel productivity is an important metric in terms of economic performance, and yields information about the financial impact of policy changes on fishing fleets. In this study, a new method is proposed to measure sector-wide commercial fishery total factor productivity (TFP), and is applied using northeastern United States fishery-level data from 2007-2018. Results from the study are linked to changes which occurred after 2006 Magnuson–Stevens Fishery Conservation and Management Reauthorization Act (MSFCMRA). This is accomplished by employing a translog production possibility frontier to measure total outputs, inputs, and TFP using Törnqvist indices. Quality differences embodied in the capital assets are accounted for, and the TFP measurement is adjusted for fishery stock changes. Results show that for most fisheries, improvements in biomass after the MSFCMRA re-authorization led to improved TFP. However, when biomass growth estimates were separated from overall TPP growth, biomass-adjusted TFP annual growth declined about 2% per year. This highlights the importance of separating biomass growth from output growth so managers understand the impact of their policies on the commercial fishing sector separately from biomass growth.

Keywords: Fishery productivity, total factor productivity (TFP), biomass-adjusted TFP, aggregate commercial fishery sector productivity, Törnqvist index

1. Introduction

Productivity is a key driver of profitability, and has been identified as an important indicator for fishery performance. In the fishery productivity literature, most productivity studies focus analysis on individual fisheries using different measurement methods, which include Data Envelope Analysis (DEA), stochastic production frontier (SPF), index number approaches, and econometric transformation functions (Morrison-Paul, Torres, & Felthoven, 2009; Pan & Walden, 2015; Squires, 1992; Squires & Vestergaard, 2015; Thunberg et al., 2015). However, there is a lack of literature on measuring productivity at an aggregate fishing industry-level. Furthermore, due to data availability or inconsistency issues, there are few cross-fishery comparison studies. For example, Thunberg et al. (2015) report annual fishery TFP indicators for 20 catch share programs using the Lowe Index approach. While their output estimates are consistent across fisheries drawing data from the landings, input estimates are inconsistent across fisheries or regions. Some cover capital and labor inputs, and others cover capital, labor, and intermediate goods. Although the TFP time series of a fishery can help understand productivity changes over time for that specific fishery, the estimates of TFP growth cannot be used to compare productivity changes across various fisheries due to input data inconsistency. Consequently, it is challenging to evaluate and compare policy impacts across fisheries unless the data and methods used to estimate productivity growth are consistent.

Under a growth accounting framework (Solow, 1957), TFP growth is the difference between output growth and input growth. Growth that cannot be explained by the productive factors (inputs) will be captured by the unexplained factor—“residual”, which is taken to be total factor productivity growth. This growth accounting framework can be easily applied to an industry, such as commercial fishing, but needs to be adjusted to account for the unique nature of fishing. Since fishing vessels harvest resources held in common, changes in biological conditions can affect the harvested output and thus TFP estimates. It is essential to account for the biological fishery stock in productivity measurement in order to separate the effects of biomass changes from technological advancement. It can also help explain how regulations, or harvest restrictions, may affect biomass and TFP estimates more accurately. Another issue with measuring fishery productivity is that each fishery may adopt fishery-specific technology embodied in heterogeneous capital assets, such as different vessels or gear types. Therefore, accounting for quality differences embodied in the capital asset will improve productivity measurement.

In this study, an analytical framework is developed that links various data sources and fisheries in order to measure biomass-adjusted TFP from both the perspective of a single fishery and the aggregate fishery sector in the U.S. Northeast (NE) region. In the rest of this article, a general definition of total factor productivity, noted as TFP^U, is differentiated from a biomass-adjusted definition of TFP, which is referred to as TFP^B. In order to understand the sources of growth for eleven NE fisheries, output growth is decomposed into its sources of growth--input growth (including capital, labor, and intermediate goods), biomass changes, and TFP^B growth. Additionally, the estimates account for quality changes embodied in capital assets in both TFP measures. This study has three major contributions that can help fill gaps in the literature. First, this study that allows the decomposition of a region's fishery output growth into its sources of growth— growth of inputs, biomass changes, and productivity growth. Secondly, it allows for a wide range (eleven fisheries) of cross-fishery productivity growth comparison based on the same input measurement[1]. Third, this is the first study that provides estimates of fishery productivity

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[1] TFP growth rate comparison is different from TFP level comparison across fisheries as the latter requires a multilateral index number technique in constructing transitive inputs, outputs, and TFP estimates across regions and time (see Caves, Christenson, and Diewert (1982^a, 1982^b) for details.

growth from the aggregate sector aspect. Results from the study are linked to changes which occurred after implementation of the 2006 Magnuson–Stevens Fishery Conservation and Management Reauthorization Act (MSFCMRA), and how it affected fishery productivity growth between 2007 and 2018. Findings show the influence of biomass growth on productivity change. Although productivity growth that can be attributed to more efficient use of inputs by vessels, or technical change may decline, overall productivity growth can be positive due to biomass growth.

The rest of the paper is organized into four sections. Section II introduces the theoretical framework in measuring output, inputs, and total factor productivity at the fishery level and the aggregate level. In section III, fisheries are defined based on the available data, and the variables and data sources used are described. In section IV, results are presented, and sources of growth for individual fisheries and the aggregate sector are identified. Conclusions and links to policy changes are presented in section V.

2. Theoretical Framework

Economists have proposed and applied various approaches in measuring multilateral output, inputs, and TFP across regions (see Caves, Christensen, and Diewert 1982a, 1982b, Inklaar and Diewert 2016, for examples on methods, and Wang et al. 2013, Jorgenson and Nomura 2007, Ball et al. 2001, and Squires 1988 for examples on empirical studies). This study does not adopt the multilateral approach, but instead focuses on developing TFP growth estimates for each fishery and the aggregate commercial fishing sector. While TFP growth rate measures allow for intemporal and cross-fishery comparison, TFP levels comparison across fisheries require a multilateral index number in constructing transitive inputs, outputs and TFP estimates across regions and times (see Caves, Christensen and Diewert 1982a, 1982b for details).

The production technology underlying the TFP framework is characterized as a stock-flow production process. That is, a flow of variable inputs is applied to a common resource stock to produce a flow of catch (Squires, 1992). This allows biomass to be separately accounted for as a factor contributing to TFP growth.

2.1 Measuring output, inputs, and total factor productivity growth by fishery

Following the growth accounting framework (Solow 1957), the gross output production function for each fishery *j* can be expressed as a general form:

$$Y_{j,t}=f_j(K_j,L_j,M_j,T_{j,t}) \qquad (1)$$

where *Y* is total output, *K* is capital service flow[2], *L* is labor input, *M* is intermediate goods, and *T* is the technology employed by fishery *j* at time *t*. Behind the function above, it is assumed that the production function is separable in *K, L, M*, and that technology (*T)* enter the function directly and symmetrically with inputs. Additionally, production is assumed to take place under constant return to scale (CRS), and all input markets are competitive, so factors are paid their marginal products[3]. The CRS assumption implies the sum of all cost shares equals one, and is commonly used in the productivity studies (Jorgenson and Stiroh, 2000; Schreyer, 2001; Oliner and Sichel, 2002; Ball et al., 2016; BLS, 2019). With the fundamental accounting identify, the value of output for each fishery exactly equals the value of inputs:

$$P_{Y,j}Y_j = P_{K,j}K_{K,j} + P_{L,j}L_j + P_{M,j}M_j \qquad (2)$$

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[2] Using capital service flow implies a full capacity utilization in the production process and thus capacity utilization is excluded from variations in TFP estimates (Hulten, 1986; Berndt and Fuss, 1986).

[3] Under this assumption and restriction all inputs are rivalrous that there are no non-rivalrous inputs or endogenous technical changes (Romer, 1986 and 1990).

Here, P is the price of outputs and inputs. The biomass unadjusted total factor productivity (TFP) growth can then be defined as:

$$\Delta lnTFP_j^U \equiv v_{T,j} \equiv \Delta lnY_j - \overline{w_{K,J}}\Delta lnK_j - \overline{w_{L,J}}\Delta lnL_j - \overline{w_{M,J}}\Delta lnM_j \quad (3)$$

where Δ denotes the change between period t-1 and t, and $\overline{w}$ is the two-period average share of the input in the nominal value of total input (total cost), or total output (total revenue) under the accounting identity assumption.

