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Measuring changes in multi-factor productivity in U.S. catch share fisheries

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ABSTRACT

By ending the “race to fish” catch share programs may be expected to lead to improved productivity at the fishery level by retiring redundant capital and by allowing fishing firms to become more technically efficient in their harvesting activities by, among other things, changing the composition of inputs and outputs. Yet, there have been relatively few empirical studies of productivity changes in catch share fisheries and no comprehensive treatment of a cross-section of programs using a common measure of productivity change. In this study estimates of multi-factor productivity change for 20 catch share fisheries in the U.S. using a Lowe index are provided. With few exceptions, productivity increased relative to baseline conditions during the first three years of catch share program implementation. For five of six of the most established catch share programs, these initial productivity gains have been maintained or have continued to improve.

1. Introduction

By ending the “race to fish” catch share programs may be expected to lead to improved productivity at the fishery level as redundant capital is retired as well as among fishing firms through the ability to better conduct harvesting activities through, among other things, changes in the composition of inputs and outputs. Yet, there have been relatively few empirical studies of productivity changes in catch share fisheries and no comprehensive treatment of a cross-section of programs using a common measure of productivity change. Productivity measurement of fishing fleets has received intermittent attention over time. This is partly because productivity measurement in fisheries presents challenges that are different from traditional industries. Unlike traditional industries, fishing vessels harvest from a renewable natural resource stock where the government typically sets the total harvest level that may be allowed in any given time period. Whether the harvest is controlled directly through a total allowable catch or indirectly through input controls, total output is constrained. Regulations can make vessels less productive. For example, managers interested in protecting stocks may close off productive areas, forcing vessels to fish less productive fishing grounds. This results in vessels using more inputs to catch the same amount of fish as they would in the more productive areas. Stock conditions and environmental factors such as changing ocean temperatures can also influence productivity. Finally, productivity assessments need to account for different technologies (typically gear types), which are often used to harvest the same resource.

Nevertheless, there have been several studies over the years which have assessed productivity change in commercial fisheries. One of the earliest works was by Comitini and Huang [1] who used a Cobb–Douglas technology to characterize the production of 32 halibut fishing vessels in the North Pacific over a seven-year period. Norton, Miller, and Kenney [2] used aggregated data from vessels fishing in five U.S. fisheries to estimate an Economic Health Index, which contained a productivity component that could be examined separately. Squires [3,4] published a study measuring

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productivity in the Pacific Coast Trawl Fishery using an index number approach. Weninger [5] examined changes in productivity for surfclam vessels using a directional distance function model. More recently [6] updated Weninger's analysis to examine productivity change in the surfclam and ocean quahog ITQ fishery using a Malmquist index. Jin et al. [7] measured total factor productivity in the New England Groundfish Fishery during the period 1964–2003. Felthoven and Paul [8] reviewed past productivity studies and suggested a method for productivity measurement to answer questions concerning economic performance. Fox et al. [9] examined changes in capacity, quota trading and productivity after a license buyback in Australian fisheries. Hannesson [10] used a growth accounting framework to measure productivity change in Norwegian fisheries. Squires, Reid, and Jeon [11] examined productivity growth in the Korean tuna purse seine fishery operating in the Pacific Ocean. Felthoven, Paul, and Torres [12] measured productivity in the Alaskan pollock fishery from 1994-2003 while incorporating environmental conditions, bycatch and stock effects. Eggert and Tveterås [13] examined productivity change in Icelandic, Norwegian and Swedish fisheries between 1973 and 2003. Torres and Felthoven [14] revisited their earlier productivity study in the Alaskan pollock fishery using a longer panel (1994–2009) and improved econometric techniques to account for the mixed distribution of the production data.

This manuscript reports results from a recent effort by NOAA Fisheries to measure productivity change across all U.S. catch share fisheries using the Lowe Index.[1] The Lowe index was selected because it is computationally easy to construct, requires less data than most alternative productivity measures, and can be applied in a consistent manner for all U.S. catch share programs. The index is a fishery-wide index, which avoids computational problems associated with changes in fleet size over time. Additionally, the Lowe index was identified by O'Donnell [15] as one that satisfies all economically relevant axioms for index number theory, including identity and transitivity. Thus, the index is both theoretically robust and easy to construct.

Catch share programs are listed in chronological order (Table 1) by the first year in which each catch share program started. For several Alaska region programs productivity was estimated for sub-components of the fleet due to differences in production functions and available data. Table 1 also includes fisheries where data were available for selected years prior to the start year of a catch share program to construct a pre-catch share baseline condition (denoted by an asterisk in Table 1) as well as fisheries where pre-catch share data were not available.

The paper is organized as follows. A technical exposition of the Lowe index is provided in the next section followed by a description of data and methods in Section 3. Our estimates of productivity change in U.S. catch share fisheries are reported in the fourth section. Section 5 synthesizes productivity change across catch share fisheries and offers conclusions.

2. Lowe multi-factor productivity change index

Simply put, multi-factor productivity (MFP) is defined as a ratio of aggregate outputs to aggregate inputs, and MFP change (ΔMFP) is the ratio of aggregate output change to aggregate input change during a time period, which for our purposes is one year.[2] Output

[1] A detailed description of each catch share program as well as input, output, and biomass data is reported in [16].

