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John Walden is the corresponding author. John Walden and Sun Ling Wang were responsible for statistical analysis, programming, interpretation of data for sections II though III. Emily Markowitz was responsible for the statistical analysis and programming for section IV and continued upkeep of the FishEconProdOutput R Package. All authors contributed to the interpretation of data for section IV and the preparation of this manuscript.

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Abstract

This proposal provides guidelines on fishery productivity measurement at the individual fishery and aggregate sector levels. Attention is given to the constructions of output, inputs, and total factor productivity (TFP) based on available data. Given that there is no nationwide standard cost survey, we recommend starting with measuring TFP at the fishery level based on a translog gross output production possibility frontier using index number techniques. Special attention is given to measuring quality-adjusted physical capital inputs in the bottom-up approach. Examples of national and regional output estimates are presented at the end of the proposal to show the preliminary usages of those estimates as a part of NMFS official statistics products in the future. In addition, price indices are developed which can be used to convert yearly price and revenue values to a common year.

Keywords: fishery productivity, total factor productivity (TFP), index number, national fishery productivity, regional fishery productivity.

1. Introduction

Productivity is a key driver of profitability and has been identified as an important indicator of fishery performance. It can be estimated using either a single factor productivity measure (such as labor productivity) or a total factor productivity (TFP) measure. This report will focus on TFP and TFP change because the single factor productivity estimate can be augmented by simply adding other inputs, and does not capture the contribution of all inputs, or technical change which may have occurred. TFP change is a more suitable productivity measure for understanding the overall technological advancement when all productive factors are accounted for in the measurement.

There are few studies on measuring industry-level fishery productivity because there are no standardized cost surveys that cover all commercial fisheries in the United States. For the literature that does exist, studies are typically based on specific fisheries, and use a variety of methods to measure TFP and TFP change. These methods include Data Envelopment Analysis (DEA), stochastic production frontier (SPF), index number approaches, and the econometric transformation function approach (Felthoven and Paul, 2004; Felthoven et al., 2009; Jin et al., 2002; Squires, 1992; Walden et al., 2017; Walden et al., 2012). With this in mind, we propose a bottom-up approach that starts with measuring TFP at the individual fishery level, and then uses those TFP measures to build a sector-wide productivity measure. We also discuss challenges in measuring output, inputs, and total factor productivity for the commercial fishery sector, and propose alternatives when choosing variables or data sources in the productivity analysis.

We develop our TFP measure using a growth accounting framework, where TFP growth is the difference between output changes and the growth of all productive inputs used to produce the outputs (also known as “input growth”). The portion of output growth that cannot be explained by the aggregate input growth is captured by a “residual” measure (or so called TFP). However, for fishing vessels, a portion of this residual is caused by changes in biological conditions of the underlying resource, which is outside of the control of individual vessels (Jin et al., 2002; Squires, 1992; Walden et al., 2017). Therefore, biomass changes need to be separated from TFP.

The rest of the report is organized into four sections. In the first, we introduce the theoretical framework in measuring output, inputs, and total factor productivity at the fishery level and the aggregate level. Next, we discuss the required variables and potential data sources based on the nature of the collected data, focusing on an example in the Northeast U.S. region. We then discuss potential outlets for the estimates. In the final section, we summarize our findings and provide concluding remarks.

2.0 Productivity at the Fishery and Aggregate Sector Levels

Our focus is on productivity change at the aggregate commercial fishing sector level, and to arrive at that metric, we begin by focusing on fisheries that operate within the aggregate sector. A fishery is defined by a Fishery Management Plan (FMP), which controls fishing activity within a region. These plans are developed either through a Fishery Management Council, or directly by the National Marine Fisheries Service. Ultimately, the aggregate commercial fishing sector level would include all fisheries operating in the United States Exclusive Economic Zone (EEZ). The first building block in this measurement is at the fishery level.

