# Do IFQs in the US Atlantic Sea Scallop Fishery Impact Price and Size?

Greg Ardini and Min-Yang Lee, *NOAA Fisheries, Northeast Fisheries Science Center*

**ABSTRACT**

Management of the "General Category" component of the US Atlantic sea scallop (*Placopecten magellanicus*) fishery changed from open access with a soft, or target, catch limit, to limited access with a hard catch limit, to individual fishing quotas (IFQs) in just three years. Two differences-in-differences (DiD) models are used to examine the causal effects of management on price and revenue. A hedonic price model finds that the IFQ program had minimal direct effects on prices. A landings composition model finds that the IFQ program increased landings of the largest scallops. The Limited Access fleet, which lands most of the scallops in the region and is managed primarily with input controls, serves as a control for both models. Our policy simulation finds that IFQs increased revenues by 2.6% compared to hard catch limits. However, the IFQ program did not increase revenues relative to the regulated open-access system.

**Key words:** Atlantic sea scallop, differences-in-differences, individual fishing quotas.
**JEL Codes:** Q22, Q58, D40.

## INTRODUCTION

Individual fishing quotas (IFQs) are generally thought to increase ex-vessel prices by ending the "race to fish" and changing the structure of the output market (Squires, Kirkley, and Tisdell 1995; Grafton 1996; Homans and Wilen 1997, 2005).[1] Market gluts caused by derby fishing can also result in diversion of high-quality (fresh) products into a low-quality (frozen) market (Homans and Wilen 2005). Ex-vessel prices increased following the implementation of individual quotas in many fisheries (Gauvin et al. 1994; Casey et al. 1995; Herrmann 1996; Tveteras, Paredes, and Peña-Torres 2011; Brinson and Thunberg 2016). We use two differences-in-differences (DiD) models (Ashenfelter and Card 1985; Card and Krueger 1994) to examine the effects of the US Atlantic sea scallop (*Placopecten magellanicus*) IFQ program on output prices, product attributes,

**Greg Ardini** is an economist, NOAA Fisheries, Northeast Fisheries Science Center, 166 Water St. MB 19, Woods Hole, MA 02543 USA (email: Gregory.Ardini@noaa.gov). **Min-Yang Lee** is an economist, NOAA Fisheries, Northeast Fisheries Science Center, 166 Water St. MB 19, Woods Hole, MA 02543 USA (email: Min-Yang.Lee@noaa.gov).

The findings and conclusions of this article are those of the authors and do not necessarily reflect the views or opinion of NOAA Fisheries. The authors thank Deirdre Boelke, Travis Ford, Benjamin Galuardi, Demet Haksever, Shannah Jaburek, and Jonathan Peros for answering many questions pertaining to the scallop fishery. We also thank Ayeisha Brinson, Geret DePiper, Dan Georgianna, Dvora Hart, Steven Kasperski, Erin Steiner, Kevin Stokesbury, Eric Thunberg, John Walden, participants at a University of Massachusetts-Dartmouth seminar, the International Pectinid Workshop in Portland, ME, and the journal's reviewers and editor for helpful comments and suggestions.

1. Individual quota allocation programs may have other socioeconomic effects. Economic efficiency gains associated with these programs have been reported in a number of studies (Arnason 2005; Andersen, Andersen, and Frost 2010; Solís, Agar, and del Corral 2015). Walden et al. (2012) do not find sustained productivity gains in the surf clam and ocean quahog individual transferable quota (ITQ) fisheries. Carothers (2013) finds both positive and negative opinions about the US halibut IFQ program among IFQ holders, including negative impacts on communities. As noted by Bromley (2015), other policies can achieve the same economic objectives without the associated distributional impacts on fishing communities.

Received January 1, 2017; Accepted March 12, 2018; Published online May 9, 2018. http://dx.doi.org/10.1086/698199

*Marine Resource Economics*, volume 33, number 3.  0738-1360/2018/3303-0005$10.00

Table 1. Number of Active Vessels by Fishing Year for the LA Fleet and the Three Periods of the IFQ-Qualifying Fleet

| Fleet: | LA | IFQ Qualifiers | | |
|---|---|---|---|---|
| Policy: | – | GC | Transition | IFQ |
| Fishing Year | | | | |
| 2004 | 316 | 145 | | |
| 2005 | 329 | 180 | | |
| 2006 | 339 | 184 | | |
| 2007 | 340 | 165 | | |
| 2008 | 328 | | 205 | |
| 2009 | 335 | | 217 | |
| 2010 | 309 | | | 165 |
| 2011 | 348 | | | 168 |
| 2012 | 348 | | | 156 |
| 2013 | 343 | | | 146 |
| 2014 | 343 | | | 153 |
| 2015 | 346 | | | 154 |

Note: Some LA vessels also qualified for an IFQ permit (see "Scallops and Scallop Management" subsection). These vessels are counted in both the LA column and the relevant IFQ Qualifiers column in a given fishing year if they operated under both permit categories.

and revenues. To examine the direct effect of the IFQ program on prices, we estimate a hedonic DiD (Parmeter and Pope 2009). We pair the results of that price model with a DiD model of the size composition of landings. This allows us to compare fishery value under the IFQ policy with two counterfactuals: regulated open access with "soft" target catch limits, and limited access with "hard" catch limits.[2]

The majority of US Atlantic sea scallops (hereafter scallops) are caught by the Limited Access (LA) fleet, which is managed primarily via limits on days at sea (DAS) and trips to rotationally closed access areas. The other component of the scallop fishery, which undergoes the policy changes we examine, is known as the General Category (GC). From 1994–2007, the GC component of the fishery was managed under regulated open-access, with a "soft" target quota and trip limits. These vessels then experienced two policy changes in rapid succession. During the 2008–2009 "Transition" period, the members of the GC that qualified for an IFQ permit were managed under a limited-access system with quarterly hard total allowable catches (TACs). In 2010, the IFQ program was implemented for these qualifying members; this fleet was allocated approximately 5.5% of the total catch. The brief limited-access period prior to IFQ management and the small fraction of commercial landings managed in the IFQ program are somewhat unusual in US fisheries.[3] Table 1 summarizes the number of active vessels by fleet and fishing year[4] for our period of interest.

From 2004–2007, those vessels in the GC component of the fishery that qualified for an IFQ permit received average prices that were slightly higher than the LA fleet on an annual basis; the

2. A "soft" limit refers to a system in which regulations are calibrated not to exceed a catch target, but the fishery is not closed when that target is exceeded. In contrast, under a "hard" limit, managers close the fishery when the catch limit is reached.

3. Three of the fifteen US catch share programs (mid-Atlantic ocean quahog, Alaska halibut, and Alaska sablefish) examined in Brinson and Thunberg (2016) implemented a catch share program simultaneously with limited access. The remainder implemented limited access well before the catch share program.

4. The scallop fishing year runs from March through February.

GC premium ranged from $0.05–0.44/lb. (0.5–5.8%). IFQ qualifiers that fished during the Transition period received prices that were $0.06/lb. (0.8%) lower than the LA fleet in 2008 and $0.26/lb. (3.6%) lower in 2009. From 2010–2015, IFQ vessels received prices that were higher annually than the LA fleet, with the IFQ price premium ranging from $0.35/lb. (3.0%) in 2013 to $0.76/lb. (8.6%) in 2010. These premia were quite variable on a quarterly basis (figure 1). Since the LA portion of the scallop fishery is concurrently active with the three different policies that IFQ qualifiers operated under, we are able to identify the discrete management effects on prices. A set of very simple DiD price models with alternative specifications of the error component terms provides further motivation for this research. This hedonic model finds modest ($0.30/lb.) discounts for the Transition period and no premium for the IFQ period (table 2), a result for the IFQ policy that differs from the general trends in figure 1.

Casual interpretation of the Qualifier*Transition and Qualifier*IFQ coefficients as the treatment effects of Transition (TAC management) and IFQ management on prices requires some strong assumptions (Blundell and Macurdy 1999; Besley and Case 2000). The simple model presented in table 2 is almost certainly misspecified. Fortunately, we are able to use micro-level data to control for many determinants of scallop ex-vessel prices, including individual size and daily quantity supplies, in a more rigorous hedonic model. By conditioning out these effects, we recover the effects of the policy treatments on price, ceteris paribus. The more rigorous price model finds that the IFQ treatment did not have a particularly large direct effect on the price of most scallop size classes. In contrast, the Transition treatment had a fairly strong negative effect on scallop prices for the largest size class. The hedonic price model also shows that larger scallops yield higher prices, especially in the later years of our dataset.

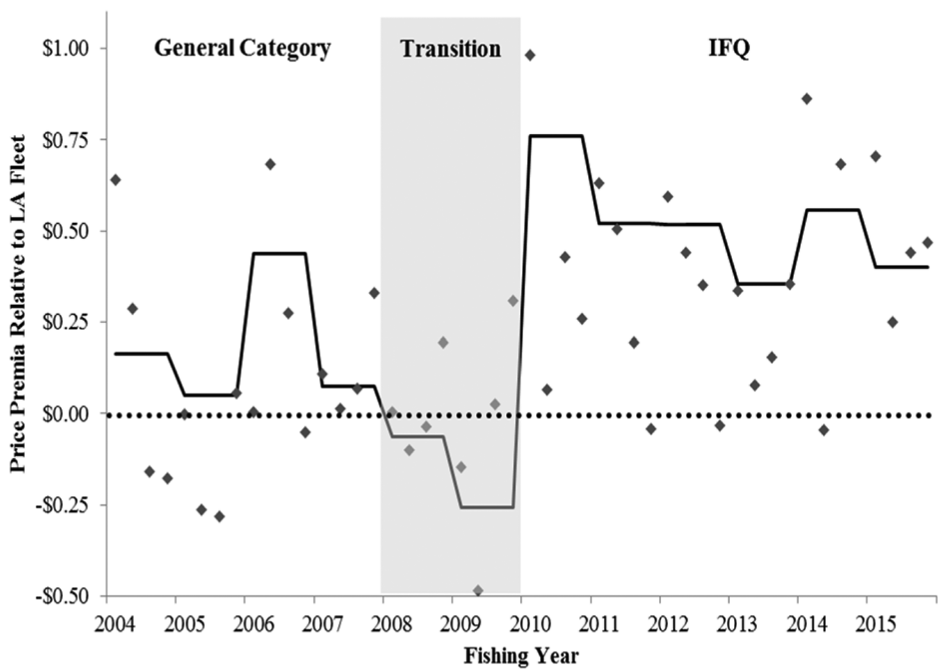



Figure 1. Quarterly (points) and Annual (lines) Average Scallop Ex-Vessel Price Premia (2016 Q1$) for Vessels Operating under the GC, Transition, and IFQ Policies, Relative to the LA fleet

Table 2. Regression Results for Four Naïve Differences-in-Differences Models

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Qualifier | 0.137*** | 0.040*** | 0.067 | 0.036 |
| | (0.053) | (0.026) | (0.081) | (0.082) |
| Qualifier*Transition | –0.257*** | –0.312*** | –0.320*** | –0.279*** |
| | (0.047) | (0.032) | (0.040) | (0.040) |
| Qualifier*IFQ | 0.098* | –0.004 | –0.009 | 0.047 |
| | (0.073) | (0.039) | (0.050) | (0.050) |
| Fixed Effects | None | Vessels | Vessels and Date | Vessels and Dealers |
| $R^2$ | 0.7463 | 0.7933 | 0.8392 | 0.8012 |
| N | 205,054 | 205,054 | 205,054 | 204,978 |

Note: All specifications include controls for Non-Qualifier and Non-Qualifier*Treatment interactions. Specifications (1), (2), and (4) also include dummy variables for Month and Fishing Year. Standard errors below are computed using a wild cluster bootstrap (clustered on vessel) with Rademacher weights with 200 replications.