[2] Throughout, MFP is used instead of the usual total factor productivity (TFP) in recognition of the fact that productivity estimates are data limited and do not include all factors of production.

Table 1
List of catch share fisheries for which multi-factor productivity was estimated.

Catch share program	Start year	Baseline year(s)
Mid-Atlantic Ocean Quahog ITQ*	1990	1987–1989
Mid-Atlantic Surfclam IFQ*	1990	1987–1989
Alaska Halibut IFQ	1995	2008
Alaska Sablefish IFQ	1995	
Catcher Vessels		2007
Catcher/Processors		1995
American Fisheries Act Pollock Cooperatives		
Catcher Vessels	2000	2007
Catcher/Processors*	1999	1996–1998
Pacific Coast Sablefish Permit Stacking	2001	2003
Bering Sea And Aleutian Island Crab Rationalization*	2005	1998, 2001, 2004
Gulf of Mexico Red Snapper IFQ*	2007	2004–2006
Non-Pollock trawl catcher/processor groundfish cooperatives (Amendment 80)	2008	2008
Mid-Atlantic Golden Tilefish IFQ*	2009	2007–2009
Northeast General Category Scallop IFQ*	2010	2007–2009
Northeast Multispecies Sectors*	2010	2007–2009
Bering Sea Freezer Longline Conservation Cooperative*[,a]	2010	2007–2009
Gulf of Mexico Grouper-Tilefish IFQ*	2010	2007–2009
Pacific Groundfish Trawl Rationalization	2011	
Non-whiting IFQ*		2009–2010
Shoreside Whiting IFQ*		2009–2010
Central Gulf of Alaska Rockfish Cooperatives[b]	2007/2012	
Catcher Vessels		2007
Catcher/Processors*		2004–2006

* Catch share programs with a pre-catch share baseline. For all other programs the baseline was the first year for which data were available.

[a] The Bering Sea Freezer Longline Cooperative operates in a manner similar to that of the Northeast Multispecies Sector Program which is not a Limited Access Privilege Program under the Magnuson-Stevens Act.

[b] The Central Gulf of Alaska Rockfish Program started out as a Pilot Program from 2007 to 2011, but was not formally implemented until 2012.

and input changes can be measured by constructing output and input quantity indices.

Lowe quantity indices are "basket" indices, meaning that multiple output and input quantities are aggregated into single output and input indices. Lowe indices use fixed reference prices to aggregate quantities. The unique feature about the Lowe index is that the reference price can come from any time period, even one outside of the time period used to estimate input and output quantities. Productivity change in catch share fisheries is measured here using what is referred to as the KLEMS-Y format where the initials in KLEMS stand for capital (K), labor (L), energy (E), materials (M) and services (S), and Y stands for output [17]. Hereafter, aggregate inputs are referred to as *I* and aggregate output as *O*. MFP in a year is defined as the aggregate value of all landings in a fishery during year *t* using fixed reference period output prices (Q_t^O,) while the denominator is the value of all inputs from a fishery during year *t*, also using fixed reference period input prices (Q_t^I), such that

$$MFP_t = Q_t^O/Q_t^I \tag{1}$$

As the interest is in changes in MFP between two time periods, Lowe output quantity ($\Delta Q_{t,b}^O$) and Lowe input quantity ($\Delta Q_{t,b}^I$) indices are created, which represent changes in output and input quantities, respectively, between a baseline period *b*, which can be any single year or time period, and year *t*. The Lowe MFP index represents the change in MFP between the baseline period *b* and year *t*, as the ratio of the Lowe output quantity index to the Lowe input quantity index, such that

$$\Delta MFP_{t,b} = \Delta Q^{O}_{t,b}/\Delta Q^{I}_{t,b}. \quad (2)$$

The index results in a measure of productivity change at the aggregate fishery level that weights the production of outputs and use of inputs in a consistent manner over the entire time period. The formulation of the Lowe output and input indices, and the Lowe biomass index is further developed below.

2.1. Lowe output quantity index

The Lowe output quantity index represents the change in output quantities between a baseline period b and year t, and is defined as

$$\Delta Q^{O}_{t,b} \equiv (p_r \cdot q_t)/(p_r \cdot q_b) \quad (3)$$

where q is a vector of output quantities in year t and baseline period b, and p is a vector of output prices during the reference period r.[3] Because the index is calculated at the fishery level the vector of outputs should include all species landed on trips on which catch share species are landed during a given year. The price vector is the price of each species in the quantity vector during the reference period. The reference period was determined separately for each catch share fishery. Note that this reference period for real prices could be a single year, or an average of several years, but the selection is constant over all years being compared for each catch share fishery. The reference prices essentially act as a fixed weight for each output over the period of examination.

2.2. Lowe input quantity index

The Lowe input quantity index represents the change in input quantities between the baseline period b and year t, and is defined as

$$\Delta Q^{I}_{t,b} \equiv (w_r \cdot x_t)/(w_r \cdot x_b) \quad (4)$$

where x is a vector of input quantities in year t and baseline period b, and w is a vector of input prices in reference period r. A complete set of input categories would include capital (K), labor (L), energy (E), materials (M) and services (S). For each input category, price and quantity is required. In cases where only cost data were available, an implicit estimate of quantity was obtained by dividing cost by a corresponding price index. When only quantity data were available, an appropriate price index was used in place of an explicit price.