2.1 Measuring TFP at a fishery level

We begin by measuring TFP at the fishery level, using a growth accounting framework (Solow, 1957). First, we define a gross output production function for each fishery j using a general form:

$$Y_{j,t}=f_j(K_{j,t}, L_{j,t}, M_{j,t}, T_{j,t}) \qquad (1)$$

where Y is total output, K is capital service flow, L is labor input, M is intermediate goods, and T is the technology employed by that fishery at time t. We assume that the production is under constant return to scale and all input markets are competitive, meaning factors are paid their marginal products. Using the fundamental accounting identity, the value of output for each fishery exactly equals the value of inputs used, and the total factor productivity growth can then be defined as the value of the output growth minus the value of the input growth:

$$\Delta lnTFP_j \equiv v_{T,j} \equiv \Delta lnY_j - \overline{w_{K,j}}\Delta lnK_j - \overline{w_{L,j}}\Delta lnL_j - \overline{w_{M,j}}\Delta lnM_j \qquad (2)$$

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 the total inputs used (also known as total cost), under the accounting identity assumption.

Here we define an aggregate (i.e., total) output model based on the translog production possibility frontier. The fishery-level gross output growth is measured as a Törnqvist index of revenue-share weighted growth of all individual species in each fishery:

$$\Delta lnY_j \equiv ln\left[\frac{Y_{j,t}}{Y_{j,t-1}}\right] = \sum_{s=1}^{n}\left[\frac{R_{s,j,t-1}+R_{sj,t}}{2}\right] ln\left[\frac{Y_{s,j,t}}{Y_{s,j,t-1}}\right] \qquad (3)$$

where Y_j is the aggregate output of fishery j, ΔlnY_j is the output growth rate of fishery j, and $Y_{s,j}$ denotes the landing quantity of species s in fishery j. The landing revenue share of species s in total landing revenue of fishery j ($R_{s,j}$) is:

$$R_{s,j} = \frac{P_{s,j}Y_{s,j}}{\sum_j P_{s,j}\, Y_{s,j}} \qquad (4)$$

Average revenue share $\overline{R_{s,j}}$ for species s between two successive periods, t-1 and t is: $\left[\frac{R_{s,j,t-1}+R_{s,j,t}}{2}\right]$.

The fishery-level input growth is measured as a Törnqvist index of cost-share weighted growth of individual inputs labor (L), capital (K), and materials (M):

$$\Delta lnX_j \equiv ln\left[\frac{X_{j,t}}{X_{j,t-1}}\right] = \sum_{i=1}^{3}\left[\frac{W_{n,j,t-1}+W_{n,j,t}}{2}\right] ln\left[\frac{X_{n,j,t}}{X_{n,j,t-1}}\right] \qquad (5)$$

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 (in this case n=3, representing L, K, M), $W_{n,j}$ is the cost share of input n in total input cost of fishery j, and $\left[\frac{W_{n,j,t-1}+W_{nj,t}}{2}\right]$ is the average cost share $\overline{W_{n,j}}$ for input n between two successive periods, t-1 and t:

$$W_{n,j} = \frac{P_{n,j}X_{n,j}}{\sum_n P_{n,j}\, X_{n,j}} \qquad (6)$$

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

$$\Delta lnTFP_j \equiv ln\left[\frac{TFP_{j,t}}{TFP_{j,t-1}}\right] = \sum_{s=1}^{n}\left[\frac{R_{s,j,t-1}+R_{s,j,t}}{2}\right] ln\left[\frac{Y_{s,j,t}}{Y_{s,j,t-1}}\right] - \sum_{i=1}^{3}\left[\frac{W_{n,j,t-1}+W_{i,j,t}}{2}\right] ln\left[\frac{X_{n,j,t}}{X_{n,j,t-1}}\right] \quad (7)$$

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

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

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

2.2 Measuring total factor productivity for the aggregate fishery sector

To measure TFP growth for the sector-wide fishery sector, we first define the aggregate gross output from the aggregate production possibility frontier, assuming each fishery has its unique output *j* using fishery estimates in the sector.

$$\Delta lnY = \sum_{j=1}^{J} \bar{R}_j \, \Delta lnY_j \quad (9)$$

where *Y* is the aggregate fishery output and $\bar{R}_j$ is the average revenue share of fishery *j* in the total landing revenue of J fisheries between time periods *t* and *t-1*.