Of course, all things are not equal. Firms and fishermen[5] could change behavior in response to changes in the management system and market incentives. The premia for large scallops, combined with changing management, could alter targeting behavior. Changes in sorting behavior that lead to more small scallops being discarded is also possible (Anderson 1994; Arnason 1994; Vestergaard 1996; Kristofersson and Rickertsen 2009). Indeed the size composition of scallop landings has varied over time for both the IFQ qualifying fleet and the LA fleet (figure 2), with a general trend towards larger scallops in the IFQ period compared to the Transition and GC periods. Accordingly, we econometrically model size selectivity of landings for all trips, just one of the many ways that fishermen may alter their operations after the implementation of the IFQ program.

Our model of the size-composition of landings finds that the IFQ program caused vessels to land a larger proportion of scallops in the largest, most valuable size class. We combine the results of the price and size models to construct counterfactual fishery value in which just one margin of fishermen behavior, size selectivity, is allowed to change after policy implementation. While we find the IFQ scenario yields an increase in revenue relative to the Transition treatment, there is little change compared to the regulated open-access period (no treatment).

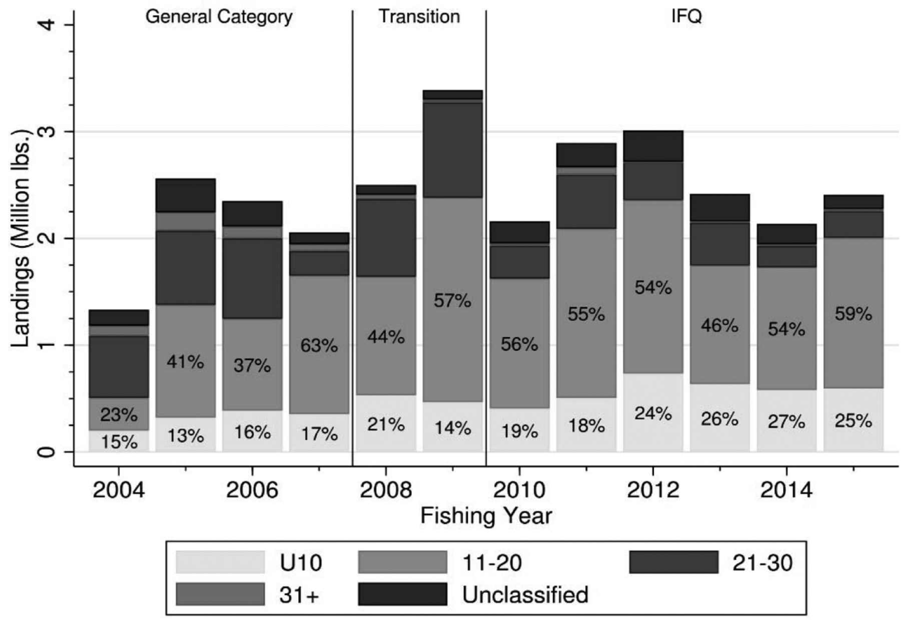
## SCALLOPS AND SCALLOP MANAGEMENT

The sea scallop fishery is currently one of the most valuable commercial fisheries on the US Atlantic coast, with recent ex-vessel value exceeding $400 million per year (NEFMC 2016). Scallops are primarily caught in the waters of Georges Bank, Southern New England, and the Mid-Atlantic Bight with dredge gear, although some vessels use bottom trawls. Virtually all sea scallops are shucked at sea and, in a holdover from the meat-count standards in the original fishery management plan (FMP), are often graded into size classes (based on number of scallops per pound) on the vessel (Georgianna, Lee, and Walden, 2017). Minimal shore-side processing occurs after landing.[6] Individual body size (meat weights) are influenced by spawning patterns and are generally

5. We will refer to "fishermen" rather than "fishers," as most US men and women who fish commercially prefer this designation (Patricia Clay and Lisa Colburn, Anthropologists, Northeast Fisheries Science Center, personal communication with author, February 2018).

6. A small fraction of scallops (<2% by value from 2004–2015) are landed live in shell. We exclude these landings from our analysis because the product market differs from scallop meats.

**(a)**




**(b)**

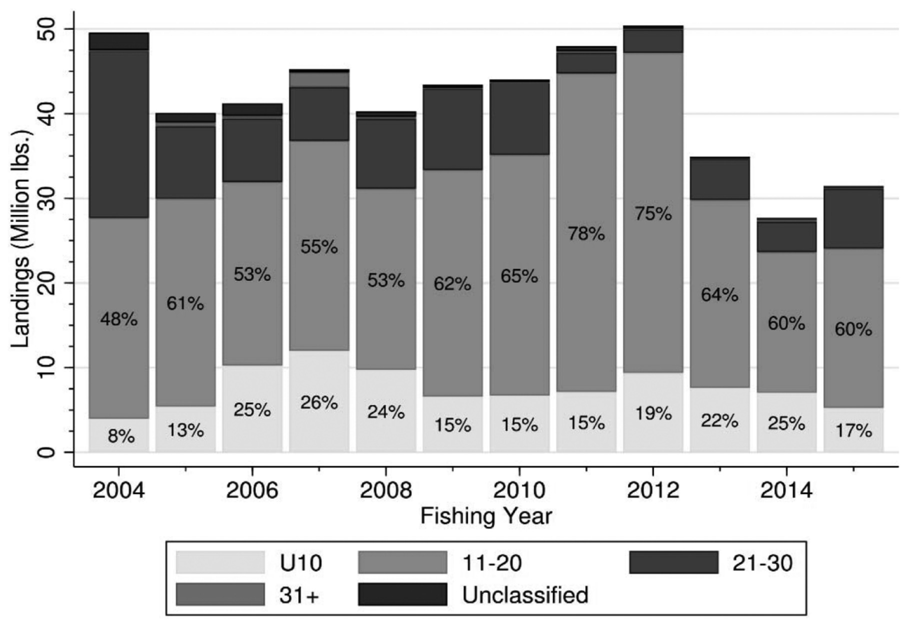



Figure 2. Yearly Landings (millions of pounds) and Size Distribution for Vessels Operating under the GC, Transition, and IFQ Policies (a) and the LA fleet (b).

Note: Percentages for the largest size classes (U10 and 11–20) inside bars. Size classes indicate the number of scallops per pound; large numbers indicate small scallops. Note the difference in scale for the two y-axes.

highest during the late spring and throughout the summer in the mid-Atlantic, and peak in early winter and early summer on Georges Bank (Hennen and Hart 2012). Fishing effort typically is highest in late spring and through summer, though the scallop fishery does operate year-round. The top landing location by volume and value for the scallop fishery is the Whaling City Auction in New Bedford, Massachusetts, with the vast majority of scallops sold at the auction landed by the LA fleet. At the auction site, scallops are offloaded from vessels, size classes are verified, and lots are made available for inspection by prospective buyers prior to the auction being conducted. Other fish auctions in Gloucester, Massachusetts, and Portland, Maine, handle small quantities of scallops as well. In addition to selling at the auctions, vessel owners sell scallops directly to many fish dealers. As of 2011, there were 161 seafood dealers purchasing scallops directly from vessels along the Atlantic coast from Maine to North Carolina (NEFMC 2013). As with most ex-vessel fish markets, it is reasonable to think that the quantity supplied and attributes are determined before price. From the initial buyer, product destination is highly varied. In addition to domestic demand, there are markets for US Atlantic sea scallops in Europe and Asia (Smolowitz 2016).

Since 1982, the fishery has been managed by the New England Fishery Management Council (NEFMC) under the sea scallop FMP. The scallop fishery was entirely open access and primarily regulated with a minimum size (meat count) standard until 1994. At this time, limited access was implemented through Amendment 4 to the FMP over concerns of the sustainability of the scallop resource.[7] Vessels that did not qualify for a LA permit could hold a GC permit, which remained an open-access fishery with a 400-pound trip limit (NEFMC 1993).

Spatial management has been an important component of the scallop fishery since the mid-1990s, when parts of Georges Bank and Southern New England were closed to bottom-tending gear to rebuild depleted groundfish stocks. Sizable amounts of large scallops were later found in some of these closed areas and, beginning in 1999, the LA fleet was allowed to fish in a portion of the closed areas (64 *Federal Register* 31144–51 [NOAA 1999]; 65 *Federal Register* 37903–17 [NOAA 2000]). The ad-hoc spatial management system eventually expanded to the mid-Atlantic. In 2004, Amendment 10 to the sea scallop FMP formalized a management system under which areas with a large abundance of small scallops are closed temporarily to allow the scallops to grow. This system addresses the "growth overfishing" problem, in which fish are caught when they are smaller than the optimal size (Diekert 2012), and the results have been biologically successful (Hart and Rago 2006). LA vessels are allocated trips, with a possession limit, to these access areas each fishing year, and DAS for use in other regions (known as open areas). LA vessels fishing in open areas are not subject to a possession limit. LA vessels are not allowed to transfer DAS or stack multiple DAS allocations on a single vessel.

By the mid-2000s, fishery managers were concerned that catch by the GC component of the scallop fishery, which was still open access, was increasing. In response, fishery managers considered limited access with quarterly or annual TACs, but ultimately chose an IFQ program (NEFMC 2007; 73 *Federal Register* 20089–133 [NOAA 2008]). The GC vessels that met qualification criteria of 1,000 pounds of scallop landings during any fishing year from March 1, 2000 through November 1, 2004 (the control date) were eligible for an IFQ permit. IFQ qualifiers first went through

7. To qualify for a limited-access permit, vessels had to have at least one trip with scallop landings greater than 400 pounds in either 1988 or 1989. Vessels under construction on March 2, 1989 or later also could be eligible if scallops were landed shortly after construction completion.

a "Transition" period during the 2008 and 2009 fishing years when they operated under quarterly TACs,[8] and the fleet was allocated 10% of the total catch during this time. IFQ allocations were then implemented in 2010, and the total allocation for qualifiers was set at 5% of the projected annual scallop catch. Leasing of quota was immediately permitted at the start of the IFQ program. Throughout all three management periods for GC vessels, a fleet-level allocation of trips into access areas was designated, and trip limits were identical whether fishing activity occurred in open areas or access areas. The trip limit of 400 pounds for the GC component of the fishery initially remained the same for those who qualified for an IFQ permit, but a modest increase to 600 pounds was later implemented on August 1, 2011.[9]

GC vessels that did not meet the IFQ landings qualification criteria were eligible for a Northern Gulf of Maine (NGOM) (200-pound possession limit in the Northern Gulf of Maine management area) or incidental permit (40-pound possession limit in any area).[10] Lastly, some LA vessels also qualified for an IFQ allocation when Amendment 11 was implemented. These dual-permitted vessels have a separate IFQ allocation (0.5% of the total fishery catch), but cannot lease or transfer their quota.

## POLICY ANALYSIS WITH DIFFERENCES-IN-DIFFERENCES MODELS

Since Ashenfelter and Card's (1985) study of job training and Card and Krueger's (1994) examination of minimum wages, quasi-experimental methods (including DiD, regression discontinuity, and synthetic control) have been frequently used to study the effects of policy changes.[11] These methods have been increasingly popular in evaluating fisheries policy. Smith, Zhang, and Coleman (2006) examine the effects of closures on catch in the Gulf of Mexico. Abbott and Wilen (2010) examine the effects of voluntary information sharing on halibut bycatch rates in the Pacific groundfish fishery. Hsueh (2017) examines effects of catch share implementation on fishing time in the Pacific Northwest. Birkenbach, Kaczan, and Smith (2017) examine the effects of catch share adoption on season length across many US fisheries.