2.3. Biomass index

A complicating factor in constructing indices for fishing fleets compared to traditional land-based industries is that MFP can be affected by changes in target species biomass. Biomass is an important input for the fishery production process as it can affect the catchability of fish, but its level and change between time periods is beyond the control of individual vessels in the fishery. Because biomass change may influence both outputs produced and the use of inputs by fishing vessels, failure to separate biomass from the remainder of the index makes it difficult to disentangle change in output and input use from biomass change [4]. The relationship between MFP that is biomass-unadjusted (MFP_{BU}) and biomass-adjusted MFP (MFP_{BA}) is

$$MFP_{BU} = MFP_{BA} * B, \quad (5)$$

where B is a biomass adjustment factor. Solving for MFP_{BA} yields:

$$MFP_{BU} * B^{-1} = MFP_{BA} \quad (6)$$

In this study the objective is to measure productivity change in the absence of biomass change, biomass-adjusted productivity change between any two periods, such as base period b and year t, $MFP^{t}_{BA}/MFP^{b}_{BA}$ can now be constructed as the ratio of productivity measures in two time periods

$$\frac{MFP^{t}_{BA}}{MFP^{b}_{BA}} = \frac{MFP^{t}_{BU} * (B^{t})^{-1}}{MFP^{b}_{BU} * (B^{b})^{-1}}. \quad (7)$$

Simplifying and rearranging terms yields:

$$\frac{\mathrm{MFP}^{t}_{\mathrm{BA}}}{\mathrm{MFP}^{b}_{\mathrm{BA}}} = \frac{\mathrm{MFP}^{t}_{\mathrm{BU}}}{\mathrm{MFP}^{b}_{\mathrm{BU}}} * \frac{\mathrm{B}^{b}}{\mathrm{B}^{t}}. \quad (8)$$

Since both left and right-hand terms can be expressed as index numbers, biomass-adjusted index of MFP change is the product of an index of unadjusted MFP change multiplied by an index of biomass change. In essence, the unadjusted productivity index is being normalized by a biomass index where the biomass index number is simply a quantity index. In order to maintain consistency with the Lowe MFP index, a Lowe quantity biomass index is constructed for biomass change which utilizes hybrid expenditure shares as prices such that:

$$\Delta B_{b,t} = \frac{\sum_{i=1}^{n} s^{i}_{r} * sb^{b}_{i}}{\sum_{i=1}^{n} s^{i}_{r} * sb^{t}_{i}}, \quad (9)$$

where:

$$s^{i}_{r} = \frac{p^{i}_{r} q^{i}_{r}}{\sum_{i=1}^{n} (p^{i}_{r} q^{i}_{r})}. \quad (10)$$

here, sb^{i}_{t} is a measure of biomass for species i in year t (equivalent to q in the output quantity index), s^{i}_{r} is the share value of landings for species i using reference period r prices and reference period quantities q, and n is the total number of species included. The value of shares sums to one. As discussed above, reference period r prices and landings quantities can be from a single time period or an average over several years. As constructed above, the biomass index is the inverse of the usual Lowe quantity index, because base period biomass is in the numerator rather than the denominator. Therefore, an increase in biomass between the baseline period and year t is represented by a biomass index value below 1.00 while a biomass index value above 1.00 signifies a decrease in biomass between the baseline period and year t.

3. Data and methods

Productivity change in each catch share fishery was estimated by economists in collaboration with biologists with experience and expertize with catch share programs in their region. Although the KLEMS-Y approach was selected to measure productivity change, sufficient data on all inputs were not available in any of the catch share programs to make full implementation of the approach possible. In all cases, capital (K) and labor (L) data were available to estimate productivity change. The extent to which changes in the use of these two inputs reflect changes in overall input use determines the robustness of our measures of MFP change in these fisheries. In fisheries where changes in the use of capital and labor do not reflect changes in overall input use, a KL-Y approach may result in substantially different estimates of MFP

[3] In the case of a single species fishery, the quantity index would simply be defined as the ratio of quantities between two time periods, q_y/q_b.

Table 2
Summary of available input data by catch share fishery.

Program	KL-Y	KLE-Y	KLEM-Y
Ocean Quahog ITQ	√		
Surfclam ITQ	√		
Atlantic Sea Scallops IFQ			√
Mid-Atlantic Golden Tilefish IFQ			√
Northeast Multispecies Sectors			√
GOM Red Snapper IFQ			√
GOM Grouper-Tilefish IFQ			√
Sablefish Permit Stacking		√	
Non-whiting IFQ		√	
Shoreside Whiting IFQ		√	
Alaska Halibut IFQ	√		
Alaska Sablefish IFQ CV	√		
Alaska Sablefish IFQ CP	√		
AFA Pollock CV	√		
AFA Pollock CP	√		
BSAI Crab IFQ	√		
Amendment 80 Cooperatives		√	
Central GOA Rockfish Cooperative CV	√		
Central Gulf of Alaska Rockfish CP	√		
Bering Sea Freezer Longliners	√		

Note – K=capital, L=labor, E=energy, M=materials, and Y=output.

change than if all input categories were used in constructing the index.