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 fishery sector can be expressed as:

$$\Delta lnX = \sum_{j=1}^{J} \bar{R}_j \, \Delta lnX_j \quad (10)$$

Combining equations (9) and (10), the rate of TFP growth of the aggregate sector can be expressed as:

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

When considering fishery biomass changes, the sector-wide biomass adjusted TFP growth is measured as:

$$\Delta lnTFP^B = \sum_{j=1}^{J} \bar{R}_j \left(\Delta lnTFP_j - \Delta lnB_j\right) = \sum_{j=1}^{J} \bar{R}_j \left(\Delta lnTFP_j^B\right) \quad (12)$$

3.0 Measuring Fishery-Level Output, Inputs, and Total Factor Productivity: An Example from the Northeast Region

In this section, we show an example of how to develop these measures using vessel-level landings data and cost data from various sources to derive input prices and quantities for labor, capital, and intermediate goods for a single fishery. We focus on the Northeast region and 11 fisheries that are managed by either the New England or Mid-Atlantic Fishery Management Councils. Our unit of time for this analysis is a calendar year, and we include the years 2007-2018. However, in order to calculate the yearly productivity measures, information for individual trips will be collected and aggregated for each calendar year.

3.1 Output

The first step in this process is to assign each vessel/trip in a given year to a specific Fishery Management Plan (FMP) because vessels can fish in multiple FMP's in the Northeast region. The decision rule chosen for assigning a trip to a fishery was whether the revenue from species included in an FMP accounted for the majority (more than 50%) of the trip revenue. For example, the northeast squid, mackerel, and butterfish (SMB) fishery includes the species loligo squid, illex squid, Atlantic mackerel, and butterfish. Using our example, if the total revenue from all four of these species is greater than 50% of the trip revenue, that trip is assigned to the SMB fishery. Other species revenues and landings from species not included in the FMP that are caught incidentally to the four species are also included as aggregate in our output estimate in an "other" category. The total output growth for the SMB fishery is then estimated using a Törnqvist index, as shown in equation (3). This process is repeated for each FMP included in the region.

3.2 Labor

Because we begin building our data sets with a fishing trip, both the quantity and price of labor need to be calculated on a trip basis. Since there is a lack of consistent labor cost data, which could yield both quantities and the price for labor, we estimate labor quantity from vessel logbooks, which includes crew size. Labor quantity on each trip is measured as the product of total crew size and total days at sea, to arrive at a measure of total crew days. The calculation for input price used for crew days is problematic since crew are typically paid a share of the proceeds from the sale of the fish. Given that these type of share arrangements differ between landing ports, and information about the percentage split between the crew and boat owner is not collected through trip reports, a proxy for the wage rate needs to be chosen. For our example, we chose a wage rate per hour for U.S. construction workers, obtained from the St. Louis Federal Reserve[1] as our proxy for the 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

Capital is measured as capital service flow, which equals the user cost (price) multiplied by capital stock flow (quantity). Capital stock can be calculated as the aggregate vessel value and value data can be estimated from various sources. For example, Färe et al. (2017) and Wang and Walden (2021) measure quality-adjusted capital stocks using a shadow value for vessel attributes, such as gross tonnage, vessel length, and engine horsepower calculated from a distance function. Other authors have used a hedonic model to similarly calculate values for vessel attributes (Kirkley and Squires, 1988). If there are other external sources of vessel value, such as owner surveys or insurance values, they could be utilized to determine vessel value. Once a value for the vessel is determined, the price of the capital stock (user cost) can be calculated. For this study, it is calculated by multiplying the vessel value by an interest rate plus depreciation rate ($r+d$). The choice of an interest rate needs to be carefully considered based on an appropriate risk level and availability of a long enough time series. Here, we use a BAA bond rate (Moody's Seasoned Baa Corporate Bond Yield[2]), adjusted for inflation, plus a depreciation rate. The choice of the BAA bond rate has a long history of use in fisheries studies (Squires, 1992; Walden and Kitts, 2014). However, another rate could be chosen if an analyst feels it is appropriate.

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[1] Data available at https://fred.stlouisfed.org/series/CES2000000003, accessed 7/9/2018.

[2] BAA bond rate (Moody's Seasoned Baa Corporate Bond Yield) can be drawn from the Federal Reserve Bank of St. Louis, available at https://fred.stlouisfed.org/series.

Because vessels in our example often fish in other fisheries, the quantity of the capital stock needs to be adjusted. In our example, the quantity of capital is the percent of the total time the vessel spent in the specific fishery in a given year that is being estimated. For example, if the vessel spent 50% of its time in the SMB fishery, the quantity of capital would be 0.5. Finally, we group vessel capital by gear type, and measure aggregate capital input change using the Törnqvist index.