We use two variants of the DiD method: a hedonic model (Rosen 1974) is used to recover the marginal prices of scallop attributes, and a set of fractional probits (Papke and Wooldridge 1996, 2008; Wooldridge 2010a) are used to examine changes in the size composition of landings. We briefly review the generic DiD method and potential complications before describing the specifics of our two models. Generally, $Y_{igt}$ is the outcome for individual $i$ in group $g$ at time $t$, and:

$$Y_{igt} = \beta D_{gt} + Ag + Bt + \alpha X_{igt} + c_i + \varepsilon_{igt}, \tag{1}$$

where $D_{gt}$ is a dummy variable taking on the value of one for the group that experiences policy change in the time periods that policy is active, $A$ and $B$ are sets of group and time effects, $X_{igt}$ are independent controls, and $c_i$ and $\varepsilon_{igt}$ are the individual-specific and idiosyncratic error terms,

8. Vessels that did not qualify could continue fishing while their status was under appeal. Landings from those vessels counted against the quarterly TAC.

9. As part of the "industry-funded" (properly resource-funded) monitoring program, vessels operating under an IFQ permit are allowed to have higher possession limits when carrying an observer on board.

10. Any vessel that possessed a GC permit on November 1, 2004, was eligible for a NGOM permit. Any vessel that possessed a GC permit during any fishing year over the qualification period (March 1, 2000 through November 1, 2004) was eligible for an incidental permit.

11. See Angrist and Pischke (2009) for an overview, Card et al. (2010) for a meta-analysis in the labor market, Parmeter and Pope (2009) for an overview of quasi-experimental methods applied to hedonic property valuation, and Panhans and Singleton (2015) for historical context.

respectively. Blundell and Macurdy (1999) note that the DiD approach is an error components model extensively described by Balestra and Nerlove (1966) and Nerlove (1971).

Under certain conditions, $\beta$ can be interpreted as the average treatment effect of the policy. Particular attention has been paid in this literature to a few issues. First, "endogenous treatment" can arise when there is correlation between $D_{gt}$ and $c_i$ causing pooled ordinary least squares (OLS) to produce bias estimates of $\beta$ (Besley and Case 2000). Fixed-effects estimators are a solution when $T$ is large; correlated random effects (CRE) are an attractive alternative to fixed effects when $T$ is small or if the data-generating process is non-linear (Mundlak 1978; Chamberlain 1980; Wooldridge 2010b). Instrumental variable (IV) methods can also be used. A second potential problem is the assumption of common time trends. Without this assumption, $\beta$ will be unidentified unless there are multiple treatments at different times. Third, conventional standard errors required for statistical inference can be misleading (Bertrand, Duflo, and Mullainathan 2004; Cameron, Gelbach, and Miller 2008). Fourth, the composition of the treatment and control groups must remain stable throughout the time period (Blundell and Macurdy 1999; Besley and Case 2000). This has some implications for the interpretation of the IFQ treatment effect. All qualifying vessels experience the IFQ treatment, though some vessels became inactive in the fishery during the IFQ period, as leasing out quota may be more profitable than fishing. If the inactive qualifiers also systematically received different prices or landed a different quality product, the treatment effect would be confounded by a selection effect. While we can partially mitigate this econometric problem using vessel-level fixed effects, we should be cautious and interpret the treatment coefficients as the average treatment effects on participants that remained active. This effect, in which the most profitable or productive participants remain active, is a well-known property of IFQs (Arnason 2005; Dupont et al. 2005; Sharp and Batstone 2008; Färe, Grosskopf, and Walden 2015).

## DATA

All entities that purchase scallops from federally permitted fishing vessels are required to obtain a federal dealer permit and submit reports to the National Marine Fisheries Service (NMFS). These reports contain data necessary for fisheries management, including quantity, value, and size class for all purchases. We use 12 years (2004–2015) of dealer data on all purchases of scallop meats from vessels (sellers) and use the sale date, state where the sale occurred, species, size class, quantity, and value directly in our model.[12] The price per pound of scallops was normalized to 2016 Q1 using the GDP implicit price deflator. Dealers must also report the permit number of the fishing vessel and a vessel trip report (VTR) serial number. These two fields were used to gather information about fishing vessels and fishing trips contained in other NMFS databases.

VTR serial numbers were used to extract fishing location, trip length, and gear fished information for each sale of scallops. Fishing location was thought to be important because scallops from the mid-Atlantic often receive lower prices, possibly because of higher water content.[13] We use trip length as an indicator of product freshness. The permit number of each vessel was used to extract the category of scallop permit(s) held by that vessel. Some vessels held multiple scallop permits in

12. 2004 was the first year that dealers were required to report electronically. This greatly increased the quality of the data, particularly the vessel trip report serial number field, which is critically important for matching to fishing trip attributes.

13. Dan Georgianna, Chancellor Professor Emeritus, University of Massachusetts-Dartmouth, School of Marine Science and Technology, personal communication with author, March, 2016.

a fishing year; for these vessels we compared landings for each trip to the relevant possession limits and assigned each trip into the appropriate permit category.[14]

Based on the scallop permit categories, we assigned our observations into three mutually exclusive groups. The first group in our model consists of the landings by the LA fleet, which does not undergo any distinct management changes based on policy treatments; this group is the baseline in our model. The second group consists of landings by vessels that qualified for IFQs, and is denoted by the variable "Qualifier" in our model. These vessels were part of the open-access GC fishery in our untreated period and were managed under fleet-wide quarterly quotas during our first treatment period (denoted "Qualifier*Transition"). They were then managed by IFQs in our second treatment period (denoted "Qualifier*IFQ"). Hereafter, we generally refer to this group of vessels as the "qualifying fleet" when comparing the untreated period to the two treatment periods. When comparing this group of vessels across all periods to the LA fleet, we generally refer to them as the "IFQ-treated fleet." The third group consists of landings by GC vessels that did not qualify for IFQs (the Non-Qualifier fleet) and are referred to as "Non-Qualifier" in our model. During the untreated period, these vessels were under the same regulations as those in the "Qualifier" group. During the two treatment periods, these vessels were part of the NGOM and incidental fisheries, though many in the "Non-Qualifier" group stopped fishing for scallops in 2008 and later. We chose to report minimally on the "Non-Qualifier" results (see the online-only Appendix), as comparing them to the "Qualifier*Transition" and "Qualifier*IFQ" results is not particularly meaningful.

Our initial dataset contains 208,070 observations; however, some data cleaning was necessary to remove observations with prices we deemed unrealistically low (below $2.00/lb.) or high (above $25.00/lb.). Additionally, we dropped 2,869 observations corresponding to non-qualifying vessels that were fishing under an appeal they eventually lost.[15] Our final dataset used to estimate the hedonic model contains 205,054 sales transactions, representing 535M pounds (98.6% of all scallop meat sales) over the 12-year period.

From preliminary model results, a few sets of categorical variables were classified together based on t-tests. A few landing states were aggregated: Maine (ME) and New Hampshire (NH), Connecticut (CT) and Rhode Island (RI), and Delaware (DE) with all states located further south (Maryland, Virginia, and North Carolina). Massachusetts (MA), New Jersey (NJ), and New York (NY) were not aggregated with other states. We constructed three day-of-week variables: Saturday and Sunday, Tuesday through Friday, and Monday. Lastly, because of sparse observations in the 41–50, 51–60, and 60+ size classes, these classifications were aggregated with the 31–40 size class to create a 31+ class. For trip length, preliminary specifications indicated that the first 24 hours of a trip did not significantly affect prices. Therefore, trip length was recoded so that all trips under 24 hours were considered one day in length. We normalized latitude by subtracting 35°, which sets the baseline at the southern edge of the sea scallop range. Latitude of fishing is highly correlated with longitude; one exception is the area east of Cape Cod, MA, where fishing at approximately 41°N latitude can occur in both the nearshore and offshore areas of Georges Bank. We allowed

14. While this is an imperfect way to classify trips, our results are robust to moderate changes to this criteria.

15. During the Transition period, vessels appealing a denial of an IFQ permit were allowed to fish as if they were a qualifier. Vessels that lost their appeal do not fit neatly into the "Qualifier" or "Non-Qualifier" groups. During the Transition period, they would have been subject to the same incentives as the IFQ qualifiers; however, during the IFQ period, they did not hold an IFQ permit.

for the possibility that prices would vary across these areas by including a dummy variable for nearshore Massachusetts.[16]

Table 3 summarizes the distribution of observations by group (fleet) and treatment policy for all categorical variables in the model. Our three continuous independent variables are trip length, latitude (mean 4.92 degrees, std. dev 1.22), and daily landings (mean = 170,000 pounds, std. dev. = 122,000). Trip length values, which indicate days spent at sea beyond 24 hours, are much higher for the LA fleet (mean = 6.28, std. dev. = 4.04), compared to the other two groups (mean = 0.22, std. dev. = 0.86).

The hedonic dataset was modified slightly to estimate the size composition model. We aggregated to the trip-level and computed the fraction of landings in each size class as our dependent variable. Location data was used to determine whether a vessel was fishing in an access or open area. The number of years that an access area was open was extracted from the *Federal Register*. We top-coded the number of years at three. For each trip, we use a dealer identification number to construct a dealer effect that is the fraction of purchases in the appropriate size class computed across the entire time series. Finally, we dropped the 55 observations corresponding to trips in which a vessel was observed only one time in our dataset. There are 144,913 observations used to estimate the size composition model (table 4).

## A MODEL OF PRICES

In our price model, we are primarily interested in two effects. First, the direct effect of the catch share program, which was implemented in two phases on a subset of the scallop fishery. Second, the effects of the subset of $X$ on prices that might be useful for fisheries managers to understand how regulations affect prices, and therefore, revenues. To accurately estimate management effects on ex-vessel prices, we control for many of the factors known to be important from other fish price models, including individual size, fishing gear, trip length, and buyer or seller effects (McConnell and Strand 2000; Asche and Guillen 2012; Asche et al. 2012; Ishimura and Bailey 2013; Lee 2014; Asche, Chen, and Smith 2015; Guillen and Maynou 2015; Hammarlund 2015; Gobillon, Wolff, and Guillotreau 2016; Lesur-Irichabeau et al. 2016). We also control for fishing location, landing location, (endogenous) quantity supplied, and time of landing by day-of-week, month, and year.

Our estimating equation modifies equation (1) to:

$$\begin{aligned} p_{igt} = {} & A_1 Qualifier_i + A_2 NonQualifier_i + \beta_1 Qualifier_i * Transition_t \\ & + \beta_2 Qualifier_i * IFQ_t + \beta_3 NonQualifier_i * Transition_t \\ & + \beta_4 NonQualifier_i * NGOM\ \ Incid_t \\ & + \sum_{m=1}^{11} B_m Year_t + \alpha X_{it} + c_i + e_{it}\,. \end{aligned} \tag{2}$$

Our preferred specification includes categorical variables for size (4 variables), month (11), interactions between size and Qualifier (4), size and Non-Qualifier (4), size and fishing year (44), size and DiD treatment dummies (16), landing state (5), trawl gear, and fishing in the nearshore

16. A few independent variables in our price model are highly correlated. One example is trawl gear, which is almost exclusively confined to the Qualifier and Non-Qualifier groups. Very few trawl trips are taken by the LA fleet.