Where reliable data on energy (E) and materials (M) were available, these inputs were used to build the estimates of productivity change (Table 2 summarizes available input data by catch share fishery). In general, data were available for some (e.g., ice, bait, supplies etc.) but not all materials that may be used by vessels harvesting fish. This means that the input and output data used in this study cannot be used as a measure of net return since the input data are incomplete relative to the more comprehensive data required to assess net return or profitability in catch share fisheries. In all cases, this study uses the most complete data set available to provide our estimate of MFP change in each of the catch share fisheries presented.

Both output quantities and prices for each catch share program were available at the regional level. Similarly, data on input quantities for the factors of production were available at the regional level either as part of landings records or by applying an average price to total expenditures as part of a cost data collection program. In cases where region-specific input prices were not available from either primary or secondary sources national average prices for labor, fuel, and capital services were used. Specifically, average hourly earnings of production and non-supervisory employees from the U.S. Bureau of Labor Statistics current employment statistics survey was used for the price of labor.[4] The average price of retail sales of No. 2 diesel fuel by refineries from the Energy Information Administration was used as the fuel price.[5] The interest rate for BAA rated bonds was used as the capital services price.[6] Each of these price series were based on national averages and unless otherwise noted were used in the absence of alternative region-specific data. All input and output prices were converted to constant 2010 dollars using the GDP implicit price deflator.[7]

[4] Source: Bureau of Labor Statistics current employment statistics series ID: CES0500000008

[5] Source: http://www.eia.gov/dnav/pet/pet_pri_refoth_dcu_nus_a.htm (accessed 3/16/2015)

[6] Source: http://research.stlouisfed.org/fred2/graph/?s[1][id]=BAA (accessed 3/16/2015)

[7] Bureau of Economic Analysis http://www.bea.gov//national/nipaweb/DownSS2.asp (accessed 3/16/2015)

Estimates of biomass for each catch share program including species that are not managed under the catch share program of interest yet were jointly harvested on catch share program trips were obtained from a combination of the NOAA Fisheries Species Information System (FSIS) and recent stock assessment reports. Biomass estimates for jointly-caught species were limited to species that may be expected to influence trip decision making thereby affecting outputs and the mix of inputs used to harvest fish. Biomass data were not used for species that were subject to significant scientific uncertainty either because stock status was unknown or the available stock assessment information was outdated. For this reason, the biomass index for the Gulf of Mexico Red Snapper and Grouper-Tilefish IFQ programs could not be constructed, which means only unadjusted MFP was estimated for these two programs,

The biomass estimates included in this study serve as a proxy for changes in the catchability of the target species and embody the assumption that, all else equal, a larger biomass will produce higher output for a given level of inputs than a smaller biomass. However, changes in biomass may not always lead to changes in catchability. As the population of a species declines, the spatial distribution of that species may decline as well and the resulting density of fish may remain constant (particularly with species that exhibit schooling behavior) and catchability can remain relatively constant if these aggregations are easy for fishing vessels to locate [4]. Since catchability may not be directly related to the size of the species biomass, it is possible to follow the approach used in [4] to adjust the biomass estimates based on individual species catchability if species and gear specific catchability coefficients are available. This would dampen the impact that changes in biomass currently have on biomass-adjusted MFP change for those species that exhibit a relatively high degree of schooling behavior. This approach is left for future analysis as these catchability coefficients are not currently available for all catch share program species.

4. Results

The catch share fisheries included in this study fall into one of three categories: catch share programs with a pre-catch share baseline that were implemented prior to 2008, catch share programs with a pre-catch share base that were implemented after 2008, and catch share programs that did not have a pre-catch share base. Both unadjusted and biomass adjusted change in MFP is reported for each catch share program. All input, output, and biomass data as well as their corresponding indices are reported in [16].

Productivity change in longer term catch share programs that include a pre-catch share base are reported in Table 3 where the base corresponds to the baseline years noted in Table 1. Unadjusted productivity for the Surfclam ITQ fishery was above the pre-catch share base from 1990 to 2007 before dropping below the base during 2009–2012. However, biomass adjusted productivity in the Surfclam ITQ fishery has remained above the pre-catch share base in every year since 1990 and has been at least twice that of the base in every year since 1999. This difference between adjusted and unadjusted MFP highlights the importance of the biomass index in estimating productivity change as biomass adjusted productivity of the surfclam ITQ fishery was higher than unadjusted productivity and biomass adjusted productivity shows no decline in MFP below the pre-catch share base while unadjusted productivity was declining and below the base over the most recent four years. These differences were also evident in the ocean quahog ITQ fishery, although they were not as pronounced. Indeed, from 1990 through 1995, unadjusted MFP was nearly identical to that of biomass adjusted MFP because the biomass

Table 3
Annual unadjusted and biomass adjusted multi-factor productivity for catch share fisheries with a pre-catch share base that were implemented before 2008