3.4 Intermediate goods

In a gross output model, intermediate goods include energy, materials, and purchased services that are used by the fishing vessel on each trip. For our example, detailed cost data are not available to calculate the quantities or input prices for the intermediate goods. Consequently, we propose to use the total number of days the vessel spent at sea in the specific fishery as a proxy for the quantity of intermediate goods. The input price for each day at sea is calculated using expenditure data collected on selected fishing trips each year and is gear specific. The expenditure data used in this calculation include the cost of fuel, oil, ice, and other materials. Data sources include both regional cost surveys and sea sample observer programs when cost data is collected at the trip level.

3.5 Biomass adjustment

We employed biomass data used in the fishery stock assessment process to construct a biomass index for each fish stock contained in an FMP. These data were extracted from stock assessment data found in the Stock Assessment Review Index (SARI) search tool maintained by the Northeast Fisheries Science Center (NEFSC)[3]. We construct an aggregate biomass index using fixed share weights in a multiplicative index formula as follows:

$$BI = \prod_{s=1}^{S} \left(\frac{B_{t,s}}{B_{0,s}}\right)^{a_s} \qquad (13)$$

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 must equal one.

3.6 Results

We measure output growth, input growth, and TFP growth for the Northeast fishery sector, and further decompose output growth into its sources of growth — labor, intermediate goods, capital, and TFP growth — following Ball et al. (2016), with an addition of biomass change. The results for output growth, input growth, biomass growth, and TFP growth for the time period 2007-2018 are shown in Table 1. Apart from dogfish (DOG), skates (SK), and tilefish (TILE), all other fisheries experienced negative output growth during the 2007-2018 time period. However, these fisheries that experienced negative output growth also incurred negative input growth, which led to positive TFP growth. All FMP's, except for bluefish (BLUE); squid, mackerel, and butterfish (SMB); and tilefish (TILE) showed positive TFP growth. However, most of these fisheries also showed positive biomass growth, which means that when biomass growth was subtracted from TFP growth, seven out of 11 fisheries experienced negative biomass adjusted TFP growth. Positive biomass adjusted TFP growth was found in the dogfish (DOG) fishery, Atlantic herring (HER) fishery, the monkfish (MONK) fishery, and the tilefish (TILE) fishery. Yearly trends for the biomass adjusted TFP indices can be seen in Table 2.

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[3] NEFSC Stock Assessment Review Index (SARI) search tool, available at https://apps-nefsc.fisheries.noaa.gov/saw/reviews_report_options.php, accessed 10/22/2020.

Table 1. Sources of growth by fishery (2007-2018).

	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 2. Biomass adjusted TFP by fishery (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	-7.0%	6.8%	-1.7%	4.8%	18.2%	-4.0%	-0.7%	-0.01%	-1.7%	3.5%	-4.2%

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

Next, we aggregate the individual fishery results to regional TFP and biomass adjusted TFP estimates. Utilizing equations (11) and (12), TFP and biomass adjusted TFP for the aggregate northeast commercial fishing sector were constructed using fishery revenue shares as weights. During the 2007-2018 time period, our estimates show that TFP increased by 25%, growing at 2% per year (Table 3). However, biomass adjusted TFP decreased by 22%, declining at an average rate of 2.2% per year. For the aggregate sector, TFP growth is being positively influenced by improved natural resource abundance, while improvement through technology and efficiency gain has not occurred.

Table 3. TFP vs. biomass adjusted TFP.

Year	NE_TFP	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%

4.0 Moving from a Regional to National Level TFP Measure

The template shown above for the Northeast region could be applied to other regions, and nationally if there were consistent quantities and prices for output and input data to estimate aggregate output, input, and TFP. Construction of these indices at the national level could provide cross-fishery comparisons of productivity growth, along with an aggregate national productivity measure. If the indices were constructed over a long period of time, they could help to infer policy effectiveness.

4.1 Measuring aggregate output for the commercial fishery: a national level example

In this section, we present a framework for using landings and revenue data in measuring total output for the aggregate fishery sector within the Fisheries Economics of the United States (FEUS) report. For this exercise, we aggregate outputs into a finfish sector and a shellfish sector. Unfortunately, at the present time there is not a consistent database of input quantities and prices that could be used to create an input index. We constructed an output price index that can be used to deflate landings revenues and that could also be used to calculate an implicit quantity amount if only revenue were available.