Table 3. Composition of Observations in Percentages by Fleet and Policy Across Categorical Variables

| Fleet: | LA | Qualifier | | | Non-Qualifier | | |
|---|---|---|---|---|---|---|---|
| Policy: | – | GC (Pre-Treatment) | Transition | IFQ | GC (Pre-Treatment) | NGOM & Incidental I | NGOM & Incidental II |
| *Size* | | | | | | | |
| U10 | 27.0 | 23.0 | 24.9 | 28.4 | 14.8 | 21.5 | 14.9 |
| 11–20 | 50.0 | 41.0 | 45.7 | 49.8 | 40.2 | 30.6 | 41.6 |
| 21–30 | 19.7 | 24.4 | 25.6 | 12.8 | 23.4 | 17.5 | 12.8 |
| 31+ | 1.7 | 4.1 | 1.1 | 1.1 | 8.0 | 14.9 | 4.2 |
| Unclassified | 1.6 | 7.6 | 2.8 | 7.9 | 13.7 | 15.5 | 26.5 |
| *Fishing Gear* | | | | | | | |
| Dredge | 98.9 | 82.8 | 83.4 | 88.4 | 75.4 | 60.4 | 78.4 |
| Trawl | 1.1 | 17.2 | 16.6 | 11.6 | 24.6 | 39.6 | 21.6 |
| *Fishing Area* | | | | | | | |
| Nearshore MA | 16.7 | 6.5 | 3.5 | 14.9 | 10.7 | 3.2 | 2.7 |
| Other Areas | 83.3 | 93.5 | 96.5 | 85.1 | 89.3 | 96.8 | 97.3 |
| *State* | | | | | | | |
| CT/RI | 3.2 | 3.3 | 3.3 | 4.2 | 2.9 | 14.0 | 7.6 |
| DE/South | 14.9 | 16.1 | 9.9 | 4.0 | 22.3 | 30.1 | 2.1 |
| MA | 47.7 | 14.3 | 9.5 | 28.6 | 19.8 | 13.6 | 21.9 |
| NH/ME | 0.0 | 0.3 | 0.0 | 0.4 | 0.3 | 0.7 | 27.9 |
| NJ | 33.8 | 58.8 | 68.0 | 53.7 | 47.7 | 27.0 | 38.4 |
| NY | 0.4 | 7.3 | 9.3 | 9.0 | 7.0 | 14.6 | 2.1 |
| *Fishing Year* | | | | | | | |
| 2004 | 9.2 | 18.3 | | | 11.9 | | |
| 2005 | 10.2 | 29.6 | | | 34.5 | | |
| 2006 | 9.3 | 26.9 | | | 30.0 | | |
| 2007 | 10.9 | 25.3 | | | 23.6 | | |
| 2008 | 8.4 | | 42.8 | | | 30.2 | |
| 2009 | 9.0 | | 57.2 | | | 69.8 | |
| 2010 | 7.7 | | | 17.2 | | | 9.2 |
| 2011 | 6.7 | | | 17.3 | | | 14.0 |
| 2012 | 7.3 | | | 16.6 | | | 16.9 |
| 2013 | 6.8 | | | 15.5 | | | 22.4 |
| 2014 | 6.4 | | | 15.9 | | | 17.6 |
| 2015 | 8.0 | | | 17.4 | | | 19.9 |
| *Month* | | | | | | | |
| Jan. | 4.4 | 3.9 | 2.9 | 5.3 | 4.0 | 8.1 | 11.0 |
| Feb. | 4.8 | 4.0 | 0.0 | 5.5 | 3.6 | 5.4 | 9.6 |
| Mar. | 8.0 | 6.3 | 14.6 | 6.2 | 6.5 | 8.6 | 10.7 |
| Apr. | 9.7 | 6.9 | 15.7 | 9.8 | 7.3 | 7.5 | 9.1 |
| May | 11.7 | 12.4 | 8.2 | 13.4 | 12.0 | 4.1 | 6.9 |
| Jun. | 12.5 | 14.1 | 22.1 | 13.3 | 14.0 | 6.6 | 7.7 |
| Jul. | 10.8 | 13.8 | 13.4 | 12.9 | 13.2 | 10.0 | 7.3 |
| Aug. | 11.0 | 13.3 | 5.9 | 10.2 | 13.9 | 11.9 | 7.5 |
| Sep. | 8.7 | 10.1 | 9.9 | 7.6 | 9.4 | 12.4 | 7.0 |
| Oct. | 7.0 | 7.2 | 1.0 | 6.2 | 6.5 | 9.4 | 7.1 |
| Nov. | 6.3 | 4.4 | 0.1 | 4.3 | 5.3 | 9.0 | 6.2 |
| Dec. | 5.3 | 3.8 | 6.1 | 5.2 | 4.3 | 7.1 | 9.9 |
| *Day-of-Week* | | | | | | | |
| Sat./Sun. | 15.3 | 21.3 | 24.1 | 23.0 | 22.2 | 17.1 | 16.7 |
| Mon. | 21.3 | 15.7 | 15.9 | 15.2 | 15.7 | 19.9 | 18.6 |
| Tue.–Fri. | 63.4 | 63.0 | 60.0 | 61.8 | 62.1 | 63.0 | 64.7 |
| Observations | 57,152 | 33,884 | 22,748 | 50,340 | 33,175 | 1,020 | 6,735 |

Note: Among the Non-Qualifier fleet, the NGOM and incidental policies did not change from the first treatment period (2008–2009) to the second treatment period (2010–2015).

Table 4. Summary Statistics for Variables used to Estimate the Landings Composition Models

| | Mean | Standard Deviation |
|---|---|---|
| *Dependent Variable: Fraction of a Trip's Landings in Size Class* | | |
| U10 | 0.158 | 0.282 |
| 11–20 | 0.494 | 0.437 |
| 21–30 | 0.215 | 0.389 |
| 31+ | 0.037 | 0.185 |
| Unclassified | 0.096 | 0.293 |
| *Fleet and Policy Treatments* | | |
| Qualifier | 0.505 | 0.500 |
| Qualifier*Transition | 0.103 | 0.305 |
| Qualifier*IFQ | 0.237 | 0.425 |
| Non-Qualifier | 0.242 | 0.428 |
| Non-Qualifier*Transition | 0.007 | 0.082 |
| Non-Qualifier*IFQ | 0.045 | 0.208 |
| LA | 0.253 | 0.435 |
| *Fishing Area and Time Controls* | | |
| CA1 First Year | 0.008 | 0.092 |
| CA1 Second Year | 0.003 | 0.050 |
| CA1 Third Year+ | 0.000 | 0.021 |
| CA2 First Year | 0.005 | 0.072 |
| CA2 Second Year | 0.004 | 0.064 |
| CA2 Third Year+ | 0.007 | 0.083 |
| DMV First Year | 0.011 | 0.104 |
| DMV Second Year | 0.009 | 0.092 |
| DMV Third Year+ | 0.003 | 0.056 |
| NLSAA First Year | 0.012 | 0.108 |
| NLSAA Second Year | 0.005 | 0.069 |
| NLSAA Third Year+ | 0.004 | 0.062 |
| ETAA First Year | 0.024 | 0.152 |
| ETAA Second Year | 0.018 | 0.132 |
| ETAA Third Year+ | 0.021 | 0.144 |
| HC First Year | 0.014 | 0.116 |
| HC Second Year | 0.005 | 0.070 |
| HC Third Year+ | 0.009 | 0.092 |
| Open Area | 0.814 | 0.389 |
| Latitude | 4.928 | 0.132 |
| FY2004 | 0.072 | 0.258 |
| FY2005 | 0.151 | 0.358 |
| FY2006 | 0.132 | 0.338 |
| FY2007 | 0.111 | 0.314 |
| FY2008 | 0.067 | 0.249 |
| FY2009 | 0.084 | 0.278 |
| FY2010 | 0.064 | 0.245 |
| FY2011 | 0.071 | 0.256 |
| FY2012 | 0.069 | 0.253 |
| FY2013 | 0.062 | 0.241 |
| FY2014 | 0.056 | 0.229 |
| FY2015 | 0.063 | 0.242 |
| *Buyer Heterogeneity Controls* | | |
| Dealer's U10 share | 0.179 | 0.136 |
| Dealer's 11–20 share | 0.517 | 0.203 |
| Dealer's 21–30 share | 0.193 | 0.171 |
| Dealer's 31+ share | 0.032 | 0.121 |
| Dealer's Unclassified share | 0.079 | 0.208 |

Note: Dependent variables, latitude, and dealer fractions are continuous; other variables are 0/1 indicators. There are six scallop access areas: Closed Area I (CAI) and Closed Area 2 (CA2) are located east of Cape Cod, MA, primarily on Georges Bank. Nantucket Lightship Access Area (NLSAA) is located southeast of Cape Cod, MA. Delmarva (DMV), Elephant Truck Access Area (ETAA), and Hudson Canyon (HC) are located in the mid-Atlantic, east to southeast of Southern New Jersey.

MA area. The fishing year dummies capture the general increase in scallop prices over the 2004–2015 period. Our model also includes continuous variables for latitude, trip length, interactions of trip length with Qualifier (plus policy treatments) and Non-Qualifier (plus policy treatments), and daily landings. We use fixed effects for vessels and instrument for likely endogenous "daily quantity supplied" with first lags. We suspect that landings may be endogenous. There is likely to be a positive relationship between price shocks and scallop landings.[17] The first-lag of landings seems to be a reasonable instrument: yesterday's quantities are clearly determined prior to today's prices, and temporally correlated fishing conditions are likely to cause temporally correlated daily quantity supplied.

Interacting size class with fishing year allows for the possibility of changes over time in the demand for large and small scallops. Interacting size class with "Qualifier," "Qualifier*Transition," and "Qualifier*IFQ" allows for heterogeneity in the size premia across groups over different policy regimes. The interaction of trip length with group and group*treatment allows for the relative importance of product freshness to vary by fleet and management policy.

As a robustness check, we estimate a model that includes fixed effects for both vessels and dates; the main drawback is that we cannot estimate an elasticity of price with respect to quantity. In a third specification, we include fixed effects for both vessels and dealers.[18] Vessel fixed effects is our method of dealing with potential endogenous treatment. Because we are modeling prices of a good with relatively low transport costs, the assumption of common trends due to a single unified market seems reasonable. We use the wild cluster bootstrap with Rademacher weights to perform inference (Cameron, Gelbach, and Miller 2008).

### A MODEL OF LANDING SIZE COMPOSITION

We estimate a DiD model for the fraction of each trip's landings in each of the five size classes. We chose to model fractions, instead of pounds, because the "common trends" assumption seemed more likely to hold. The LA fleet and IFQ-treated fleet have different possession limits that changed over time, and modeling the right-censoring at varying levels for different fleets over time appeared difficult.

We estimate a variant of equation 1; however, a few major modifications are necessary. First, because our dependent variable is between 0 and 1 (inclusive), a fractional model is warranted (Papke and Wooldridge 1996, 2008). Our dataset is an unbalanced panel (vessels take different numbers of trips); therefore, we employ the CRE method with unobserved heterogeneity (Papke and Wooldridge 2008; Wooldridge 2010b). This method requires strict exogeneity described by Wooldridge (2010a, 146) and an assumption that the individual effects are normally distributed with a mean that is a linear function of time-averaged covariates. Therefore:

$$E\left[y_{igt}|Z_{igt}, c_i\right] = \Phi\left(\alpha Z_{igt} + c_i\right) \tag{3}$$

$$c_i \sim N\left(\psi + \bar{z}_i\xi, \sigma_a^2\right) \tag{4}$$

17. While landings quantities are likely determined before prices are set, it seems reasonable (1) to account for the possibility that this is not true and (2) that an omitted variable (namely expected prices at time $t$ or shocks known to both suppliers and demanders but not known to us) could cause this endogeneity.