Year	Mid-Atlantic Surfclam ITQ		Mid-Atlantic Ocean Quahog ITQ		AFA Pollock Catcher/Processors		BSAI Crab Fisheries		Central GOA Rockfish Catcher/Processors		GOM Red Snapper IFQ
	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP
Base	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1990	1.28	1.34	0.92	0.92							
1991	1.36	1.50	0.95	0.94							
1992	1.47	1.65	1.04	1.03							
1993	1.64	1.90	0.94	0.95							
1994	1.51	1.82	0.96	0.99							
1995	1.46	1.79	1.06	1.12							
1996	1.52	1.95	1.12	1.20							
1997	1.51	2.00	1.08	1.18							
1998	1.45	1.89	1.05	1.17							
1999	1.53	2.03	1.02	1.17	1.19	1.14					
2000	1.65	2.32	0.88	1.02	1.70	1.75					
2001	1.56	2.36	0.92	1.09	1.96	2.06					
2002	1.52	2.47	0.96	1.16	2.01	2.03					
2003	1.42	2.48	0.96	1.19	2.15	1.82					
2004	1.28	2.28	0.93	1.17	2.12	1.91					
2005	1.24	2.26	1.10	1.42	2.34	2.52	0.77	0.78			
2006	1.26	2.44	1.22	1.60	2.32	3.24	1.23	1.16			
2007	1.10	2.38	1.20	1.61	2.28	3.91	1.42	1.35	1.39	1.39	1.04
2008	1.00	2.37	1.22	1.67	1.91	4.09	1.65	1.60	0.89	0.89	1.15
2009	0.89	2.35	1.28	1.79	1.97	3.30	1.57	1.44	0.70	0.69	1.16
2010	0.83	2.30	1.19	1.70	2.02	3.55	1.50	1.43	0.99	0.96	1.07
2011	0.79	2.22	1.17	1.72	2.38	3.13	1.52	1.41	1.68	1.70	1.15
2012	0.76	2.14	1.21	1.82	2.61	3.40	1.62	1.73	1.59	1.66	1.19

index was virtually unchanged. Since then, the ocean quahog biomass has been declining resulting in an increasing biomass index and a positive trend in biomass adjusted MFP relative to the base. Consequently, the divergence between unadjusted and biomass adjusted MFP has increased.

Estimates for both unadjusted and biomass adjusted MFP were consistent relative to the pre-catch share base for the AFA Pollock catcher/processor (CP), BSAI crab, and CGOA Rockfish CP catch share fisheries. For the AFA Pollock CP fishery, unadjusted and biomass adjusted MFP were roughly equivalent during the start year (1999) at 19% and 14% above the pre-catch share base respectivel, and in all subsequent years, both unadjusted and biomass adjusted MFP show substantial gains (an average annual growth of 7% and 10%, respectively). The estimated annual productivity gains are larger than those found in some other studies of productivity gains ([18]), 0.8%; [10], 1%; and [7], 4.4%) but only modestly above estimates on this same fleet of 8.8% by Paul et al. [19] using the years 1994–2004 and 8% by Torres and Felthoven [14] using the years 1994–2009 (the latter of which accounts for the role of biomass changes). As this study only focuses on post-AFA productivity gains, while [19] and [14] use data back to 1994, it is reasonable that productivity gains would be higher in this study as many of the gains result from increasing flexibility in harvesting and processing decisions after implementation of the catch share program.

Estimated MFP in the BSAI crab IFQ fishery declined relative to the pre-catch share base during 2005, the first year of program implementation.[8] With the exception of the first year both unadjusted and biomass adjusted MFP have been above the pre-catch share base in all other years. However, the biomass adjusted MFP has been below that of undajusted MFP as the crab biomass has a dampening effect on estimated productivity change. Productivity in the CGOA Rockfish Catchcr Processor fishery initially increased in the first year of the catch share program, but was below the pre-catch share base from 2008-2010 before increasing in 2011 to about 68% above the pre-catch share base. Note that there were only minor differences between unadjusted and biomass adjusted MFP in the CGOA rockfish catch share program because biomass was nearly constant at pre-catch share base levels over the period of analysis.

For the Gulf of Mexico Red Snapper IFQ program, only unadjusted MFP estimates are reported because of the absence of recent stock assessments for many important species that are jointly-caught with red snapper, particularly vermilion snapper and red grouper (Table 3). Red snapper fishermen increasingly targetted these latter species after the adoption of the IFQ program [20]. Unadjusted MFP in the Red Snapper IFQ program was above the pre-catch share based in the first year of implemetation and remained above the pre-catch share base through 2012 with only small changes in productivity over time.

Estimated MFP for more recently impemented catch share programs that include a pre-catch share base are reported in Table 4. Of these catch share programs, unadjusted and biomass adjusted MFP was above the pre-catch share base in every year in the Genercal Category Scallop IFQ, Mid-Atlantic Tilefsh IFQ, and in the Non-whiting IFQ fishery. Both unadjusted and biomass adjusted MFP were above the pre-catch share base in both 2010 and 2011 in the Northeast Multispecies Sector program but below the pre-catch share base in 2012.