We draw landings data from the NOAA Fisheries One Stop Shop (FOSS) landings data query tool[4] in order to measure fishery output. This tool contains the most up to date commercial fisheries landings and revenue data for all 50 states by species that are not confidential. While total output quantity changes can be measured directly using equation (3), we first construct a Törnqvist price index (PI) and then use the PI to deflate nominal landings value to arrive at an inflation adjusted (i.e., real) landings value. We then use the deflated landings value to calculate a Törnqvist quantity index (QI).

For our analysis, we aggregated landings and revenue data into two different fisheries: finfish (defined as all organisms in the infraphylum Gnathostomata) and shellfish (defined as all organisms in the phyla Arthropoda and Mollusca). Any species outside of these taxonomic definitions were excluded from the analysis because they were uncommon and not generally targeted. The FOSS database defines all species using a Taxonomic Serial Number as defined by the Integrated Taxonomic Information System.[5] Distinguishing species fishery categories was done easily with the R package 'taxize' (release number 0.9.99; Baumgartner et al., 2020; Chamberlain and Szocs, 2013), which was used to bin species into the appropriate fishery category.

A price index yields a measure of inflation between two time periods and reveals how much more or less money it takes to purchase a similar bundle of goods or services in a different time period. Price indices are useful in comparing relative price change and for converting all estimates of value in a time series to value in a common year. Constructing price indices that are specific to the seafood harvesting sector means that they more closely reflect price changes that occurred in that sector. Popular price indices such as the Producer Price Index (PPI) or the GDP implicit price deflator (GDPD) reflect price changes in the production sector (PPI) and general economy (Consumer Price Index), respectively, but may not be consistent with price changes occurring in the seafood harvest sector. Our index is constructed based on identified shellfish and finfish species and therefore more accurately mirrors relative prices for those species groups in the harvest sector. We construct the Törnqvist price index between any two time periods *t* and 0 as (Balk, 2008):

$$PI_t = \prod_{n=1}^{N} (p_n^t/p_n^0)^{(r_n^0+r_n^t)/2} \qquad (14)$$

Here, *n* denotes the fish or shellfish species, *p* is the price, and *r* is the revenue share of product *n* in either period *t* or 0. The revenue share (*r*) of product *n* is calculated as:

$$r_n^t = \frac{p_n^t q_n^t}{\sum_{n=1}^{N} p_n^t q_n^t} \qquad (15)$$

The additive form of the Törnqvist price index is shown in equation 16:

$$\Delta lnPI_t \equiv ln\left[\frac{PI_t}{PI_0}\right] = \sum_{j=1}^{J}\left[\frac{r_n^0+r_n^t}{2}\right] ln\left[\frac{P_{n,t}}{P_{n,0}}\right] \qquad (16)$$

The deflated value of total output (i.e. implicit quantity) for fishery sector A in time period *t* can now be estimated as:

$$Y_{A,t} = \frac{TR_t}{PI_t} \qquad (17)$$

where *TR* is the nominal total landing revenue. The PI index is constructed beginning with a bilateral price index between consecutive years. These bilateral indices are then multiplied

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[4] NOAA Fisheries Office of Science and Technology's Fisheries Statistics Division's Commercial Landings Query. Available at https://foss.nmfs.noaa.gov/apexfoss/f?p=215:200; accessed 8/2020.

[5] https://www.itis.gov/, accessed 8/2020.

together to form a chain index. For example, the PI in period 3, PI^3.is calculated as $PI^3 = PI_2^3 x PI_1^2 x PI^1$. Here $PI^1=1$ since it is the first year in the chain. The chained value in any time period shows the relationship between prices in the reference year time period to the base time period (*t*=1in this example). We do not adjust these price indices for chain drift, though this could be included at a later time.

For the purposes of FEUS, price indices are calculated as chained Törnqvist indices over a 20-year period (here, 1999-2018) and then converted to a base year index with 2015 as the base time period using the formula $PI^t=PI^t/PI^{2015}$. In other words, for a given year we take the chained PI for that year and divide by the chained PI in 2015. Consequently, the PI in 2015 will equal one, and for all other years the PI show the relationship between prices in that year and 2015. The data window and base year will be adjusted every five years. For example, in the 2020 edition of the report, the base year will be 2020 and the minimum year of the data used in the analysis will be 2001 to ensure consistency between editions of the FEUS report.