18. All hedonic models were estimated in linear form. A Box-Cox transformation suggested a functional form somewhere in between linear and log-log; we elected to estimate a linear model for ease of interpretation. As part of our specification search, we also investigated alternative models including pooled OLS and fewer classes of fixed effects.

$$\bar{z}_i = \frac{1}{T_i}\sum_{t=1}^{T_i} z_{igt}, \tag{5}$$

where $y_{igt}$ is the fraction of a trip's landings taken by vessel $i$ in group $g$ at time $t$ in a particular size class. $\Phi(\cdot)$ is the standard normal cumulative distribution function, and $Z_{igt}$ includes exogenous covariates (including time effects, group effects, DiD dummies, and other controls). Equation (4) is the CRE components. The individual-specific effects are assumed to be normally distributed, conditional on the individual-specific averages of the exogenous covariates. We also allow for heteroscedasticity of the remaining error term. Therefore, we estimate:

$$E\left[y_{igt}|Z_{igt}, c_i\right] = \Phi\left(\frac{\psi + \alpha Z_{igt} + \bar{z}_i \xi}{\exp(\gamma \nu)}\right), \tag{6}$$

where $\nu$ are variables that affect the variance of the error term. Wooldridge (2010b) suggests modeling heteroscedasticity by including dummies for the number of times that a cross-sectional unit is observed. This would not be possible with our panel, as $T_i$ ranges from 1 to over 2,000. Instead, we model the heteroscedasticity in equation 5 as a linear function of the number of trips taken by a vessel. The effects of vessel-level covariates that are constant across the panel cannot be estimated, just like in fixed-effects models. Note that we have, with the exception of some data-cleaning steps, the census of trips by vessels that participate in the federally managed scallop fishery.

To control for features of the spatial management system, we include a set of categorical variables for each access area and the number of years that area was open at the time the trip occurred. This controls for differences in the size structure of the biomass that vessels fish upon. These differences can arise due to spatial heterogeneity in individual growth rates (Hart and Chute 2009) or a combination of natural variability and management decisions. We, therefore, strongly caution against interpreting these effects as evidence that any areas are better or worse at producing large scallops. We include month and year categorical variables, as well as latitude. We also include a control that captures a buyer's propensity to purchase scallops of a particular size class. While estimating a system of five equations would allow cross-equation correlation, we estimate equation by equation.

We deal with potential endogenous treatment using vessel CRE. One of the drivers of the size composition mix is the underlying biomass upon which vessels are fishing. The larger LA vessels are able to access offshore areas that are infeasible for the generally smaller vessels in the IFQ-treated group. However, we include controls for area fished in the model; therefore, common trends seems reasonable. Papke and Wooldridge (2008) use a block bootstrap to perform inference; we employ the (substantially faster) score-based wild cluster bootstrap instead (Kline and Santos 2012; Roodman 2017).

## A (PARTIAL) POLICY ANALYSIS

The hedonic model provides insight into the direct effects of the two policy changes on prices. The size composition model provides insight into the effects of the two policy changes on the landings composition of trips. By combining the two, we can simulate fishery value for the IFQ qualifiers under alternative policies. To do this, we simulate the predicted fraction of landings in each of the five size classes for the 144,913 trips taken by all three groups in our dataset using equation (6) under four policy scenarios: LA, GC, Transition, and IFQ.[19] Because we estimated these five fractional probits separately, the predicted probabilities do not sum to unity. We, therefore, adjust them by dividing by the trip-level sum of predicted probabilities.

We convert the fractions into landings by multiplying the adjusted predictions by total scallop landings on a trip. We multiply these simulated landings with simulated prices corresponding to the appropriate policy scenario using the method described in footnote 19. We report ex-vessel value, aggregated to the fishing year, for the qualifying fleet under the GC, Transition, and IFQ management regimes. This partial policy analysis assumes that vessel operators can only change the relative size composition of landings on a trip; changes in trip-level landings or the timing of trips in reaction to the policy changes are precluded in this analysis.

## RESULTS

### PRICE MODEL

The highly interacted price model can be difficult to interpret directly; the marginal effect of an independent variable on price is a function of other independent variables. We present a subset of estimated coefficients, bootstrap standard errors, and model specification diagnostics in table 5 (see online-only Appendix table 1 for full results). While we focus on our preferred specification, IV model with vessel fixed effects, our findings are quite robust to the choice of model specification. Our preferred model fits well, with high $R^2$ and rejection of both weak and under-identification (Kleibergen and Paap 2006). We omitted one dummy variable per set of categorical variables. Our base is 11–20 count scallops, caught with dredge gear, outside of the nearshore MA area, landed in New Jersey, during March, on Saturday or Sunday, in the 2004 fishing year, by LA vessels, as well as any interactions of these observation characteristics.

The effects of fishery management and scallop size on price are the primary foci and are discussed in detail below. However, the effects of other explanatory variables may also be of interest. As expected, the IV coefficient (–0.255) for landings is more negative than the same-day landings coefficient in our vessel/dealer FE model (–0.098). This is consistent with the underlying motivation for estimating an IV model; there is likely to be a positive relationship between price shocks and fish landings. Our trip length coefficient is negative (–.017), consistent with the idea that a fresher product will fetch a higher price. The coefficient on fishing location latitude (.081) represents a roughly \$0.08/lb. increase for every additional degree north of 35°N, the southern boundary for inclusion in the model (e.g., roughly a \$0.40/lb. premium for scallops caught east of Cape Cod, MA, relative to scallops caught east of Southern Virginia). Scallops caught close to the coast of Massachusetts (Nearshore_MA) also receive an additional premium of \$.08/lb. over those caught at the same latitude but farther offshore on Georges Bank.

In general, the IFQ treatment did not have a particularly strong effect on scallop prices among the five size classes, and a positive effect was estimated for only one size class. For U10 scallops, the IFQ treatment reduced price by \$0.21/lb. Combined with the untreated Qualifier*U10 result (0.379), vessels fishing under an IFQ receive higher U10 prices than the LA fleet. For 11–20 count

19. To simulate the IFQ policy, we set the IFQ variable and IFQ interactions to 1 and set the Transition variable and Transition interactions to zero. To simulate the Transition policy, we set the Transition variable and Transition interactions to 1 and the IFQ variable and IFQ interactions to zero. To simulate the GC policy, we set the IFQ, Transition, and respective interactions to zero. For all other variables, we set them at the observed values.

Table 5. Regression Results for Select Independent Variables (three price models)

| | (1) | (2) | (3) |
|---|---|---|---|
| | 2SLS Vessel FE | Vessel and Day FE | Vessel and Dealer FE |
| *Group*Treatment* | | | |
| Qualifier | –0.089* | –0.063 | –0.093* |
| | (0.064) | (0.063) | (0.066) |
| Qualifier*Transition | –0.194*** | –0.135*** | –0.152*** |
| | (0.039) | (0.033) | (0.038) |
| Qualifier*IFQ | –0.052 | –0.009 | –0.009 |
| | (0.050) | (0.044) | (0.047) |
| *Group*Treatment*Size* | | | |
| Qualifier*U10 | 0.379*** | 0.372*** | 0.412*** |
| | (0.065) | (0.057) | (0.062) |
| Qualifier*21–30 count | –0.037 | 0.002 | –0.063 |
| | (0.048) | (0.041) | (0.052) |
| Qualifier*31+ count | 0.242*** | 0.187*** | 0.084 |
| | (0.109) | (0.083) | (0.130) |
| Qualifier*Unclassified | –0.102 | –0.064 | –0.082 |
| | (0.118) | (0.117) | (0.118) |
| Qualifier*Transition*U10 | –0.475*** | –0.455*** | –0.508*** |
| | (0.071) | (0.061) | (0.068) |
| Qualifier*Transition*21–30 count | 0.204*** | 0.147*** | 0.221*** |
| | (0.055) | (0.047) | (0.057) |
| Qualifier*Transition*31+ count | 0.284** | 0.188* | 0.331*** |
| | (0.140) | (0.112) | (0.144) |
| Qualifier*Transition*Unclassified | 0.163 | 0.177 | –0.013 |
| | (0.187) | (0.161) | (0.202) |
| Qualifier*IFQ*U10 | –0.208*** | –0.184*** | –0.231*** |
| | (0.070) | (0.066) | (0.065) |
| Qualifier*IFQ*21–30 count | 0.144** | 0.071 | 0.129** |
| | (0.072) | (0.062) | (0.065) |
| Qualifier*IFQ*31+ count | –0.292* | –0.155 | –0.230 |
| | (0.221) | (0.176) | (0.221) |
| Qualifier*IFQ*Unclassified | –0.758*** | –0.632*** | –1.053*** |
| | (0.250) | (0.229) | (0.230) |
| ***Size*** | | | |
| U10[a] | 1.060*** | 1.144*** | 1.060*** |
| | (0.069) | (0.067) | (0.076) |
| 21–30 count[a] | –0.377*** | –0.316*** | –0.388*** |
| | (0.034) | (0.031) | (0.035) |
| 31+ count[a] | –0.654*** | –0.650*** | –0.498*** |
| | (0.104) | (0.073) | (0.093) |
| Unclassified[a] | –0.133 | –0.105 | –0.065 |
| | (0.121) | (0.090) | (0.119) |
| *Other Notable Variables* | | | |
| Trip_length[a] | –0.017*** | –0.010*** | –0.019*** |
| | (0.002) | (0.002) | (0.002) |
| Latitude | 0.081*** | 0.064*** | 0.079*** |
| | (0.009) | (0.009) | (0.008) |
| Nearshore_MA | 0.081*** | 0.064** | 0.075*** |
| | (0.032) | (0.028) | (0.024) |
| Landings (100k) | –0.255*** | | –0.098*** |
| | (0.009) | | (0.003) |

Table 5 (*Continued*)

| | (1) | (2) | (3) |
|---|---|---|---|
| | 2SLS Vessel FE | Vessel and Day FE | Vessel and Dealer FE |
| F | 1121.19 | 2700 | 992.63 |
| $R^2$ | 0.8836 | 0.9283 | 0.8929 |
| N | 205,054 | 205,054 | 204,978 |

Note: All specifications include dummies for State, Fishing Area, Day-of-Week, Fishing Year. All specifications include Group*Trip_Length, Group*Treatment*Trip_Length, and Size*Fishing Year interactions.

Standard errors, below, are computed using a wild cluster bootstrap (clustered on vessel) with Rademacher weights with 200 replications.

See online-only Appendix: table 1 for full model results.

[a] Un-interacted-term represents the premium/discount for the LA fleet.

*** $p < .01$ ** $p < .05$ * $p < .10$.

scallops, the size class with the highest landings volume, the IFQ treatment did not result in a statistically significant difference in price. IFQ prices for 11–20 count scallops are also similar to the LA fleet, given the Qualifer coefficient (–0.089) is not highly significant. For 21–30 count scallops, the IFQ treatment had a slightly positive effect (0.144). The largest negative effect from the IFQ treatment was seen for Unclassified scallops (–0.758).

The effects of the Transition treatment were generally negative. The Qualifier*Transition coefficient (–0.194) represents a decrease in the price of 11–20 count scallops from the Transition treatment. This coefficient applies to the other four size classes interacted with Qualifier*Transition. For U10 scallops, the Transition treatment had a rather sharp negative effect on prices of $0.67/lb. (–0.194 – 0.475) relative to the untreated Qualifier results. Relative to the LA fleet, the U10 discount is smaller in magnitude, due to the positive Qualifier*U10 coefficient. For 21–30 count scallops, the Transition treatment (0.204) had a negligible effect when factoring in the Qualifier*Transition coefficient (–0.194). Similarly for 31+ count scallops, the positive coefficient is neutralized by the Qualifier*Transition coefficient.