For each fishery, define an aggregate output, utilizing a translog aggregate production possibility frontier, as a Tornqvist index. This relates the growth of aggregate output to cost-share weighted growth of inputs—including labor (L), capital (K), and intermediate goods (M). Fishery-level output growth is measured as a Tornqvist index of the revenue-share weighted growth of individual species—including major and minor species—in that fishery:

$$\Delta lnY_j \equiv ln\left[\frac{Y_{j,t}}{Y_{j,t-1}}\right] = \sum_{s=1}^{n}\left[\frac{R_{sj,t-1}+R_{sj,t}}{2}\right] ln\left[\frac{Y_{sj,t}}{Y_{sj,t-1}}\right] \qquad (4)$$

Here, Y_j is the aggregate output of fishery j, ΔlnY_j is the output growth rate of fishery j, Y_{sj} denotes the landing quantity of species *s* in fishery *j*, R_{sj} is the landing revenue share of species *s* in total landing revenue of fishery *j*:

$$R_{sj} = \frac{P_{sj}Y_{sj}}{\sum_j P_{sj}\, Y_{sj}} \qquad (5)$$

, and $\left[\frac{R_{sj,t-1}+R_{sj,t}}{2}\right]$ is the average revenue share $\overline{R_{sJ}}$ for species *s* between two successive periods, *t-1* and *t.*

The fishery-level input growth is also measured as a Tornqvist index of cost-share weighted growth of individual inputs L, K, and M:

$$\Delta lnX_j \equiv ln\left[\frac{X_{jt}}{X_{j,t-1}}\right] = \sum_{i=1}^{3}\left[\frac{W_{ij,t-1}+W_{ij,t}}{2}\right] ln\left[\frac{X_{ij,t}}{X_{ij,t-1}}\right] \qquad (6)$$

where X_j is the aggregate input quantity of fishery j, ΔlnX_j indicates the input growth rate of fishery j, X_{nj} denotes the quantity of the n^th^ input—including L, K, M, W_{nj} is the cost share of input n in total input cost of fishery j:

$$W_{nj} = \frac{P_{nj}X_{nj}}{\sum_n P_{nj}\, X_{nj}} \qquad (7)$$

, and $\left[\frac{W_{nj,t-1}+W_{nj,t}}{2}\right]$ is the average cost share $\overline{W_{nj}}$ for input *n* between two successive periods, *t-1* and *t.*

Unadjusted TFP growth can be defined as the aggregate output growth less individual input growth weighted by their cost shares:

$$\Delta lnTFP_j^U \equiv ln\left[\frac{TFP_{j,t}^U}{TFP_{j,t-1}^U}\right] = \sum_{s=1}^{n}\left[\frac{R_{sj,t-1}+R_{sj,t}}{2}\right] ln\left[\frac{Y_{sj,t}}{Y_{sj,t-1}}\right] - \sum_{i=1}^{3}\left[\frac{W_{ij,t-1}+W_{ij,t}}{2}\right] ln\left[\frac{X_{ij,t}}{X_{ij,t-1}}\right] \qquad (8)$$

Since resource abundance can affect fishery output in a specific year[4] and results in a spurious TFP estimate, we adjust the TFP growth by removing the impact of biomass changes (Squires 1992):

$$\Delta lnTFP_j^B \equiv ln\left[\frac{TFP_{j,t}^B}{TFP_{j,t-1}^B}\right] = \sum_{s=1}^{n}\left[\frac{R_{sj,t-1}+R_{sj,t}}{2}\right] ln\left[\frac{Y_{sj,t}}{Y_{sj,t-1}}\right] - \sum_{i=1}^{3}\left[\frac{W_{ij,t-1}+W_{ij,t}}{2}\right] ln\left[\frac{X_{ij,t}}{X_{ij,t-1}}\right] - ln\left(\frac{B_{j,t}}{B_{j,t-1}}\right) \qquad (9)$$

where B_j indicates the biomass estimates for fishery *j*, a composite index of resource abundance, TFP_j^B indicates the biomass-adjusted *TFP* for fishery *j.*

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[4] This assumes that higher biomass levels are translated into quota changes which fishing vessels can access. Alternatively, lower biomass estimates will lead to lower quotas or reduced resource availability.

Fishery output growth can now be decomposed into its sources of growth by rearranging equation (9) and combining it with equation (3):

$$\Delta lnY_j = \overline{w_l}\Delta lnL_j + \overline{w_k}\Delta lnK_j + \overline{w_m}\Delta lnM_j + \Delta lnB_j + \Delta lnTFP_j^B \qquad (10)$$

where $\Delta lnTFP_j^B$ denotes the biomass-adjusted TFP growth, $\overline{w_l}$ is the average cost share for input L, $\overline{w_k}$ is the average cost share for input *K*, and $\overline{w_m}$ is the average cost share for input *M*.

2.2 Measuring total factor productivity for the aggregate fishery sector

Using an aggregate production function in measuring economic performance for an aggregate sector has been challenged in the economic literature due to aggregation issue (see Felipe and Fisher, 2003, for literature review and discussion). Fischer (1969) indicates that the necessary conditions for the existence of an aggregate production function raised by Nataf (1948) almost never exist as they require firm-level production functions to be linearly additive, separable in capital units and labor units, and linear in labor units with the same linear labor coefficient for each firm. Fischer (1993) also notes that Nataf (1948) fails imposing an efficiency condition in his proposition that the aggregate output cannot be maximized if there is no efficient allocation for all production factors. According to Fischer (1969, 1993) the necessary conditions for the existence of aggregates of output and inputs simultaneously are quite stringent. In this study, following Jorgenson (1996), a less restrictive aggregate production possibility frontier approach for the sector-wide productivity measurement is applied. The main difference between the two is the relaxation of the restriction that all fisheries face the same production function in the aggregate production possibility frontier. Given that each fishery faces a different production function, the price of each fishery output is no longer the same across fisheries and it is inappropriate to simply sum fishery output. We assume factor mobility and factor market equilibrium and that each type of K, L, and M receive the same price in all fisheries. This allows summation each input type across fisheries.

The aggregate gross output from the production possibility frontier is defined as a Tönqvist index of fishery output:

$$\Delta lnY = \sum_{j=1}^{11} \bar{R}_j \, \Delta lnY_j \qquad (11)$$

Here, Y is the aggregate fishery output, and $\bar{R}_j$ is the average revenue share from two successive periods of fishery j in the total landing revenue of eleven fisheries.

Diewert (1978) has shown that the Törnqvist index procedure is "exact" for the translog production or utility function. He points out that the Törnqvist index is a "superlative" index as it can approximate any smooth production or cost function that any small changes in relative prices for a good will be associated with small changes in the quantity of it used. Törnqvist index[5] is approximately "consistent in aggregation" in that the index numbers will be almost the same resulting from either the combination of all the prices and quantities of individual goods together or the combination of all the subgroups of the combining prices and quantities of individual goods.

The relationship between the aggregate gross output, aggregate input, and technology for the aggregate production possibility frontier is defined as:

$$Y=f(K, L, M, T) \qquad (12)$$

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[5] Törnqvist index is a weighted geometric mean function. The use of geometric aggregator functions is important. When the separable form of a translog function is interpreted as an exact production function the aggregator function should be a Cobb-Douglas function (Denny and Fuss, 1977).

where K is capital input, L is labor input, M is intermediate goods, and T is the technology adopted in the fishing industry. Input are estimated across fisheries following the same methodologies (see section below). The fishing industry employs all inputs and technology available to the industry to produce all output jointly. There are a few assumptions behind the function above. First, the production function is assumed to be separable in K, L, and M. Second, technology T is assumed to enter the function directly and symmetrically with inputs.