In both the Shoreside Whiting IFQ and the Alaska Bering Sea Freezer Longline Cooperative catch share fisheries unadjusted MFP was above the pre-catch share base. However, taking biomass into account yields a different perspective as biomass adjusted MFP in the Shoreside Whiting IFQ fishery was barely above the pre-catch share based in 2011 and was 36% below the base in 2012. In the Alaska Bering Sea Freezer Longline Cooperative fishery biomass

[8] The years 1999, 2001, and 2004 were used to be consistent with the baseline years selected by the North Pacific Fishery Management Council's for the BSAI Crab Rationalization five-year program review. These years were selected to represent a wide-ranging set of conditions in the fishery prior to rationalization.

Table 4
Annual unadjusted and biomass adjusted multi-factor productivity for catch share fisheries with a pre-catch share base that were implemented after 2010.

Year	General Category Scallop IFQ		Mid-Atlantic Golden Tilefish IFQ		Northeast Multispecies Sectors		Alaska Bering Sea Freezer Long-line Cooperative		GOM Grouper-Tile-fish IFQ
	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjus-ted MFP	Unadjusted MFP
Base	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	1.27	1.21	1.63	1.56	1.12	1.24	1.00	0.88	1.11
2011	1.58	1.54	2.08	1.79	1.07	1.26	1.16	0.76	1.30
2012	1.63	1.57	2.12	1.75	0.88	0.97	1.22	0.74	1.35

	Non-whiting IFQ		Shoreside Whiting IFQ	
Year	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP
Base	1.00	1.00	1.00	1.00
2011	1.27	1.32	1.52	1.02
2012	1.19	1.29	1.24	0.64

adjusted MFP was 18% below the pre-catch share base in 2010; a gap that increased to 24% in 2011 and to 26% in 2012.

In the case of the Gulf of Mexico Grouper-Tilefish IFQ program, recent stock assessments were lacking on some of the key species under this program such as red grouper and gag as well as some of the jointly-caught species such as vermilion snapper so unadjusted MFP estimates are reported (Table 4). Unadjusted MFP was 11% above the pre-catch share base in 2010, the first year of program implementation. Unadjusted MFP increased in both 2011 and 2012 and was 35% above the pre-catch share base.

There were seven catch share fisheries where data collection needed to estimate productivity was not initiated until after the catch share program had begun so a pre-catch share base could not be constructed. In these cases the first year where data was available was used as the base. These fisheries include five where the base year was either 2007 or 2008 (Table 5) as well as the Alaska Sablefish IFQ Catcher Processor fishery with a base year of 1995 (Table 6) and the Pacific Sablefish Permit Stacking program with a 2003 base year (Table 6). Productivity change for these fisheries exhibits mixed results. In only the Amendment 80 (Table 5) and the West Coast Sablefish Permit Stacking programs (Table 6) were biomass adjusted MFP above the base year in all years. By contrast, biomass adjusted MFP was below the base year in every year for both the Alaska Sablefish IFQ Catcher Vessel (CV) and the Alaska AFA CV catch share fisheries (Table 5). In the Alaska Rockfish Program CV fishery biomass adjusted MFP was above its 2007 base year in 2008 then was below the base year in both 2009 and 2010 before rising above the base year in both 2011 and 2012 (Table 5).

In the Alaska Sablefish IFQ CP fishery biomass adjusted MFP has undergone a couple of periods of increasing and decreasing productivity change (Table 6). Biomass adjusted MFP was above the 1995 base from 1996 to 2001 but was either below the 1995 base or just above the base over the next three years. From 2005 to 2007 biomass adjusted MFP improved ranging from 24% to 35% above the 1995 base then declined 28% below the 1995 base in 2008. Productivity was close to base year levels in 2009 and 2010.

Table 6
Annual unadjusted and biomass adjusted multi-factor productivity for Alaska sablefish and Sablefish Permit Stacking Programs

Year	Alaska Sablefish IFQ Catcher/ Processors		West Coast Sablefish Permit Stacking	
	Unadjusted MFP	Biomass Adjus-ted MFP	Unadjusted MFP	Biomass Adjus-ted MFP
1995	1.00	1.00		
1996	1.33	1.43		
1997	1.25	1.37		
1998	1.62	1.88		
1999	1.10	1.22		
2000	1.24	1.32		
2001	1.15	1.21		
2002	1.00	0.94		
2003	1.16	1.07	1.00	1.00
2004	1.20	1.09	1.24	1.26
2005	1.33	1.24		
2006	1.42	1.35		
2007	1.29	1.27	1.49	1.74
2008	0.71	0.72	0.95	1.18
2009	1.00	1.04	1.46	1.90
2010	0.95	0.99	1.69	2.32
2011	1.10	1.19		
2012	1.50	1.65		

Table 5
Annual unadjusted and biomass adjusted multi-factor productivity for catch share fisheries with no pre-catch share base

Year	Alaska Rockfish Program Catcher Vessels		Alaska Sablefish IFQ Catcher Vessels		Alaska AFA Catcher Vessels		Amendment 80		Alaska Halibut IFQ	
	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP	Unadjusted MFP	Biomass Adjusted MFP
2007	1.00	1.00	1.00	1.00	1.00	1.00				
2008	1.09	1.09	0.91	0.94	0.79	0.98	1.00	1.00	1.00	1.00
2009	0.77	0.77	0.84	0.89	0.70	0.69	1.07	1.10	0.90	1.01
2010	0.93	0.92	0.84	0.90	0.77	0.79	1.11	1.19	0.85	1.02
2011	1.32	1.27	0.80	0.88	1.07	0.82	1.16	1.25	0.76	0.99
2012	1.24	1.26	0.78	0.88	0.96	0.73	1.19	1.32	0.69	0.88

Since 2010, biomass adjusted MFP improved in both 2011 (19% above the 1995 base) and to 65% above the 1995 base in 2012.