While we present the size coefficients in table 5, the Group*Treatment*Size interactions can be put into context by looking at the overall per-pound premia by size class relative to 11–20 scallops in each year of our model (figure 3). The premium for U10 scallops has been quite variable over time—under $1.00 in 2005–2008 and around $1.00 in 2011–2013. During 2009–2010 and 2014–2015, however, the premium increased to over $2.00. For 21–30 count scallops, the discount was not particularly large during 2004–2014, generally under $0.50, but increased to nearly $1.00 in 2015. Following a similar trend, the discount for 31+ count scallops was roughly $0.50 to $1.00 from 2004–2013, but was over $2.00 during 2014–2015. Unclassified scallops received a small discount from 2004–2007, but received a premium during 2008–2015. It is not clear why Unclassified prices showed an increasing trend relative to 11–20 scallops over the 12-year period.

Taken altogether, scallop price can be heavily influenced by size. In more recent years, differences in price by size class have generally increased, though the reason is not clear. A shift in consumer preferences towards larger scallops is one possibility. The overall premia/discount by size class are often much larger than the effects of management on a particular size class. The premia for U10 scallops are relatively large, and changes in incentives may allow the treated group greater flexibility to change fishing or culling behavior. For example, during the Transition period vessels were competing with each other for a share of the quarterly quotas. This did not happen during

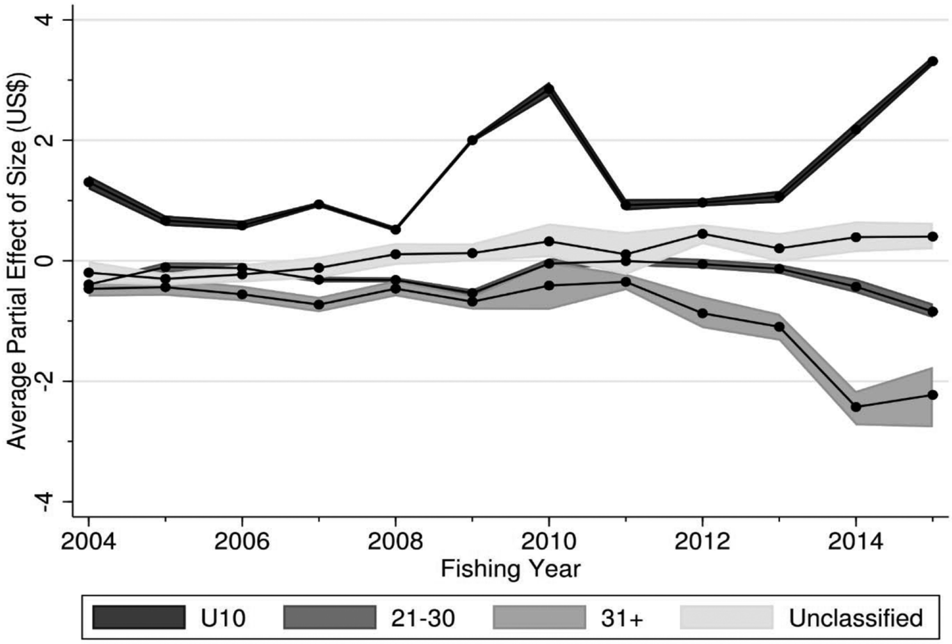



Figure 3. Average Discrete Premia (lines) and 90% Confidence Intervals (ranges) Relative to the 11–20 Scallop Size Class for the other Four Size Classes

the pre-treatment or IFQ-time periods, and the lower costs of both searching and discarding could lead to larger-sized scallops being landed during these times. In all periods, there is likely to be serial depletion in either low-cost or high-valued fishing areas (Valcu and Weninger 2013). Next, we present the effects of management on scallop quantity, by size, in order to more fully evaluate the Transition and IFQ policy treatments.

## SIZE COMPOSITION MODEL

We report only the DiD coefficient results along with diagnostic statistics in table 6; model fit varies a bit across the 5 models. Full results are reported in online-only Appendix table 2, with an alternative specification given in online-only Appendix table 3. The group means that control for unobserved heterogeneity are found to be jointly significant in all models, as is the heteroscedasticity term ($T_i$).[20] The magnitude of compositional change from the Transition and IFQ treatments is not intuitive, but the sign of the coefficients indicates that the IFQ treatment had a positive impact on U10 scallops landed and a negative impact on 21–30 count scallops landed. The IFQ treatment is not statistically significant for the three other size classes (11–20, 31+, and Unclassified). The Transition treatment had a negative impact on U10 scallops landed and a

20. As a robustness check, we also estimated the five size composition models by OLS with fixed effects for dealers and vessels. Many of the coefficients were similar in sign and significance. Although the OLS model is misspecified, we can accommodate vessel- and dealer-level fixed effects in the typical way, and the similarities between the OLS and fractional probit give us additional confidence that the CRE method is capturing some of the unobserved heterogeneity in a reasonable way.

Table 6. Correlated Random Effects (by vessel and dealer) Fractional Probit Results for the Five Size Classes. Differences-in-Differences Effects Only (Coefficients and Bootstrap Z test statistic below).

| Variable | U10–Fraction | 11–20 Fraction | 21–30 Fraction | 31+ Fraction | Unclassified Fraction |
|---|---|---|---|---|---|
| Qualifier | –0.051 | 0.086* | –0.221*** | –0.163* | 0.081 |
| | (–0.615) | (1.806) | (–3.156) | (–1.718) | (0.540) |
| Qualifier*Transition | –0.232*** | 0.233*** | –0.006 | 0.072 | 0.154 |
| | (–2.676) | (3.725) | (–0.084) | (0.601) | (0.935) |
| Qualifier*IFQ | 0.282*** | 0.077 | –0.209** | –0.224 | 0.035 |
| | (3.269) | (1.087) | (–2.156) | (–1.530) | (0.138) |
| Model Diagnostics | | | | | |
| $X^2$ for vessel CREs | 38.49 | 48.87 | 51.58 | 88.05 | 26.11 |
| Log-pseudolikelihood | –47,728 | –81,243 | –56,084 | –10,768 | –15,152 |
| Pseudo $R^2$ | 0.222 | 0.189 | 0.248 | 0.517 | 0.668 |
| Wald $X^2$ | 2,933 | 1,851 | 2,124 | 5,012 | 4,902 |

Note: All specifications include variables for access area-years open, fishing year, month, latitude, and gear. All specifications include vessel level means in the model of vessel-level CRE and dealer fractions to model dealer effects. Z-statistics calculated using the score-based wild cluster bootstrap using Rademacher weights and 5,000 replications (Kline and Santos 2012; Roodman 2017).

See online-only Appendix table 2 for full model results and online-only Appendix table 3 for alternative specification.

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$.

positive impact on 11–20 count scallops landed. The Transition treatment did not produce statistically significant results for the 21–30, 31+, or Unclassified size classes.

The magnitudes of the coefficients are difficult to interpret directly. The partial effect for continuous covariate 1 for the heteroscedastic probit is:

$$\widehat{\alpha_1}\phi\left(\frac{\hat{\psi} + Z_{igt}\hat{\alpha} + \bar{z}_i\hat{\xi}}{\exp(z\hat{\gamma})}\right). \tag{7}$$

The partial effect for discrete covariate $X_2$ is:

$$\Phi(\cdot)|_{X2=1} - \Phi(\cdot)|_{X2=0}, \tag{8}$$

both of which can be averaged over all $NT$ or a subset of $NT$. We plot the adjusted fractions of landings in each size class for the qualifying fleet under each of the three policies aggregated to the fishing year in figure 4. This figure illustrates how the outputs of the fleet changed in response to management changes. Consistent with the direction of the table 6 results, landings by these vessels under a simulated IFQ policy would have more U10s and less 21–30 count scallops compared to landings under simulated pre-treatment (regulated open-access) or Transition policies. The pre-treatment policy results in more U10s and less 21–30 count scallops than the Transition policy as well. The landings proportions for the other three size classes exhibit only minor changes across the three simulated policies.

## SIMULATED PRICES, SIZES, AND REVENUE

Combining the results of our price and size models shows that the IFQ program increased fleet-level revenue by an average of \$0.6 million per year (2.6%) relative to Transition period policies (limited-access with quarterly hard TACs). IFQs outperformed the Transition treatment in each

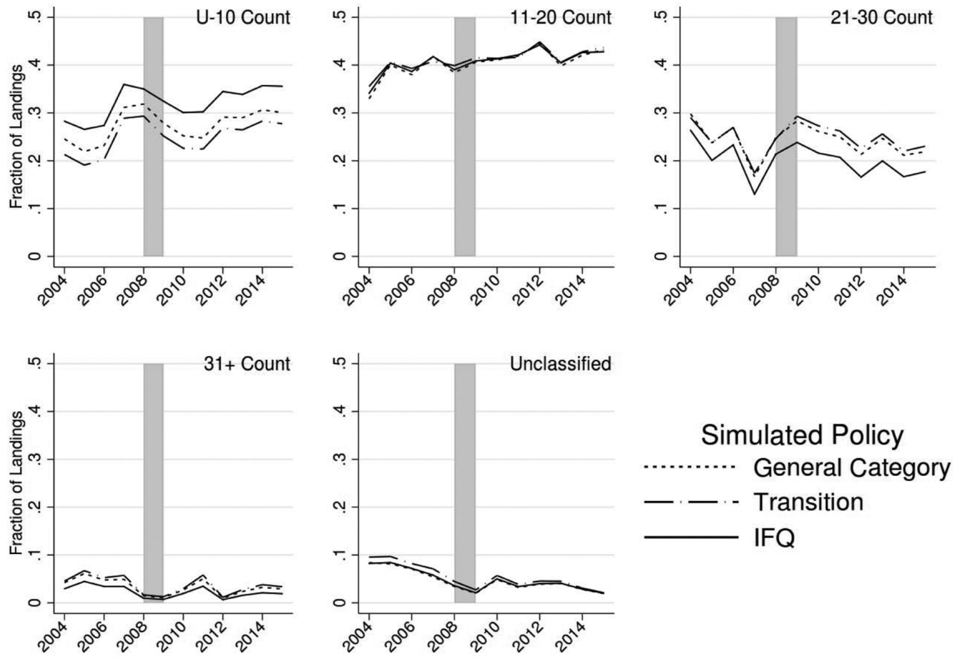



Figure 4. Simulated Annual Fractions for the Five Sizes of Scallop Landings by the Qualifying Fleet

of the 12 years evaluated. The range of yearly revenue increases from IFQs compared to Transition policies was \$0.2 to \$1.2 million. However, IFQs had virtually no effect on fleet-level revenue compared to fishing under regulated open-access (table 7). IFQs resulted in an average annual decrease in revenue of \$0.1 million (0.4%) over the 2004–2015 time period relative to regulated open access. There was minor year-to-year variation, with the largest increase in revenue from IFQs occurring in 2015 (\$0.3 million) and the largest decrease occurring in 2005 (–\$0.3 million).

Table 7. Simulated Revenue (2016 US\$ in millions) for the Qualifying Fleet under Three Policy Scenarios

| Year | GC | Transition | IFQ |
|---|---|---|---|
| 2004 | **8.9** | 8.6 | 8.8 |
| 2005 | **24.0** | 23.5 | 23.7 |
| 2006 | **18.6** | 18.2 | 18.4 |
| 2007 | **15.8** | 15.2 | 15.6 |
| 2008 | 19.9 | **19.2** | 19.8 |
| 2009 | 25.0 | **24.0** | 25.2 |
| 2010 | 21.1 | 20.4 | **21.1** |
| 2011 | 32.6 | 32.0 | **32.5** |
| 2012 | 32.8 | 32.0 | **32.7** |
| 2013 | 29.8 | 29.1 | **29.7** |
| 2014 | 28.2 | 27.5 | **28.3** |
| 2015 | 30.9 | 30.0 | **31.2** |
| Average | 24.0 | 23.3 | 23.9 |

Note: Bold text represents years in which the policy in the column was actually in effect.