The unadjusted TFP growth for the entire sector can be derived from (12) as:

$$\Delta lnTFP^{U} \equiv \Delta lnY - \overline{w_K}\Delta lnK - \overline{w_L}\Delta lnL - \overline{w_M}\Delta lnM \qquad (13)$$

where $\overline{w}$ is the average cost share in the total cost from two successive periods for each input.

Sector-level TFP growth can also be expressed in terms of the decompositions of fishery-level input factors using Törnqvist index.

$$\Delta lnTFP^{U} \equiv \Delta lnY - \sum_{j=1}^{11} \overline{w_{K,j}}\Delta lnK_j - \sum_{j=1}^{11} \overline{w_{L,j}}\Delta lnL_j - \sum_{j=1}^{11} \overline{w_{M,j}}\Delta lnM_j \qquad (14)$$

where, $\overline{w}_{K,j}$ is the average cost share from two successive periods of input K for fishery j in total sector cost (the sum of eleven fisheries), and the same for $\overline{w}_{L,j}$ and $\overline{w}_{M,j}$ as for labor and intermediate goods.

Following the same assumptions and the accounting identity addressed above, the revenue share of each fishery in the total landing revenue would equal the input cost share of that fishery in the economy-wide total cost. Therefore, the rate of total input growth for the NE fishery can also be expressed as:

$$\Delta lnX = \sum_{j=1}^{11} \overline{R}_j \, \Delta lnX_j \qquad (15)$$

Combining (11) and (14), the rate of unadjusted TFP growth of the aggregate sector can then be expressed as:

$$\Delta lnTFP^U = \Delta lnY - \Delta lnX = \sum_{j=1}^{11} \bar{R}_j \left(\Delta lnY_j - \Delta lnX_j\right) = \sum_{j=1}^{11} \bar{R}_j \left(\Delta lnTFP_j\right) \qquad (16)$$

Equation (16) is a weighted geometric mean of fishery-level $\mathrm{TFP}^{\mathrm{U}}$ growth. When considering fishery biomass changes (see next section on how biomass stock in measured consistently across fishery), the sector-wide biomass-adjusted TFP growth is measured as:

$$\Delta lnTFP^B = \sum_{j=1}^{11} \bar{R}_j \left(\Delta lnTFP_j^U - \Delta lnB_j\right) = \sum_{j=1}^{11} \bar{R}_j \left(\Delta lnTFP_j^B\right) \qquad (17)$$

3 Data

Data used in this study to analyze productivity growth at both the fishery-level and sector level in this study is derived from vessels fishing in the U.S. Northeast region. This region geographically extends from the Hague Line, marking the border between Canadian and U.S. waters, southward to Cape Hatteras, North Carolina. There are 13 Fishery Management Plans (FMP's) managed by either the New England Fishery Management Council (NEFMC), the Mid-Atlantic Fishery Management Council (MAFMC), or jointly by the two Councils, in partnership with the National Marine Fisheries Service (NMFS). The 13 FMP's include Squid, Mackerel and Butterfish (SMB), Atlantic Herring (HER), Golden and Blueline Tilefish (TILE), Red Crab (RC), Bluefish (BLUE), Northeast Multispecies (MULT), Small-Mesh Multispecies (SMESH), Skates (SK), Monkfish (MONK), Atlantic Sea Scallop (SCAL), Spiny Dogfish (DOG), Summer Flounder, Scup and Black Sea Bass (SFLDR), and Surfclam and Ocean Quahog (SCOQ). Given that there is a lack of input data for the SCOQ fishery, and the Red Crab fishery data contains confidential information, those two fisheries are excluded from the analysis, and only eleven fisheries are included in this study. Overall, the two excluded fisheries accounted for about 10%

of the total landing values in the NE region. Pseudo panel data were constructed for the remaining eleven fisheries spanning the years 2007 to 2018, with multiple outputs and multiple inputs in each fishery dataset based on vessel trip data records.

3.1 Output

Each vessel/trip in a given year is identified and assigned to a specific Fishery Management Plan (FMP) if the revenue from one FMP accounted for the majority (more than 50%) of the trip revenue. During each fishing trip, a vessel may catch more than one species besides its primary fishing target. Therefore, to measure fishery-level productivity, we include all landings other than the primary species as they share the same inputs. Landing revenues and volumes (pounds) are aggregated for individual species within each fishery. The total output for each fishery is estimated using a Tornqvist index, as shown in equation (4).

3.2 Labor

Labor data is developed from vessel trip logs. Labor quantity on each trip is measured as total crew size × total days at sea. Since crew are typically paid a share of the total trip revenue, there is no available wage rate for the fishing activity. Therefore, a wage rate per hour for U.S. construction workers, obtained from the St. Louis Federal Reserve[6] is used as a proxy of hourly labor opportunity cost at sea. We multiply this wage rate by eight hours per day to convert it to a daily opportunity cost of labor.

3.3 Capital

Vessel values were calculated using vessel attributes (vessel age, horsepower, length, hull type) and their shadow values using results from a published study by Färe, Grosskopf, and Walden

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[6] The data is accessed at https://fred.stlouisfed.org/series/CES2000000003, 7/9/2018.

(2017). Once a vessel value was calculated, the price of the capital stock in each year was calculated as the user cost of capital, which is the vessel value times the opportunity cost of capital plus a depreciation rate of 5%. The opportunity cost of capital is the BAA bond rate (Moody's Seasoned Baa Corporate Bond Yield, from Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/series accessed 12/31/2019). The quantity of capital service used is the percent of the total time the vessel spent in that fishery with a specific gear type. To account for the quality differences associated with various gear types, capital is classified into nine groups based on gear type. The annual changes of an aggregate capital input, ΔlnK_j, in each fishery is calculated using Törnqvist index as:

$$\Delta lnK_j = \sum_{k=1}^{9} \overline{w}_{kj} \, \Delta lnK_{kj} \tag{18}$$

Here, $\overline{w}_{kj}$ is the average cost share between two consecutive time periods for each gear-type based capital input deployed in fishery j. This will allow for adjusting quality changes (components changes) so the measured capital inputs are in constant quality unit. The aggregation across various capital components using the Tornqvist index will also result in approximately consistent in aggregation (Diewert, 1978).

3.4 Intermediate goods

Since there is no detailed information on intermediate goods, the total number of days the vessel spent at sea in the specific fishery with one particular gear type is used as a proxy. The input price for each day at sea is calculated from expenditure data collected on fishing trips in each year where an observer was aboard the vessel. Expenditure data used in this calculation included the cost of fuel, oil, ice, and materials.

3.5 Biomass

In order to construct a biomass index for each stock contained in an FMP, biomass data used in the fishery stock assessment process were utilized. These data were extracted from the Stock Assessment Review Index (SARI) search tool maintained by the Northeast Fisheries Science Center (NEFSC)[7]. For single species fisheries, or in fisheries where there was limited data on only one stock, the biomass index was a simple measurement and was calculated as $BI=B_t/B_{2007}$, where B is the measure of biomass and t is the year in question. There were six fisheries that had single species biomass indices (i.e HER, BLUE, TILE, SFLDR, SCAL, DOG).

For fisheries that involved more than one species, or more than one fish stock based on geographic location (i.e. SMB, MULT, SK, MONK and SMESH), a basket-type index was constructed. As an example of a multiple-stock fishery, monkfish (MONK) is comprised of a northern and southern stock, each with their own biomass level. An example of a multi-species, multi-stock fishery is the small mesh multispecies (SMESH) fishery, which has two species with each species being comprised of two different stocks based on geographic location. In order to construct an aggregate biomass index, a multiplicative index was constructed using fixed share weights by the formula so the aggregation is consistent:

$$BI = \prod_{s=1}^{S} \left(\frac{B_{ts}}{B_{2007s}}\right)^{a_s} \tag{19}$$

Where s is the species or stock, t is the reference year and a_s is the share of the biomass for the species s. Note that the sum of all a_s values must equal one. For the BI, all stocks in the complex were weighted equally. As an example, the small mesh multispecies fishery with two species and two stocks had, each species-stock combination was assigned an a_s value of 0.25. Implicit in the

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[7] From https://apps-nefsc.fisheries.noaa.gov/saw/reviews_report_options.php?login=missing1, accessed July 1, 2020

biomass index calculation is the assumption that in a multispecies fishery all vessels in the fishery are able to take advantage of the higher biomass level. If the change in the biomass index is being driven by one specific stock, or species, this assumption may not be true as some vessels in the fishery may not land the specific species which is causing the increase. Given that the output index and biomass index are basket-type indices, it is not possible to explore this possibility further and maintain the focus on each fishery in its entirety. Nevertheless, since the harvesting technologies and gear types are generally similar within the same fishery, our fishery-level measurement lessens this issue.