Using the PI calculated above, we next construct a Törnqvist quantity index for finfish, shellfish, and the combined finfish and shellfish category. This shows how the production of these two categories by the commercial fishing fleet has changed over the 20-year time period. We begin this by first deflating all the nominal values for each category using our previously calculated PI. The quantity index is then calculated as:

$$QI^t = \prod_{n=1}^{N} (q_n^t / q_n^0)^{(r_n^0 + r_n^t)/2} \qquad (18)$$

The additive version of the Törnqvist quantity index is shown in equation 19.

$$\Delta lnQI_t \equiv ln\left[\frac{QI_t}{QI_0}\right] = \sum_{j=1}^{J} \left[\frac{r_n^0 + r_n^t}{2}\right] ln\left[\frac{Q_{n,t}}{Q_{n,0}}\right] \qquad (19)$$

As before, *n* is the product, and *q* is the quantity of product *n* produced in time period *t*. However, *r* is now the *deflated* share value of product *n* in period *t* or 0, calculated with our PI described above. Again, we chain together bilateral indices, and then convert the base year to 2015. If quantities are unavailable, then a quantity index can be constructed with implicit quantities using a price index, such as we constructed above. In that situation, $QI=IQI_t/IQI_0$. This is a base year index, but could easily be constructed as a chain index by substituting IQI_{t-1} for IQI_0 in the denominator.

4.2 R Package 'FishEconProdOutput'

All analysis and methodology have been made available to other users in an R Package called FishEconProdOutput (release 0.1.0) available on https://zenodo.org/badge/latestdoi/291852337. The package depends on the tidyverse (1.3.0), reshape2 (1.4.4), data.table (1.13.4), plyr (1.8.6), and rlist (0.4.6.1). Analysis was developed in R (version 4.0.3, 10/10/2020) and RStudio (version 1.2.5042). A vignette describing this analysis using the functions in FishEconProdOutput and how to create the tables that are used in the Fisheries Economics of the U.S. report is accessible by loading the package and navigating to the vignettes on the GitHub repository[6] or package.

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[6] Vignette available at https://github.com/EmilyMarkowitz-NOAA/FishEconProdOutput/blob/FishEconProdOutput/vignettes/FEUS-tables.pdf

4.3 Results

Table 4 presents the PI for shellfish, finfish, and the combined total of these two categories, constructed from harvest sector landings data, and the deflated values for each category. In Table 4, the nominal values of the shellfish and finfish will equal the total annual value. However, the sum of the inflation-adjusted (i.e., real) values for shellfish and finfish will not equal the total. This is because the price indices are calculated separately for each category. In order for the total real values to sum correctly, a common deflator would need to be used for all three categories. Based on the calculated price indices, all categories showed strong price increases over the 20-year time period. Prices for finfish rose 102% while shellfish prices rose 62%. For the aggregate total category, prices rose 79%. The strong price increases led to increased nominal value of landings for all three categories over the 20-year time period. However, real values declined due to lower landings during our 20-year study period, as seen in the quantity index trends (Table 5). In 2018, the quantity of finfish landed was 80% of what was landed in 1999 (0.89/1.12) while the quantity of shellfish was about 89% of the 1999 landings (1.08/1.21). Total shellfish and finfish combined in 2018 was 85% of the 1999 level (0.99/1.17). Because the increases in prices were greater than the decline in quantities landed, nominal revenue increased. However, the decline in real values was caused by decreased landings and suggests that in revenue terms, the harvest sector was worse off in 2018 than in 1999.

Table 4. Nominal landings value ($Million), Törnqvist price index (2015=1), and real landing values (2015 $Million), 1995-2018.