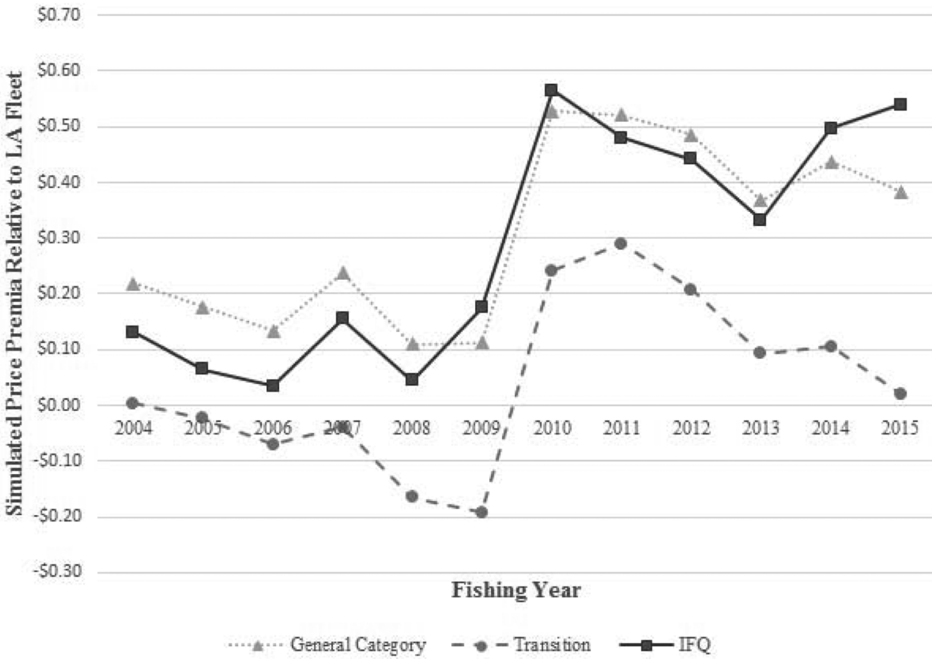



Figure 5. Simulated Average Ex-vessel Price Premia (2016 Q1$) for the Qualifying Fleet under Three Policy Scenarios Relative to the LA Fleet.

We also compare yearly average prices for the three policies of the qualifying fleet relative to the LA fleet (figure 5). We predict an annual IFQ price premia of $0.33–$0.57/lb. relative to the LA fleet over the actual IFQ period (2010–2015), a similar range as to what actually materialized. We predict that under GC management (regulated open access), a comparable annual price premia ($0.37–$0.52/lb.) would have occurred during the six-year period. During the actual Transition period (2008–2009), both regulated open-access management and IFQs would result in minor price premia relative to the LA fleet, while TACs would result in annual discounts, as was actually observed. When aggregate predicted revenue is divided by actual landings for the entire 12-year period, IFQs yield an average scallop price of $9.83/lb., regulated open-access management yields $9.85/lb., and quarterly TACs yield $9.58/lb.

## DISCUSSION AND CONCLUSIONS

The General Category (GC) component of the Atlantic sea scallop fishery experienced rapid changes in management—from regulated open access with a soft (target) aggregate quota to limited access with hard aggregate quotas, to individual fishing quotas (IFQs). During these three management regimes, roughly 5–10% of annual fishery landings were from the GC component of the fishery. The activity of the Limited Access (LA) fleet, which is managed primarily with input controls and is responsible for virtually all other landings in the fishery, can be used as a control for some outcomes to learn about the causal effects of implementing an IFQ program. However, we caution that this unique management system may limit the external validity to other fisheries or IFQ programs.

In contrast to Transition period policies of hard quarterly total allowable catches (TACs), vessels fishing under IFQs received premium prices compared to the LA fleet (figure 1). Our policy analysis conducted using differences-in-differences (DiD) models for price and size finds that the IFQ program did, in fact, cause price increases relative to management under quarterly TACs (figure 5). A modest, but not insignificant, increase in average annual revenue of $0.6 million (2.6%) was predicted from this policy change (table 7). Overall, simulated prices for the IFQ and regulated open-access management systems were quite similar. Furthermore, our hedonic model reveals minimal direct effects of the IFQ program on price by size class relative to regulated open-access management. The hedonic model recovers the average marginal implied prices of scallop attributes. Further research to recover the demand curve would enable us to describe consumer welfare changes due to changes in individual size (Kristofersson and Rickertsen 2004, 2007; Hammarlund 2015). Our simulation of scallop sizes landed finds that the IFQ program caused vessel operators to deliver more large scallops (figure 4).

The Homans and Wilen (1997, 2005) models of regulated open access are quite useful to understand the size and revenue results in the IFQ scallop fishery. Individual vessel operators who make decisions about where, when, and how to fish must balance the marginal benefits of those decisions (for example, in the output quality dimension) against the opportunity costs of foregone fishing opportunities. Compared to both soft aggregate TAC and IFQ management, individual vessel operators managed under hard aggregate TACs face much higher opportunity costs of foregone fishing opportunities (due to competition with other vessels).

Our partial policy analysis examines only changes in size selectivity; vessel operators could certainly change behavior on other margins, including area fished or landing state. While our dataset did not allow for testing changes in fishing costs arising from IFQ implementation, these effects may also be significant. One dimension that may prove fruitful to explore is the timing of trips. Since there is a downward-sloping demand curve for scallops (the quantity landed coefficient is negative; table 5), the IFQ component of the fishery could change the timing of their landings within the fishing year. While we did not examine this change in behavior, we suspect that removal of race-to-fish incentives during the Transition period (when the fishery closed during 6 of 7 quarters) would result in changes in market timing.

Changes in composition of the treatment group in both sets of econometric models present some interpretation issues for the DiD coefficients (Blundell and Macurdy 1999; Besley and Case 2000). The most skilled (lowest cost or highest productivity) participants are likely to remain active after IFQ program implementation (Arnason 2005; Dupont et al., 2005; Sharp and Batstone 2008; Färe, Grosskopf, and Walden 2015). These attributes are difficult to observe. While fixed effects and correlated random effects (CRE) mitigate the selection problem, it is still possible for these DiD coefficients to contain both treatment and selection effects if the vessel-level unobservable characteristics change over time. Since the most productive or adaptable vessels are likely to remain active in the fishery, we suspect that the DiD coefficients may be optimistic compared to the true treatment effects. Despite this shortcoming, the policy analysis should correctly account for changes in revenue at the aggregate level.

Regarding the finding of the size composition model that the IFQ program caused qualifiers as a whole to land more U10 scallops, we cannot distinguish between a change in fishing practices (for example, fishing in areas with lower overall densities of scallops but higher proportions of large scallops) and discarding behavior. Depending on the discard mortality rates, high grading could impose a cost on the biomass. If resource conditions change and large scallops are not found close to shore, IFQ vessels may be unable to target large scallops. With relatively low possession limits and total quota, IFQ vessels are unlikely to be able to significantly deplete inshore concentrations of large scallops. The LA fleet could contribute to this depletion of large scallops inshore to a much greater extent.

In seeing similar predicted price premia for the qualifying fleet relative to the LA fleet under no treatment and IFQ scenarios (figure 5), a natural question is, what are the contributing factors to these premia? One possibility is the demand for "dayboat" U10 scallops. By and large, the qualifying fleet consists of small-scale operators whose fishing trips last only a day or two. We find that these vessels receive higher prices than the LA fleet for U10 scallops, except when operating under quarterly TACs. The market for large "dayboat" scallops may be highly responsive to changes in quantity, and a race-to-fish could have driven down prices during the Transition period. A second possible contributor to the premia could be related to interactions between buyers and sellers. For example, Lesur-Irichabeau et al. (2016) examined scallop markets in various regions of France and found larger-volume transactions result in buyers paying lower prices, on average. This could be a potential market limitation case, which also may extend to our analysis—the LA fleet sells substantially higher quantities per transaction than the qualifying fleet. While this would be true during all three management periods for the qualifying fleet, a potential race-to-fish during the Transition period may factor in as well.

While we can make comparisons between the regulated open-access, limited-access with TACs, and IFQ management systems, comparing the IFQ system with TACs is probably the most relevant evaluation. In response to increases in catch by the GC fleet, the New England Fishery Management Council (NEFMC) wanted to put an upper bound on catch from that component of the fishery and explicitly voiced a preference against continuing the regulated open-access fishery (NEFMC 2007). Limited access for the GC fleet with hard TACs was the only other serious alternative to the IFQ program (NEFMC 2007). Our results imply that, judged only on the basis of fishery value, the NEFMC made a good policy choice for the qualifiers.

## REFERENCES

Abbott, J. K., and J. E. Wilen. 2010. "Voluntary Cooperation in the Commons? Evaluating the Sea State Program with Reduced Form and Structural Models." *Land Economics* 86(1):131–54.

Andersen, P., J. L. Andersen, and H. Frost. 2010. "ITQs in Denmark and Resource Rent Gains." *Marine Resource Economics* 25(1):11–22.

Anderson, L. G. 1994. "An Economic Analysis of Highgrading in ITQ Fisheries Regulation Programs." *Marine Resource Economics* 9(3):209–26.

Angrist, J. D., and J. S. Pischke. 2009. *Mostly Harmless Econometrics*. Princeton, NJ: Princeton University Press.

Arnason, R. 1994. "On Catch Discarding in Fisheries." *Marine Resource Economics* 9(3):189–207.

———. 2005. "Property Rights in Fisheries: Iceland's Experience with ITQs." *Reviews in Fish Biology and Fisheries* 15(3):243–64.

Asche, F., L. S. Bennear, A. Oglend, and M. D. Smith. 2012. "US Shrimp Market Integration." *Marine Resource Economics* 27(2):181–92.

Asche, F., Y. Chen, and M. D. Smith. 2015 "Economic Incentives to Target Species and Fish Size: Prices and Fine-scale Product Attributes in Norwegian Fisheries." *ICES Journal of Marine Science* 72(3):733–40.

Asche, F., and J. Guillen. 2012. "The Importance of Fishing Method, Gear, and Origin: The Spanish Hake Market." *Marine Policy* 36(2):365–69.

Ashenfelter, O., and D. Card. 1985. "Using the Longitudinal Structure of Earnings to Estimate the Effect of Training Programs." *Review of Economics and Statistics* 67(4):648–60.

Balestra, P., and M. Nerlove. 1966. "Pooling Cross Section and Time Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas." *Econometrica* 34(3):585–612.

Bertrand, M., E. Duflo, and S. Mullainathan. 2004. "How Much Should We Trust Differences-In-Differences Estimates?" *The Quarterly Journal of Economics* 119(1):249–75.

Besley, T., and A. Case. 2000. "Unnatural Experiments? Estimating the Incidence of Endogenous Policies." *The Economic Journal* 110(467):672–94.

Birkenbach, A. M., D. J. Kaczan, and M. D. Smith. 2017. "Catch Shares Slow the Race to Fish." *Nature* 544 (7649):223–26.

Blundell, R., and T. Macurdy. 1999. "Labor Supply: A Review of Alternative Approaches." In *Handbook of Labor Economics 3A*, ed. O. Ashenfelter and D. Card, 1559–1695. Amsterdam: Elsevier.