4. Results

Annual growth rates of aggregate output, aggregate input, and TFP^B for eleven fisheries, spanning the 2007-2018 period, were calculated following equations (4), (6), (9), and (14), respectively with Törnqvist indices (see tables 1, 3, 4, and 5). Given that the weighting scheme under the Törnqvist index number approach is based on the average cost or revenue shares from two successive periods, the constructed index numbers are bilateral instead of multilateral indices. Using 2007 as the reference period we form a series of chain index that shows the relationship between the period of interest and the reference period within each fishery for all fisheries. Since the weights used in aggregating a composite quantity or price are kept up-to-date, chain indices are usually preferable to fixed-base indices for intertemporal comparison (Squires, 1988).

Between 2007 and 2018, only four fisheries—Dogfish, Skates, SMB, and Tilefish—experienced positive output growth, with the Dogfish fishery experiencing the fastest growth (table 1). Annual average rates of output growth ranged from -15% for Bluefish to 18% for Dogfish (figure 1). For other fisheries with positive output growth, the annual average rates of growth are between 1% and 2%. Dogfish seems to be an exception, as the quota for Dogfish was expanded several times during the time period. In 2018, the quota for Dogfish was nearly ten times that which existed in 2007 (table 2). At the same time, increasingly strict regulations in other fisheries, along with limited entry, made the dogfish fishery a viable alternative for displaced vessels. However, with the exception of 2007 and 2008, landings were generally well under the quota, which suggests that there were limited market opportunities for Dogfish.

Year	BLUE	DOG	MULT	HER	MONK	SCAL	SFLDR	SK	SMESH	SMB	TILE
2007	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	1.05	1.04	1.10	1.02	1.02	0.90	1.00	0.91	1.00	0.95	0.99
2009	1.09	3.39	1.08	1.45	0.89	0.94	1.04	0.96	1.35	0.91	1.18
2010	1.44	4.66	0.95	0.90	0.77	0.93	1.36	1.21	1.46	0.71	1.38
2011	0.73	6.56	0.92	1.22	0.96	0.97	1.61	1.10	1.47	0.80	1.27
2012	0.42	7.39	0.82	1.31	0.94	0.98	1.46	1.25	1.34	0.86	1.26
2013	0.48	5.85	0.63	1.43	0.72	0.72	1.52	1.13	1.21	0.63	1.27
2014	0.82	8.29	0.63	1.29	0.64	0.55	1.38	1.29	1.27	0.83	1.31
2015	0.57	7.36	0.52	1.02	0.74	0.47	1.39	1.24	1.24	0.68	0.93
2016	0.57	17.20	0.49	0.81	0.76	0.52	1.13	1.13	1.06	0.98	0.75
2017	0.56	13.18	0.52	0.73	0.78	0.66	1.03	1.10	0.88	0.93	1.02
2018	0.19	7.29	0.49	0.66	0.74	0.74	0.94	1.27	0.74	1.10	1.08
average annual rate	-15%	18%	-6%	-4%	-3%	-3%	-1%	2%	-3%	1%	1%

BLUE=Bluefish, DOG=Dogfish, MULT=Northeast Multispecies, HER=Herring, Monk=Monkfish, SCAL=Atlantic Sea Scallop, SFLDR=Summer Flounder, SK=Skates, Smesh=small mesh multispecies, SMB=Squid, Mackerel and Butterfish, Tile=Tilefish

Note: the index numbers in the table are chain indices using 2007 as the reference period for each fishery.

Table 1 Output index by fishery (Index numbers 2007=1)

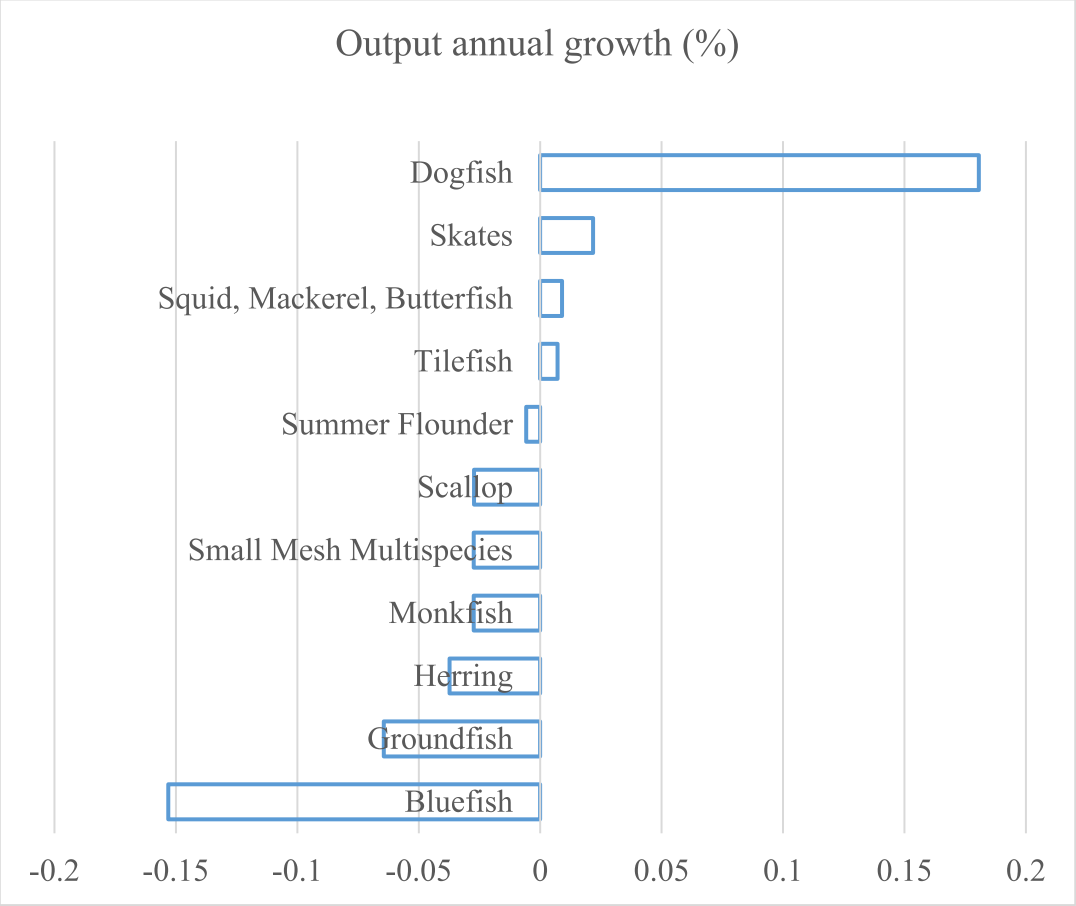

Figure 1 Output annual growth rate by fisheries (2007-2018)

Year	Quota Pounds (Millions)	Landings Pounds (Millions)
2007	4	4.74
2008	4	6.88
2009	12	10.41
2010	15	10.69
2011	20	17.21
2012	35.96	20.76
2013	40.84	9.77
2014	48.79	16.65
2015	50.61	12.66
2016	40.36	18.89
2017	39.1	13.2
2018	38.2	10.69

Source: https://www.fisheries.noaa.gov/new-england-mid-atlantic/commercial-fishing/quota-monitoring-greater-atlantic-region, accessed 7/15/2020

Table 2. Dogfish Quota and Landings 2007-2018

The patterns of input growth among eleven fisheries seem to be consistent with the patterns of output growth. There are only four fisheries—Dogfish, Skates, SMB, and Tilefish—which demonstrated positive input growth. As with output growth, Dogfish input grew much faster than all others (table 3). Annual input growth rates ranged from -8% for Groundfish to 13% for Dogfish (table 3, figure 2). While seven out of eleven fisheries had negative output growth during 2007-2018, when combined with negative input growth, there are only three fisheries that showed negative TFP growth They were Bluefish (-12%), SMB (-0.4%), and Tilefish (-0.2%) (Table 4).