	Finfish			Shellfish			Total		
Year	Nominal value ($Millions)	PI	Real value ($Millions)	Nominal value ($Millions)	PI	Real value ($Millions)	Nominal value ($Millions)	PI	Real value $(Millions)
1999	1,471	0.61	2,424	1,813	0.61	2,956	3,283	0.61	5,419
2000	1,496	0.64	2,346	1,876	0.66	2,848	3,372	0.64	5,231
2001	1,373	0.59	2,344	1,607	0.61	2,648	2,980	0.59	5,025
2002	1,245	0.54	2,320	1,616	0.57	2,835	2,861	0.55	5,194
2003	1,396	0.58	2,419	1,702	0.58	2,927	3,098	0.58	5,386
2004	1,631	0.66	2,466	1,773	0.59	2,980	3,404	0.62	5,479
2005	1,739	0.73	2,381	1,912	0.69	2,754	3,650	0.71	5,171
2006	1,957	0.89	2,209	1,919	0.62	3,117	3,877	0.73	5,303
2007	1,917	0.87	2,194	1,915	0.71	2,712	3,832	0.78	4,932
2008	2,109	1.05	2,013	1,932	0.73	2,645	4,041	0.87	4,663
2009	1,699	0.86	1,982	1,850	0.63	2,938	3,549	0.73	4,880
2010	2,058	1.03	2,007	2,110	0.74	2,855	4,168	0.86	4,838
2011	2,497	1.17	2,135	2,543	0.84	3,030	5,040	0.98	5,140
2012	2,456	1.20	2,040	2,554	0.82	3,104	5,010	0.98	5,088
2013	2,524	1.21	2,078	2,646	0.92	2,885	5,169	1.04	4,947
2014	2,283	1.10	2,080	2,832	1.04	2,733	5,115	1.06	4,809
2015	2,177	1.00	2,177	2,581	1.00	2,581	4,758	1.00	4,758
2016	2,262	1.10	2,062	2,819	1.01	2,785	5,081	1.05	4,841
2017	2,334	1.05	2,220	2,676	0.99	2,715	5,010	1.01	4,937
2018	2,390	1.23	1,944	2,751	0.99	2,779	5,140	1.09	4,699

Table 5. Törnqvist quantity index (2015=1) by species category, 1995-2018.

	Finfish	Shellfish	Total
Year	QI	QI	QI
1999	1.12	1.21	1.17
2000	1.09	1.16	1.13
2001	1.09	1.07	1.08
2002	1.07	1.16	1.13
2003	1.12	1.2	1.17
2004	1.14	1.2	1.18
2005	1.1	1.11	1.11
2006	1.04	1.25	1.15
2007	1.02	1.06	1.05
2008	0.93	1.03	0.99
2009	0.92	1.15	1.04
2010	0.93	1.11	1.02
2011	0.99	1.18	1.09
2012	0.95	1.2	1.08
2013	0.97	1.12	1.05
2014	0.96	1.06	1.01
2015	1	1	1
2016	0.94	1.08	1.02
2017	1.02	1.05	1.04
2018	0.89	1.08	0.99

5.0 Conclusions

This report proposes a total factor productivity measure based on a growth accounting framework using a Törnqvist index. Overall, fishery output data are available at national and regional levels, which allows us to measure gross output. However, detailed input data (such as labor, capital, and intermediate goods) are not consistently available across regions and fisheries, which inhibits us from constructing a gross input index. Developing a consistent cost survey across regions and fisheries is critical for improving the quality of productivity measurement for the U.S. fishery sector. Presently, since cost data are more likely to be collected at regional and fishery levels, we propose measuring output, inputs, and TFP using a bottom-up approach that starts with the fishery-level estimates. Furthermore, fish biomass data needs to be made available in order to adjust the TFP estimates for changes in biomass.

In the Northeast region example we presented, biomass adjusted TFP change was often opposite in sign from the initial TFP estimate due to biomass increases or decreases. It is important to separate changes in productivity brought about by biomass change from that brought about through improved efficiency or technical change.

At a national level, we developed both price and quantity indices for total landings of finfish and shellfish. Both were based on a chained Törnqvist index that was then changed to a base year of 2015. The price index was used to deflate landings revenue, which yielded an inflation adjusted (i.e., real) revenue value. Calculating the price index in this way could also be used to estimate implicit landings quantities if quantity data were missing. The price index used to deflate the nominal landings value was then used to construct the Törnqvist quantity index. Examination of both indices showed an increasing price trend and a declining quantity trend. Taken together, this shows that the declining real value of landings was caused by reduced landings volumes.

Development of price and quantity indices allows fishery managers to view a consistent set of indicators that help to inform their understanding about how their management measures are influencing the well-being of the commercial fishing fleet harvesting our natural resource stocks. A more complete picture would be possible if there were consistent input quantity and price data available to construct both profitability and productivity measures. Working toward a harmonization of cost collection data would advance the ability of the National Marine Fisheries Service to construct a fuller suite of indicators.

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