Brinson, A. A., and E. M. Thunberg. 2016. "Performance of Federally Managed Catch Share Fisheries in the United States." *Fisheries Research* 179:213–23.

Bromley, D. W. 2015. "Correcting the Whimsies of U.S. Fisheries Policy." *Choices* 30(4):1–8.

Cameron, A. C., J. B. Gelbach, and D. L. Miller. 2008. "Bootstrap-Based Improvements for Inference with Clustered Errors." *The Review of Economics and Statistics* 90(3):414–27.

Card, D., J. Kluve, A. Weber, and L. Kluve. 2010. "Active Labour Market Policy Evaluations: A Meta Analysis." *The Economic Journal* 120(548):F452–F477.

Card, D., and A. B. Krueger. 1994. "Minimum Wages and Employment: A Case Study of the Fast Food Industry in New Jersey and Pennsylvania." *American Economic Review* 84(4):772–93.

Carothers, C. 2013. "A Survey of US Halibut IFQ Holders: Market Participation, Attitudes, and Impacts." *Marine Policy* 38:515–22.

Casey, K. E., C. M. Dewees, B. R. Turris, and J. E. Wilen. 1995. "The Effects of Individual Vessel Quotas in the British Columbia Halibut Fishery." *Marine Resource Economics* 10(3):211–30.

Chamberlain, G. 1980. "Analysis of Covariance with Qualitative Data." *The Review of Economic Studies* 47 (1):225–38.

Diekert, F. K. 2012. "Growth Overfishing: The Race to Fish Extends to the Dimension of Size." *Environmental and Resource Economics* 52(4):549–72.

Dupont, D. P., K. J. Fox, D. V. Gordon, and R. Q. Grafton. 2005. "Profit and Price Effects of Multi-species Individual Transferable Quotas." *Journal of Agricultural Economics* 56(1):31–57.

Färe, R., S. Grosskopf, and J. Walden. 2015. "Productivity Change and Fleet Restructuring After Transition to Individual Transferable Quota Management." *Marine Policy* 62:318–25.

Gauvin, J. R., J. R. Ward, J. M. Burgess, and E. Richardson. 1994. "Description and Evaluation of the Wreckfish (*Polyprion americanus*) Fishery under Individual Transferable Quotas." *Marine Resource Economics* 9(2):99–118.

Georgianna, D., M. Lee, and J. Walden. 2017. "Contrasting Trends in the Northeast United States Groundfish and Scallop Processing Industries." *Marine Policy* 85:100–06.

Gobillon, L., F.-C. Wolff, and P. Guillotreau. 2016. "The Effect of Buyers and Sellers on Fish Market Prices." *European Review of Agricultural Economics* 44(1):149–76.

Grafton, R. Q. 1996. "Individual Transferable Quotas: Theory and Practice." *Reviews in Fish Biology and Fisheries* 6(1):5–20.

Guillen, J., and F. Maynou. 2015. "Characterisation of Fish Species Based on Ex-vessel Prices and its Management Implications: An Application to the Spanish Mediterranean." *Fisheries Research* 167:22–9.

Hammarlund, C. 2015. "The Big, the Bad, and the Average: Hedonic Prices and Inverse Demand for Baltic Cod." *Marine Resource Economics* 20(2):157–77.

Hart, D. R., and A. S. Chute. 2009. "Estimating von Bertalanffy Growth Parameters from Growth Increment Data Using a Linear Mixed-Effects Model, with an Application to the Sea Scallop *Placopecten magellanicus*." *ICES Journal of Marine Science* 66(10):2165–75.

Hart, D. R., and P. J. Rago. 2006. "Long-Term Dynamics of the U.S. Atlantic Sea Scallop *Placopecten magellanicus* Populations." *North American Journal of Fisheries Management* 26(2):490–501.

Hennen, D. R., and D. R. Hart. 2012. "Shell Height-To-Weight Relationships for Atlantic Sea Scallops (*Placopecten magellanicus*) in Offshore U.S. Waters." *Journal of Shellfish Research* 31(4):1133–44.

Herrmann, M. 1996. "Estimating the Induced Price Increase for Canadian Pacific Halibut with the Introduction of the Individual Vessel Quota Program." *Canadian Journal of Agricultural Economics* 44(2):151–64.

Homans, F. R., and J. E. Wilen. 1997. "A Model of Regulated Open Access Resource Use." *Journal of Environmental Economics and Management* 32(1):1–21.

———. 2005. "Markets and Rent Dissipation in Regulated Open Access Fisheries." *Journal of Environmental Economics and Management* 49(2):381–404.

Hsueh, L. 2017. "Quasi-Experimental Evidence on the Rights to Fish: The Effects of Catch Shares on Fishermen's Days at Sea." *Journal of the Association of Environmental and Resource Economists* 4(2):407–45.

Ishimura, G., and M. Bailey. 2013. "The Market Value of Freshness: Observations from the Swordfish and Blue Shark Longline Fishery." *Fisheries Science* 79(3):547–53.

Kleibergen, F., and R. Paap. 2006. "Generalized Reduced Rank Tests Using the Singular Value Decomposition." *Journal of Econometrics* 133(1):97–126.

Kline, P., and A. Santos. 2012. "A Score Based Approach to Wild Bootstrap Inference." *Journal of Econometric Methods* 1(1):23–41.

Kristofersson, D., and K. Rickertsen. 2004. "Efficient Estimation of Hedonic Inverse Input Demand Systems." *American Journal of Agricultural Economics* 86(4):1127–37.

———. 2007. "Hedonic Price Models for Dynamic Markets." *Oxford Bulletin of Economics and Statistics* 69 (3):387–412.

———. 2009. "Highgrading in Quota-Regulated Fisheries: Evidence from the Icelandic Cod Fishery." *American Journal of Agricultural Economics* 91(2):335–46.

Lee, M. 2014. "Hedonic Pricing of Atlantic Cod: Effects of Size, Freshness, and Gear." *Marine Resource Economics* 29(3):259–77.

Lesur-Irichabeau, G., O. Guyader, M. Frésard, C. Leroy, K. Latouche, and L. Le Grel. 2016. "Information on Sellers and Buyers Characteristics: Added Value to Explain Price Formation at Primary Fish Markets in Managed French Scallop Fisheries." *Applied Economics* 48(22):2078–92.

McConnell, K., and I. Strand. 2000. "Hedonic Prices for Fish: Tuna Prices in Hawaii." *American Journal of Agricultural Economics* 82(1):133–44.

Mundlak, Y. 1978. "On the Pooling of Time Series and Cross Section Data." *Econometrica* 46(1):69–85.

NEFMC (New England Fishery Management Council). 1993. "Amendment 4 to the Atlantic Sea Scallop Fishery Management Plan." Newburyport, MA.

———. 2007. "Amendment 11 to the Atlantic Sea Scallop Fishery Management Plan." Newburyport, MA.

———. 2013. "Framework 24 to Atlantic Sea Scallop Fishery Management Plan: Appendix I-Economic and Social Trends in the Sea Scallop Fishery." Newburyport, MA.

———. 2016. "Framework 27 to the Atlantic Sea Scallop Fishery Management Plan." Newburyport, MA.

Nerlove, M. 1971. "A Note on Error Components Models." *Econometrica* 39(2):383–96.

NOAA (National Oceanic and Atmospheric Administration). 1999. "Fisheries of the Northeastern United States; Atlantic Sea Scallop Fishery, Framework Adjustment 11; Northeast Multispecies Fishery, Framework Adjustment 29." *Federal Register* 64(111):31144–51. https://www.gpo.gov/fdsys/pkg/FR–1999–06–10/pdf/99–14745.pdf.

———. 2000. "Fisheries of the Northeastern United States; Atlantic Sea Scallop Fishery, Framework Adjustment 13; Northeast Multispecies Fishery, Framework Adjustment 34." *Federal Register* 65(118):37903–17. https://www.gpo.gov/fdsys/pkg/FR–2000–06–19/pdf/00–15360.pdf.

———. 2008. "Magnuson-Stevens Fishery Conservation and Management Act Provisions; Fisheries of the Northeastern United States; Atlantic Sea Scallop Fishery; Amendment 11." *Federal Register* 73(72):20089–133. https://www.gpo.gov/fdsys/pkg/FR–2008–04–14/pdf/E8–7795.pdf.

Panhans, J. D., and M. T. Singleton. 2015. "The Empirical Economist's Toolkit: From Models to Methods." Unpublished manuscript, Duke University.

Papke, L. E., and J. M. Wooldridge. 1996. "Econometric Methods for Fractional Response Variables with an Application to 401(k) Plan Participation Rates." *Journal of Applied Econometrics* 11(6):619–32.

———. 2008. "Panel Data Methods for Fractional Response Variables with an Application to Test Pass Rates." *Journal of Econometrics* 145(1–2):121–33.

Parmeter, C. F., and J. C. Pope. 2009. "Quasi-Experiments and Hedonic Property Value Methods." In *Handbook on Experimental Economics and the Environment*, ed. J. A. List and M. K. Price, 3–66. Northampton, MA: Edward Elgar.

Roodman, D. 2017. "BOOTTEST: Stata Module to Provide Fast Execution of the Wild Bootstrap with the Null Imposed." https://econpapers.repec.org/software/bocbocode/s458121.htm.

Rosen, S. 1974. "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition." *Journal of Political Economy* 82(1):34–55.

Sharp, B. M., and C. J. Batstone. 2008. "Factor Use and Productivity Change in a Rights-based Fishery." In *Advances in Fisheries Economics*, ed. T. Bjorndal, D. Gordon, R. Arnason, U. Ussif, and R. Sumaila, 257–69. Oxford: Wiley-Blackwell.

Smith, M. D., J. Zhang, and F. C. Coleman. 2006. "Effectiveness of Marine Reserves for Large-Scale Fisheries Management." *Canadian Journal of Fisheries and Aquatic Sciences* 63(1):153–64.

Smolowitz, R. 2016. "Status and Trends of the U.S. Sea Scallop Fishery." http://atlanticscallops.org/wp-content/uploads/2015/10/2016_US_Scallop_Industry.pdf.

Solís, D., J. J. Agar, and J. del Corral. 2015. "IFQs and Total Factor Productivity Changes: The Case of the Gulf of Mexico Red Snapper Fishery." *Marine Policy* 62:347–57.

Squires, D., J. Kirkley, and C. A. Tisdell. 1995. "Individual Transferable Quotas as a Fisheries Management Tool." *Reviews in Fisheries Science* 3(2):141–69.

Tveteras, S., C. E. Paredes, and J. Peña-Torres. 2011. "Individual Vessel Quotas in Peru: Stopping the Race for Anchovies." *Marine Resource Economics* 26(3):225–32.

Valcu, A., and Q. Weninger. 2013. "Markov-Perfect Rent Dissipation in Rights-based Fisheries." *Marine Resource Economics* 28(2):111–31.

Vestergaard, N. 1996. "Discard Behavior, Highgrading and Regulation: The Case of the Greenland Shrimp Fishery." *Marine Resource Economics* 11(4):247–66.

Walden, J. B., J. E. Kirkley, R. Färe, and P. Logan. 2012. "Productivity Change under an Individual Transferable Quota Management System." *American Journal of Agricultural Economics* 94(4):913–28.

Wooldridge, J. M. 2010a. *Econometric Analysis of Cross Section and Panel Data*. Cambridge, MA: MIT Press.

———. 2010b. "Correlated Random Effects Models With Unbalanced Panels." Unpublished manuscript, Department of Economics, Michigan State University.