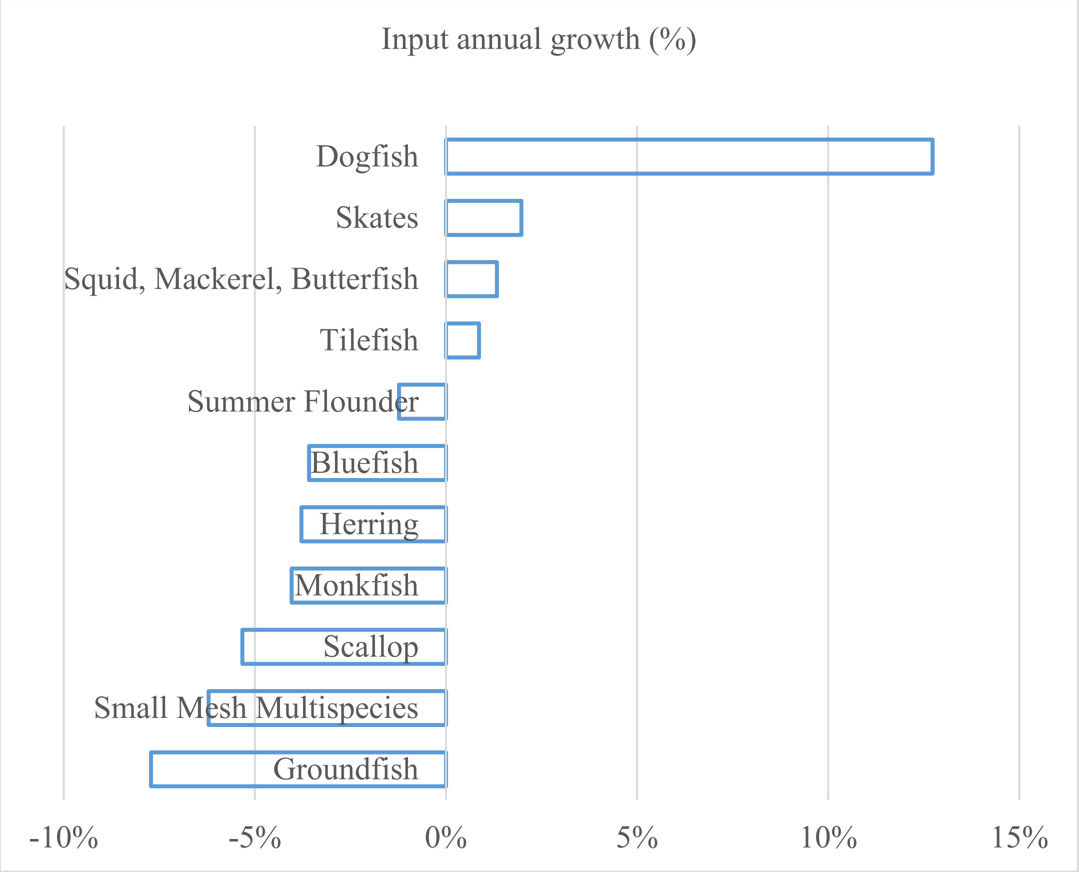

Figure 2 Input annual growth rate by fisheries (2007-2018)

Year	BLUE	DOG	MULT	HER	MONK	SCAL	SFLDR	SK	SMESH	SMB	TILE
2007	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	1.08	1.39	0.98	0.82	1.15	0.80	0.89	0.88	0.87	1.00	1.51
2009	1.33	3.55	0.96	1.08	1.01	0.79	0.98	0.90	1.05	1.05	1.51
2010	1.44	4.91	0.80	0.95	0.95	0.77	1.17	1.38	1.22	0.89	0.96
2011	1.55	6.05	0.75	0.96	1.25	0.70	1.21	1.46	1.10	1.02	0.96
2012	1.10	6.17	0.83	1.04	0.93	0.74	1.16	1.46	0.90	0.99	0.96
2013	1.06	5.36	0.73	1.36	0.98	0.60	1.19	1.58	0.99	0.84	1.41
2014	1.04	5.99	0.65	0.96	0.75	0.52	1.21	1.69	0.81	1.00	1.65
2015	1.09	4.82	0.58	0.77	0.81	0.48	1.21	1.68	0.82	0.94	1.57
2016	1.15	7.64	0.50	0.70	0.78	0.54	1.03	1.34	0.68	1.11	1.49
2017	1.00	6.17	0.52	0.76	0.78	0.53	0.94	1.37	0.63	1.09	1.41
2018	0.67	4.06	0.43	0.66	0.64	0.56	0.87	1.24	0.50	1.16	1.10
average annual rate	-4%	13%	-8%	-4%	-4%	-5%	-1%	2%	-6%	1%	1%

BLUE=Bluefish, DOG=Dogfish, MULT=Northeast Multispecies, HER=Herring, Monk=Monkfish, SCAL=Atlantic Sea Scallop, SFLDR=Summer Flounder, SK=Skates, SMESH=small mesh multispecies, SMB=Squid, Mackerel and Butterfish, TILE=Tilefish

Note: the index numbers in the table are chain indices using 2007 as the reference period for each fishery.

Table 3 Input index by fishery (Index numbers 2007=1)

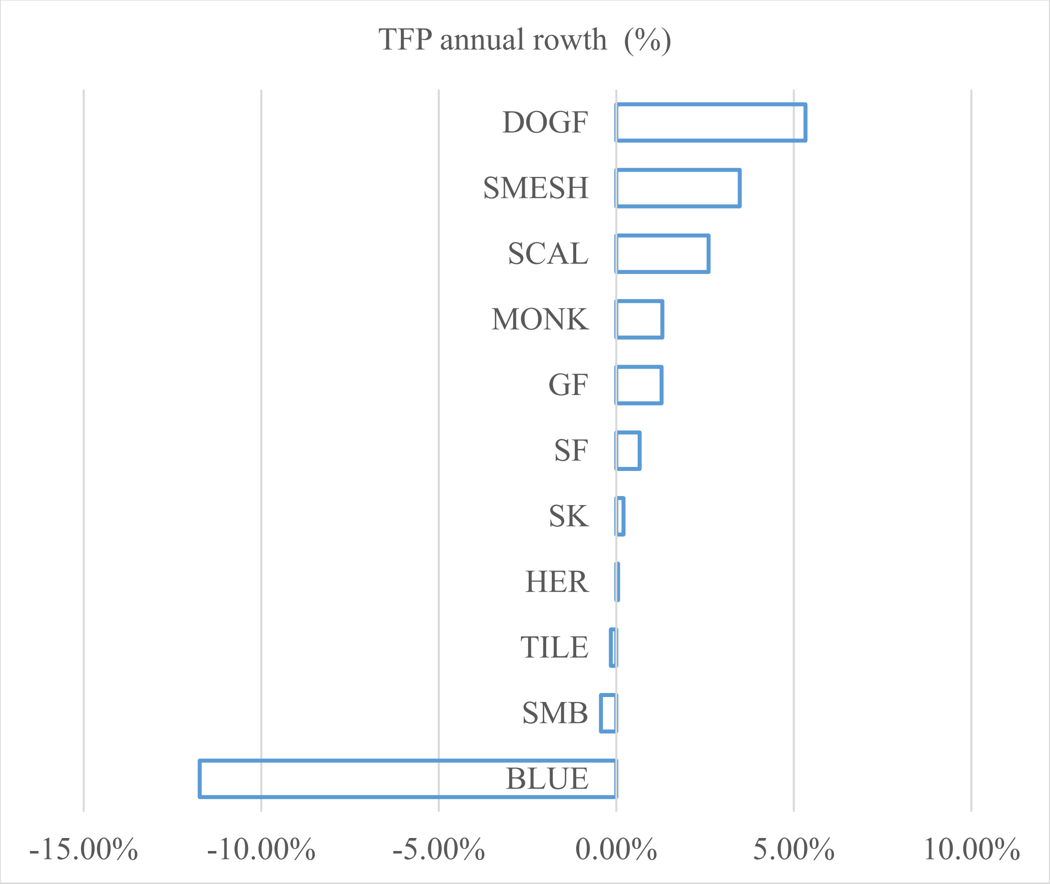

Figure 3 TFP annual growth rate by fisheries (2007-2018)