5. Discussion and conclusions

This paper provides the first comprehensive estimate of productivity change in U.S. catch share fisheries. In all, annual MFP was estimated for a total of 20 catch share programs or subcomponents of catch share programs using a base period Lowe index. There is an expectation that catch share programs will, among other things, lead to improved productivity at a fleet level through retirement of redundant capital, more efficient use of retained capital and other inputs, and through quota transfers from less efficient to more efficient vessels. Evaluating this expectation requires the time period selected for the base to include years before and after catch share program implementation, which is the case for 13 of the 20 catch share fisheries included herein. Several of the 13 programs have been operating for 10 or more years, while others have been more recently implemented. Therefore, productivity change was evaluated for the first three years (two years for both Shoreside Whiting and Non-whiting IFQ programs) for all 13 fisheries and was evaluated over the longer term for the six programs that were implemented in 2007 or earlier. With the exception of the Gulf of Mexico Red Snapper and Grouper-Tilefish IFQ programs, this evaluation was based on biomass adjusted MFP. MFP was above pre-catch share levels in each of the first three years in six fisheries and was above pre-catch share levels in each of the first two years for the Non-whiting IFQ program (Table 7). In the Shoreside Whiting IFQ, biomass was substantially above baseline levels in 2011 and 2012 resulting in a two-year average MFP of 0.83, which is 17% lower than the baseline. In only the Bering Sea Freezer Longline fishery was MFP below baseline levels in all three years, although MFP was below the pre-catch share baseline in years two and three in the CP subcomponent of the Central GOA Rockfish program.

Over the longer term, MFP has remained above the pre-catch share time period baseline in the Surfclam ITQ, the CP Sub-component of the AFA Pollock Cooperatives, and the GOM Red Snapper IFQ program (Table 8). Furthermore, MFP was above pre-catch share time period baseline levels in the Ocean Quahog IFQ for 19 of 23 years and in 7 of 8 years for the BSAI Crab IFQ program. In the CP sub-component of the Central Gulf of Alaska Rockfish program MFP was above the baseline for 3 years and below the baseline for 3 years. In all cases, average MFP after the first 3 years of program implementation was higher than average MFP during the first 3 years.

Table 7
Multi-factor productivity for first three years of catch share program implementation

Program	Year 1	Year 2	Year 3	Three-Year Average
Mid-Atlantic Ocean Quahog ITQ	0.92	0.94	1.03	0.96
Mid-Atlantic Surfclam ITQ	1.34	1.50	1.65	1.50
Atlantic Sea Scallops General Category IFQ	1.21	1.54	1.57	1.44
Mid-Atlantic Golden Tilefish IFQ	1.56	1.79	1.75	1.70
Northeast Multispecies Sectors	1.24	1.26	0.97	1.16
GOM Red Snapper IFQ[a]	1.04	1.15	1.16	1.12
GOM Grouper-Tilefish IFQ[a]	1.11	1.30	1.35	1.25
Non-whiting IFQ	1.32	1.29		1.31
Shoreside Whiting IFQ	1.02	0.64		0.83
AFA Pollock CP	1.14	1.76	2.06	1.65
BSAI Crab IFQ	0.78	1.16	1.35	1.10
Central GOA Rockfish CP	1.39	0.89	0.69	0.99
Bering Sea Freezer Longliners	0.88	0.76	0.74	0.79

[a] Unadjusted MFP, MFP for all other programs are biomass adjusted.

Table 8
Multi-factor productivity for catch share programs implemented prior to 2008.

Program	Start Year	Years MFP Above Baseline	Years MFP Below Baseline	Mean MFP for First 3 Years	Mean MFP After 3 Years
Ocean Quahog ITQ	1990	19	4	0.96	1.34
Surfclam ITQ	1990	23	0	1.50	2.19
GOM Red Snapper IFQ[a]	2007	6	0	1.12	1.14
AFA Pollock CP	1999	14	0	1.66	2.99
BSAI Crab IFQ	2005	7	1	1.10	1.52
Central GOA Rockfish CP	2007	3	3	0.99	1.44

[a] Unadjusted MFP, MFP for all other programs are biomass adjusted.

In all but three of the 13 fisheries reported in Tables 7 and 8, MFP improved or was improving during the first three years after program implementation. In the three instances where MFP had declined relative to the baseline during the first three years, the common denominator was a substantial increase in biomass resulting in changes in catchability that offset any changes that may have been made in the ratio of outputs to inputs used to harvest fish. For programs that have been in existence since at least 2007, productivity gains during the first three years were positive, and more often than not, MFP continued to improve after the first three years of program implementation.

The shorter and longer term inferences about productivity change in catch share fisheries need to be considered in context. Estimated productivity change under pre- and post-catch share conditions may be affected by differences in input data among programs, and in the case of the GOM Red Snapper and GOM Grouper-Tilefish IFQ programs, the lack of available biomass data. The former may affect estimated productivity change particularly for inputs that are not used in fixed proportions, while omitting biomass data creates uncertainty over the “true” change in MFP.