Year	BLUE	DOG	MULT	HER	MONK	SCAL	SFLDR	SK	SMESH	SMB	TILE
2007	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.97	0.75	1.13	1.24	0.89	1.13	1.11	1.04	1.14	0.95	0.66
2009	0.82	0.95	1.13	1.34	0.88	1.19	1.06	1.08	1.29	0.86	0.78
2010	1.00	0.95	1.19	0.95	0.81	1.22	1.16	0.88	1.20	0.81	1.44
2011	0.47	1.08	1.23	1.27	0.76	1.38	1.33	0.76	1.33	0.79	1.33
2012	0.38	1.20	0.99	1.25	1.01	1.33	1.26	0.86	1.50	0.88	1.32
2013	0.45	1.09	0.86	1.05	0.74	1.20	1.28	0.71	1.22	0.76	0.90
2014	0.79	1.38	0.98	1.35	0.86	1.06	1.14	0.76	1.57	0.83	0.79
2015	0.53	1.53	0.90	1.31	0.92	0.99	1.15	0.74	1.51	0.73	0.60
2016	0.50	2.25	0.98	1.15	0.97	0.96	1.09	0.85	1.56	0.88	0.50
2017	0.56	2.14	1.01	0.96	1.01	1.25	1.10	0.80	1.41	0.86	0.72
2018	0.28	1.80	1.15	1.01	1.15	1.33	1.08	1.02	1.47	0.95	0.98
average annual rate	-12%	5%	1%	0%	1%	3%	1%	0%	3%	0%	0%

BLUE=Bluefish, DOG=Dogfish, MULT=Northeast Multispecies, HER=Herring, Monk=Monkfish, SCAL=Atlantic Sea Scallop, SFLDR=Summer Flounder, SK=Skates, SMESH=small mesh multispecies, SMB=Squid, Mackerel and Butterfish, TILE=Tilefish

Note: the index numbers in the table are chain indices using 2007 as the reference period for each fishery.

Table 4 TFP (Biomass Unadjusted) index by fishery (Index numbers 2007=1)

As discussed above, output growth can be affected by resource abundance. Fishery stock changes, affected by catch restrictions, can create a disturbance component causing the "residual" to be overestimated when the biomass of a fishery increased, or underestimated if the biomass decreased. The MSFCMRA mandated strict catch limits and accountability measures which were to be implemented by 2010 in fisheries where overfishing was occurring, and in 2011 for all others. Based on our biomass index calculations, the average annual growth of biomass was positive for six of our 11 fisheries (SCAL, SMESH, TILE, GF, SF, and SK) between 2007 and 2018, which seems to be consistent with the regulatory effects of strict catch limits implemented beginning in 2010 (figure 4). For those six fisheries, the biomass-adjusted TFP growth turned from positive to negative, while for the other fisheries it turned from negative to positive growth (table 5, figure 5). This implies that with increasing natural resource abundance, technology advancement seemed to slow down, while with decreasing abundance, the reverse happens. With a decline in biomass, vessels have to improve their technology or efficiency in order to maintain their productivity, while increasing biomass means they can be less efficient and technologically stagnant and maintain their productivity. One limitation regarding incorporating biomass changes in the calculation is the arbitrary weight we assign for biomass changes in the TFP calculation. Biomass-adjusted TFP (TFP^{B}) can be altered if we adopt a different weighting scheme when adjusting for biomass changes. However, the adjustment direction will remain the same.

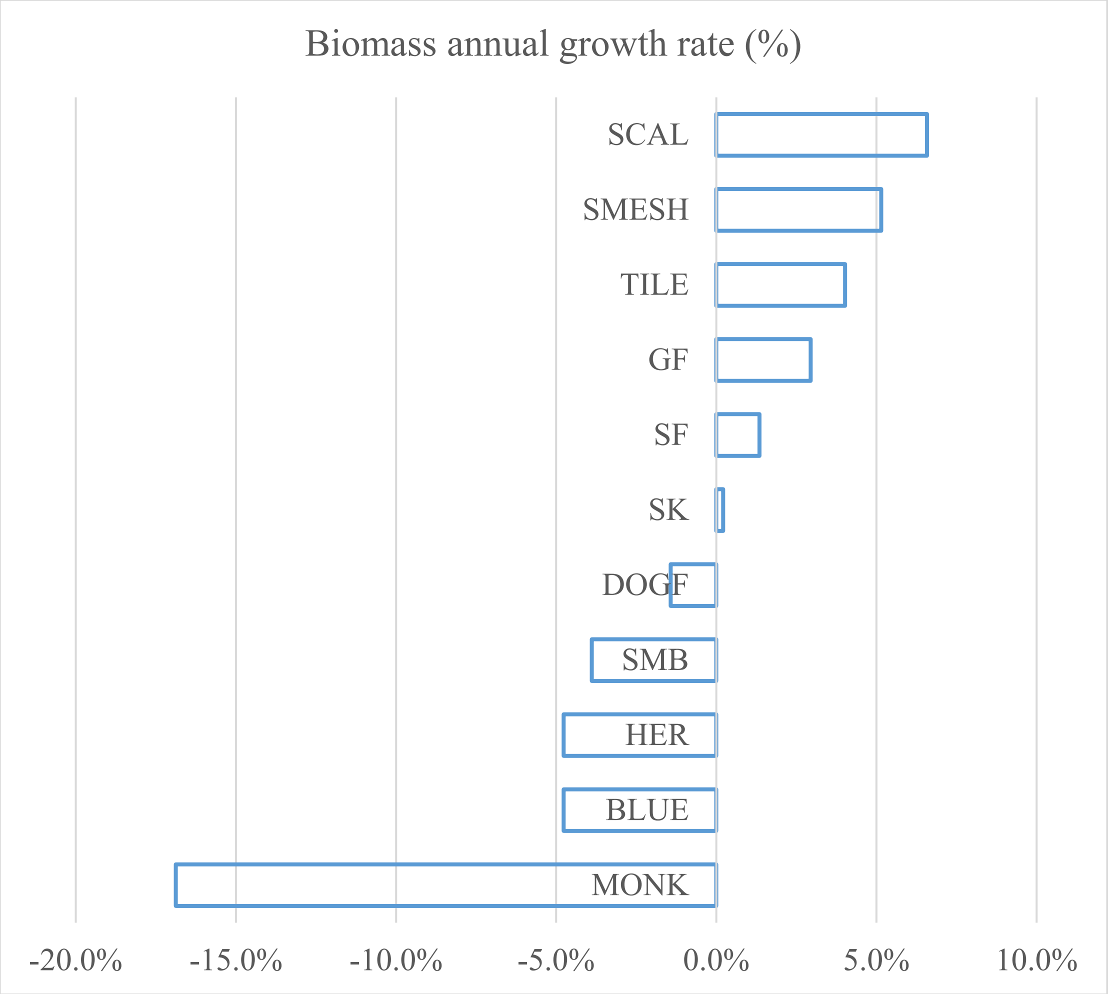

Figure 4 Biomass annual growth rate by fishery (2007-2018)