The KLEMS-Y approach was selected as the most complete measure of MFP while recognizing that data would not be available to support full implementation. In about half of the fisheries MFP estimates were based only on capital and labor. Evaluation of the potential contribution of having additional data on energy and materials showed that in four of the five fisheries where these inputs were included the contribution of energy to MFP exceeded that of materials [16]. This suggests that new data collection or new methods to estimate fuel use may be a priority in improving estimation of MFP in future studies. Additional research on materials used particularly for catch share fisheries where bait is an important input would also aid in refining future MFP estimates.

The biomass index plays an important role in characterizing changes in MFP. However, obtaining biomass data was a time consuming process, and in some cases, required a stock-by-stock evaluation of the reliability of the biomass information that was available. In most instances, the direction of change between biomass adjusted and biomass unadjusted measures of MFP were consistent [16]. However, the magnitude of the difference between unadjusted and adjusted MFP increases with the magnitude of change in biomass. If the changes in biomass are sufficiently large, then biomass unadjusted MFP may provide a false impression of the change in productivity. This means that obtaining reliable biomass data will be important in any future updates to MFP in catch share fisheries conducted by NOAA Fisheries.

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References

[1] Comitini S, Huang DS. A study of production and factor shares in the halibut fishing industry. J. Polit. Econ. 1967;75(4):366–72.
[2] V.J. Norton M.M. Miller E. Kenney Indexing the Economic Health of the U.S. Fishing Industry's Harvesting Sector. NOAA Technical Memorandum NMFS-F/NEC-40 U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Science Center. Woods Hole, Massachusetts 1985.
[3] D. Squires Index Numbers and Productivity Measurement in Multispecies Fisheries: An application to the Pacific Coast Trawl Fleet. NOAA Technical Report NMFS 67. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA 1988.
[4] Squires D. Productivity measurement in common property resource industries: an application to the Pacific coast trawl fishery. RAND J. Econ. 1992;23(2):221–36.
[5] Weninger Q. An analysis of the efficient production frontier in the fishery: implications for enhanced fisheries management. Appl. Econ. 2001;33(1):71–9. http://dx.doi.org/10.1080/00036840122937.
[6] Walden JB, Kirkley JE, Färe R, Logan P. Productivity change under an individual transferable quota management system. Am. J. Agric. Econ. 2012;94(4):913–28.
[7] Jin Di, Thunberg E, Kite-Powell H, Blake K. Total factor productivity change in the New England groundfish fishery: 1964–1993. J. Environ. Econ. Manag. 2002;44(3):540–56.
[8] Felthoven RG, Paul CJM. Directions for productivity measurement in fisheries. Mar. Policy 2004;28(2):161–9.
[9] Fox KJ, Grafton RQ, Kompas T, Che TN. Capacity Reduction, quota trading and productivity: the case of a fishery. Aust. J. Agric. Resour. Econ. 2006;50(2):189–206.
[10] Hannesson R. Growth accounting in a fishery. J. Environ. Econ. Manag. 2007;53(3):364–76.
[11] Squires D, Reid C, Jeon Y. Productivity growth in natural resource industries and the environment: an application to the Korean tuna purse-seine fleet in the Pacific Ocean. Int. Econ. J. 2008;22(1):81–93.
[12] Felthoven RG, Paul CJM, Torres M. Measuring productivity and its components for fisheries: the case of the Alaskan pollock fishery, 1994–2003. Nat. Resour. Model. 2009;22(1):105–36.
[13] Eggert H, Tveterås R. Productivity development in Icelandic, Norwegian and Swedish fisheries. Appl. Econ. 2011;45(6):709–20.
[14] Torres M, Felthoven R. Productivity growth and product choice in catch share fisheries: the case of the Alaska pollock. Mar. Policy 2014;50:280–9.
[15] O'Donnell C. Nonparametric Estimates of the components of productivity and profitability change in U.S. agriculture. Am. J. Agric. Econ. 2012;94(4):873–90.
[16] J. Walden J. Agar R. Felthoven A. Harley S. Kasperski J. Lee T. Lee A. Mamula J. Stephen A. Strelcheck E. Thunberg Productivity Change in U.S. Catch Shares Fisheries. U.S. Dept. of Commer NOAA Technical Memorandum NMFS-F/SPO 146 2014 122.
[17] Balk BM. An assumption-free framework for measuring productivity change. Rev. Income Wealth 2010;56(1):224–56.
[18] Kirkley J, Paul CJM, Cunningham S, Catanzano J. Embodied and disembodied technical change in fisheries: an analysis of the sète trawl fishery, 1985–1999. Environ. Resour. Econ. 2004;29(2):191–217.
[19] Paul CJM, Torres M, Felthoven R. Fishing revenue, productivity and product choice in the Alaskan pollock fishery. Environ. Resour. Econ. 2009;44:457–74.
[20] Agar JJ, Stephen J, Strelcheck A, Diagne A. The Gulf of Mexico red snapper IFQ program: the first five years. Mar. Resour. Econ. 2014;29(2):177–98.