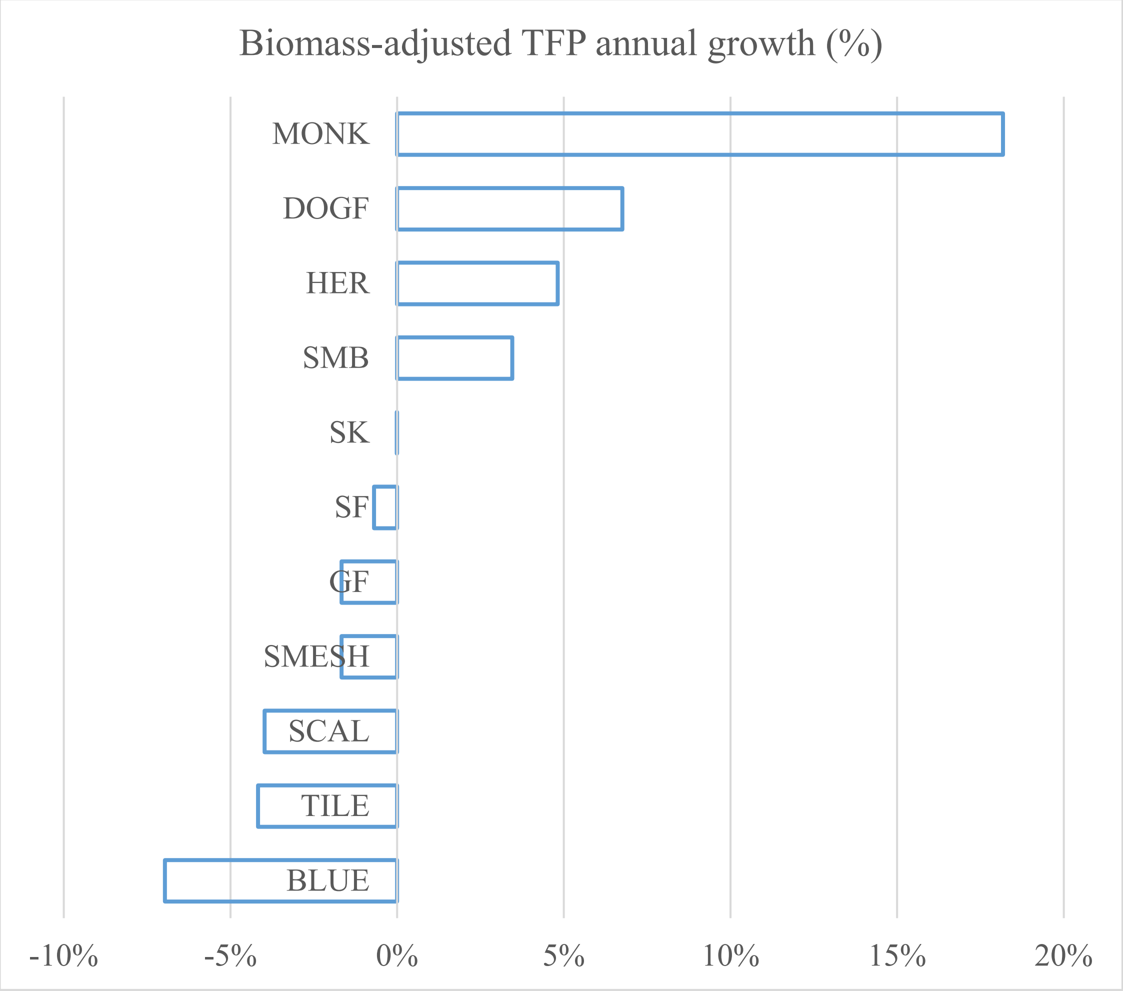

Figure 5 Biomass-adjusted TFP annual growth rate by fisheries (2007-2018)

Year	BLUE	DOG	MULT	HER	MONK	SCAL	SFLDR	SK	SMESH	SMB	TILE
2007	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.91	0.48	1.05	1.16	0.98	1.22	1.05	1.03	0.91	1.28	0.61
2009	0.81	0.73	1.07	1.33	1.10	1.41	0.86	0.97	0.87	1.48	0.73
2010	1.10	0.71	0.90	1.04	1.08	1.44	0.83	0.75	0.71	1.43	1.34
2011	0.55	0.80	1.08	1.47	1.09	1.62	1.02	0.63	0.72	1.74	1.12
2012	0.47	0.69	0.91	1.53	1.75	1.56	1.07	0.77	0.75	1.78	1.06
2013	0.57	0.72	0.83	1.30	1.67	1.40	1.20	0.74	0.57	1.82	0.63
2014	1.40	1.05	0.94	2.39	2.84	0.99	1.23	0.81	0.80	1.64	0.49
2015	0.93	1.37	0.80	2.31	6.18	0.77	1.36	0.73	0.75	1.25	0.33
2016	0.86	2.19	0.81	1.99	6.52	0.58	1.11	0.83	0.82	1.41	0.25
2017	0.96	2.27	0.75	1.64	6.47	0.61	1.07	0.77	0.74	1.43	0.41
2018	0.46	2.10	0.83	1.70	7.39	0.65	0.93	1.00	0.83	1.46	0.63
average annual rate	-6.97%	6.76%	-1.67%	4.82%	18.18%	-3.98%	-0.69%	-0.01%	-1.67%	3.46%	-4.17%

BLUE=Bluefish, DOG=Dogfish, MULT=Northeast Multispecies, HER=Herring, Monk=Monkfish, SCAL=Atlantic Sea Scallop, SFLDR=Summer Flounder, SK=Skates, SMESH=small mesh multispecies, SMB=Squid, Mackerel and Butterfish, TILE=Tilefish

Note: the index numbers in the table are chain indices using 2007 as the reference period for each fishery.

Table 5: Biomass-adjusted TFP by fishery (Index numbers 2007=1)

4.1 Sources of output growth by fishery

Fishery-level output growth was decomposed into its sources of growth—the growth of inputs (including changes of labor, intermediated goods, and capital), the growth of biomass, and the growth of biomass-adjusted TFP (table 6.) The four fisheries with positive output growth all had positive input growth, while all other fisheries experienced declining use of inputs. Most of the decline in input growth can be attributed to labor, followed by intermediate goods. Increased biomass boosted landings and became a significant source of growth for Scallop, Small mesh multispecies, Tilefish, Groundfish, Summer flounder, and Skates fisheries, contributing to 6.6, 5.2, 4.0, 2.9, 1.35, and 0.2 percentage points of output growth, respectively. There are only four fisheries—Monkfish, Dogfish, Herring, and SMB—showing significant technological advancement as a source of output growth, contributing 18.2, 6.8, 4.8, and 3.5 percentage points to output growth, respectively.

Fishery	BLUE	DOG	MUL	HER	MONK	SCAL	SFLDR	SK	SMESH	SMB	TILE
Output growth (%)	-15.3	18.1	-6.4	-3.7	-2.7	-2.7	-0.6	2.2	-2.7	0.9	0.7
Input growth (%)	-3.6	12.7	-7.7	-3.8	-4.0	-5.3	-1.2	2.0	-6.2	1.3	0.9
Labor (%)	-2.8	5.9	-5.6	-2.6	-3.0	-4.3	-0.8	0.8	-4.9	0.9	0.5
Intermediate goods (%)	-0.37	1.4	-1.28	-1.1	-0.47	-0.8	-0.2	0.4	-1.1	0.3	0.2
Capital (%)	-0.4	5.38	-0.8	-0.1	-0.56	-0.19	-0.2	0.8	-0.3	0.1	0.2
TFP growth	-11.7	5.3	1.3	0.05	1.3	2.6	0.7	0.2	3.5	-0.4	-0.2
Biomass change (%)	-4.77	-1.4	2.9	-4.8	-16.9	6.6	1.35	0.2	5.2	-3.9	4.0
TFP^B change (%)	-7.0	6.8	-1.7	4.8	18.2	-4.0	-0.7	-.01	-1.7	3.5	-4.2

BLUE=Bluefish, DOG=Dogfish, MUL=Northeast Multispecies, HER=Herring, Monk=Monkfish, SCAL=Atlantic Sea Scallop, SFLDR=Summer Flounder, SK=Skates, SMESH=small mesh multispecies, SMB=Squid, Mackerel and Butterfish, TILE=Tilefish

Table 6 Sources of growth by fishery (2007-2018)

4.2 Total factor productivity estimates for the aggregate sector

Based on equations (13) and (14), regional-level TFP and biomass-adjusted TFP for the aggregate sector was constructed using fishery revenue shares as weights. Between 2007 and 2018, TFP estimates increased by 25%, growing at 2% per year, while biomass-adjusted TFP decreased by 22%, at an average decline rate of 2.2% per year (Table 7). This indicates that for the aggregate sector, TFP growth is being positively influenced by improved natural resource abundance. This is readily apparent after 2014, when TFP was increasing while biomass adjusted TFP (NE_TFP) was declining (Figure 6). This could only occur with positive biomass growth. The lack of productivity growth brought about by improvements in technology and efficiency is somewhat troubling. If vessel owners had adopted new technologies or operated more efficiently there might have been greater productivity gains. However, part of the issue with technological improvements might have been due to regulations designed to limit catch. For example, some fisheries have limits on vessels upgrading their engines or hold capacity. Other fisheries have limits on crew size or are limited in geographic scope as to where they can fish. Improvements in technology or efficiency may force managers to place increasingly strict regulations in order to protect the fish stocks which then contributes to stagnant future productivity gains. A strategy of restricting productivity growth to be equal to the biomass growth may better fit with manager's ideas about limiting catch and vessel exit from the fishery. On the other hand, it can also limit the ability of vessels to lower their costs through technological improvement, and thus improve their profitability. Ultimately, changes in profitability, which are tied to productivity change, are what will determine fleet dynamics and the economic well-being of the industry.

YEAR	NE_TFP^U	NE_TFP^B
2007	1.00	1.00
2008	1.11	1.14
2009	1.16	1.25
2010	1.16	1.22
2011	1.29	1.37
2012	1.25	1.34
2013	1.11	1.21
2014	1.06	1.04
2015	1.00	0.88
2016	0.99	0.72
2017	1.17	0.73
2018	1.25	0.78
Average annual rate	2.03%	-2.27%

Note: the index numbers in the table are chain indices using 2007 as the reference period for each fishery.

Table 7 Unadjusted TFP vs. biomass-adjusted TFP

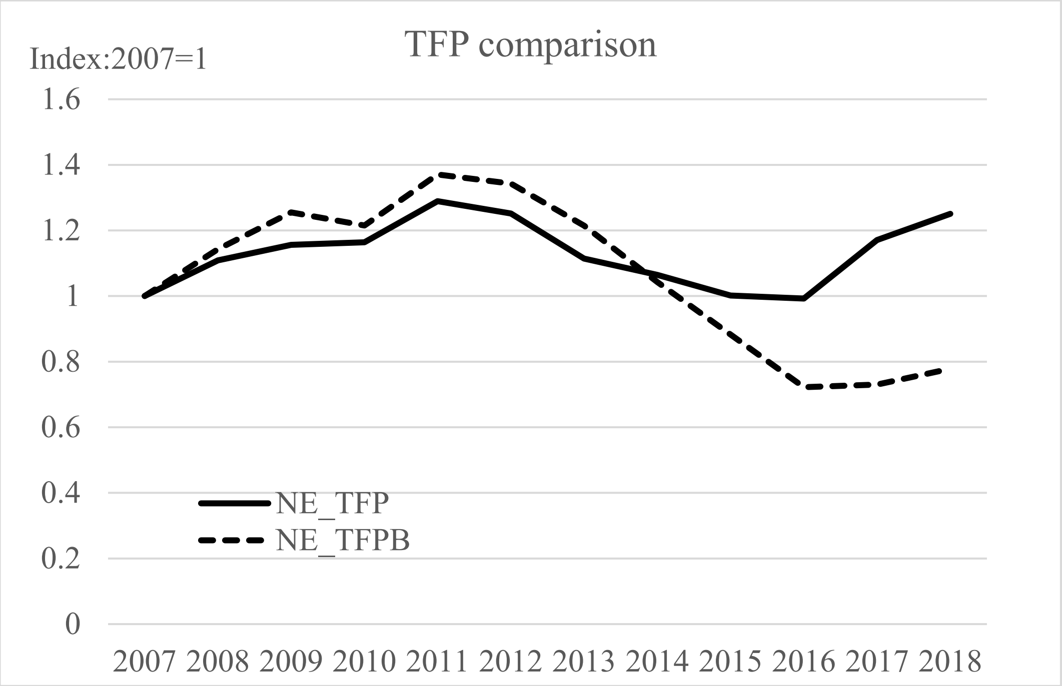

Figure 6. TFP (NE_TFP) vs. biomass-adjusted TFP (NE_TFPB) (2007-2018)

5. Conclusions

The measurement of sector-wide productivity usually relies on national-level data, such as Bureau of Labor Statistics (BLS) productivity estimates by industry and the U.S. agricultural productivity estimates by U.S. Department of Agriculture (USDA). In terms of the commercial fishing sector, productivity estimates are lacking as a whole because there are no nation-wide cost surveys across fisheries and regions. This study is a first attempt to measure sector-wide commercial fishery productivity beginning with fishery-level estimates, as the data is more available at the fishery level. Assuming a multiple-output with multiple-input technology for each fishery to measure total factor productivity, a translog production possibility frontier was employed to measure output, input, and TFP using Törnqvist indices. Quality differences embodied in the capital assets were accounted for, and TFP estimates were adjusted for fish biomass changes in the TFP measurement.

Results show patterns of input growth which seem to be consistent with the patterns of output growth among eleven fisheries. There are only four fisheries—Dogfish, Skates, Squid, Mackerel and Butterfish, and Tilefish— which demonstrated positive growth in both outputs and inputs. However, given that many of the rates of input growth are smaller than the rates of output growth, six of eleven fisheries demonstrated positive TFP^U growth rates during the study period. Nevertheless, the positive estimates of fishery-level TFP growth were mostly driven by the growing fishery specific biomass. After adjusting for the biomass changes, TFP^B growth rates have shown a different pattern for some fisheries, with average growth rates changing form positive (negative) to negative (positive). Regarding sources of growth, labor input and intermediate goods are more closely aligned to the reduction of output growth than the capital service flow. The changes in public fish resources for the industry plays a significant role in output growth and TFP measurement. The results show that policy regulations have affected fishery-level biomass changes and resulted in improved TFP^U before the estimates were adjusted for biomass change. Without adjusting for biomass changes, TFP^U estimates grew at an annual rate of 2%, and this demonstrates that improved productivity can occur through positive biomass change. However, after adjusting the measure of TFP^U growth for biomass change, TFP^B annual growth declined 2% per year. This shows that if we miss capturing the effects of biomass increases (decreases), TFP estimates would be "biased" in the sense that they include factors which are not in the control of individual fishing vessels. Using overstating/understating TFP estimates in policy evaluation the implications can be fallacious.

The Fishery Management Councils, along with the National Marine Fisheries Service, are primarily responsible for productivity gains which occur in the commercial fishing sector, although it may not always be apparent to them. On one hand, they are forced to put in place regulations which restrict productivity gains in order to limit removals from the resource stock. To the extent that they are successful in this, and are able to generate positive fish biomass growth, they will likely generate positive productivity growth either through improved output growth, or reduced input growth. However, by limiting technological or efficiency gain, they also interfere with a vessel's ability to reduce their costs though lower input usage and improve their productivity and profitability. Thus, they walk a tightrope; too much regulation without subsequent biomass growth will stifle productivity gains and may reduce vessel profitability. Too little regulation may lead to reduced biomass and lower biomass growth which may limit productivity gains in subsequent periods, and result in tighter regulations that will further reduce productivity, and potentially profitability.

In this study, there was adequate data to use a “bottom-up” approach and construct an aggregate measure of productivity for the commercial fishing sector. Unfortunately, it is not currently possible to do the same type of analysis nationally. This is due to a lack of standardized cost data, and limited resources to regularly produce productivity measurement. This is unfortunate as understanding sources of productivity growth would help guide future policy choices, and would provide an important economic metric for stakeholders.

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