Efficiency Costs of Social Objectives in Tradable Permit Programs

Kailin Kroetz, James N. Sanchirico, Daniel K. Lew

Abstract: Objectives of tradable permit programs are often broader than internalizing an externality and improving economic efficiency. Many programs are designed to accommodate community, cultural, and other nonefficiency goals through restrictions on trading. However, restrictions can decrease economic efficiency gains. We use a policy experiment from the Alaska halibut and sablefish tradable permit program, which includes both restricted and unrestricted permits, to develop one of the few empirical measurements of the costs of meeting nonefficiency goals. We estimate that restrictions are reducing resource rent in the halibut and sablefish fisheries by 25% and 9%, respectively.

JEL Codes: Q22, Q28

Keywords: Alaskan halibut and sablefish fishery, Catch shares, Created markets, Individual transferable quota, Tradable permits

TRADABLE PERMIT PROGRAMS (TPPS) are a market-based policy designed to internalize externalities. Examples include management of air pollutants such as CO_2 and SO_2, point and nonpoint source water pollution, as well as the allocation of catch

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Received April 23, 2014; Accepted March 12, 2015; Published online May 15, 2015.

JAERE, volume 2, number 3. 2333-5955/2015/0203-0001$10.00 http://dx.doi.org/10.1086/681646

in commercial fisheries (Boyd et al. 2003). Regardless of their application, TPPs establish a cap (e.g., amount of pollution or resource extraction) and then allocate a share of the cap to participants in the form of a permit. In many programs, however, trading of the permits is restricted (Tietenberg 2007).

Restrictions on trade, such as who can trade with whom and whether permits can be borrowed or banked, are often implemented to address cultural, secondary environmental issues, and other nonefficiency goals.[1] Often the justification is based on "equity" issues and concerns over the "winners" and "losers" (Hahn 1984). For example, an often-stated concern in commercial fisheries is that larger operators may buy out smaller operators, which could have negative implications for the social fabric of coastal communities and ports (see, e.g., Willmann 2000).

Trading rules are one possible means of addressing nonefficiency goals.[2] While they may produce societal benefits, they may also reduce the cost effectiveness of a program (Stavins 1995) and/or reduce the potential for increases in revenue to occur through changes, such as increases in product quality and switching to more valuable product forms (see, e.g., Wilen [2005] for further discussion and examples of revenue-side gains in fisheries after management changes). The extent to which the benefits outweigh the costs or vice versa is not fully understood. We provide one of the few empirical estimates of the magnitude of the efficiency costs of trading restrictions, thereby enabling policy makers to understand the trade-offs associated with includ-

or the US Department of Commerce. We thank Joshua Abbott, Isabel Call, Ghada Elabed, Harrison Fell, Ron Felthoven, Jacqueline Ho, Larry Karp, Stephen Kasperski, Douglas Larson, Clayton Munnings, Aaron Smith, Martin Smith, James Wilen, Zhongmin Wang, the participants of the AERE conference (Seattle June 2011), the participants at the Property and Environment Research Center (PERC) Lessons Learned in Rights-Based Fisheries Management workshop (Bozeman, July 2011), and two anonymous reviewers for helpful comments on earlier drafts of the manuscript. Jessica Gharrett and Terry Hiatt were very helpful in providing and explaining the nuances of the data.

1. This encompasses many types of restrictions, including restrictions on trade between economic agents within the program, including who can trade with whom and the limitations placed on those transactions, as well as the exclusion of potential participants from a program (e.g., the exclusion of some sectors from a program).

2. Of course, there are other means besides trading restrictions to address these goals. For example, when Peru implemented a TPP to manage the Anchoveta stock, the program included a social fund called FONCOPES to provide crew financial incentives for early retirement, retraining opportunities, and assistance in small business development (Young and Lankester 2013). In the carbon abatement context, rebates can be used to offset increases in the costs of energy associated with permit costs and therefore prevent low-income households from experiencing an increase in energy costs (see, e.g., Kunkel and Kammen 2011). An assessment of the most cost-effective means to address nonefficiency goals is beyond the scope of the paper.

ing restrictions in the design of a TPP (see also Gangadharan 2000, 2004; Grafton, Squires, and Fox 2000; Singh, Weninger, and Doyle 2006).

In general, we contribute to the set of ex post evaluations of TPPs, albeit with a more limited focus on measuring the costs of restrictions.[3] Our analysis is similar to that of Gangadharan (2004), who obtains an estimate of the variation in permit price by geographic area in the Regional Clean Air Incentives Market (RECLAIM). However, we focus on restrictions that affect the use of capital inputs, divisibility of a permit, corporate ownership, and consolidation and therefore have the potential to affect profitability through mechanisms including limiting size and returns to scale, access to credit and interest rates, and limiting technology and constraining variable cost structures. Similar mechanisms in other contexts, including the lead phase out program and wetland credit trading, have been shown to reduce program efficiency (see, e.g., Kerr and Maré 1998; Shabman 2004). Furthermore, restrictions based on similar mechanisms exist or are proposed for other TPPs, most notably in contexts with multiple user groups. For example, geographical sectors can arise through the division of markets by political entity, such as the European Union, Californian, and Chinese carbon markets (see, e.g., Pizer et al. 2006; Munnings et al. 2014). User groups may also be separated within a program, such as mobile and stationary emission sources, nonpoint and point sources, and commercial and recreational fisheries sectors (see, e.g., Call and Lew 2015).

To estimate the impact of the restrictions we exploit a real-world policy experiment where the designers of the Alaska federal halibut and sablefish Individual Transferrable Quota (ITQ) program created both restricted (to varying degrees) and unrestricted markets. This variation allows us to identify the costs of trading restrictions without imposing structural assumptions necessary to estimate a counterfactual. Specifically, we consider the question of whether the restrictions in the ITQ program resulted in lower resource rent than hypothetically would have existed if the program had been implemented without the restrictions in place. We conduct our analysis using a reduced form model of quota prices, with dummy variables capturing the impact of restrictions. Similar identification strategies have been used to measure the underlying costs and benefits of programs in a variety of settings. For example, Chattopadhyay and Duflo (2004) exploit randomization across village councils of a mandate that a leadership role be filled by a woman to study public good provision and gender in India, while Bai, Li, and Ouyang (2014) use geographic variation in property tax implementation to consider property taxation effects in China.

3. See, e.g., OECD (2004) and Tietenberg (2006) for summaries of multiple programs, and for specific examples, see Schmalensee et al. (1998), Stavins (1998), Montero (1999), Ellerman and Buchner (2007), and Fowlie and Perloff (2013).

In the fisheries context, our work contributes to the growing body of research utilizing policy experiments to identify the impacts of policies. For example, Newell, Sanchirico, and Kerr (2005) use information on fish stocks that had the greatest reduction in catches before and after the ITQ program to identify the rate of return in an ITQ program; Smith, Zhang, and Coleman (2006) use data from before and after the creation of closed areas to measure the impact of the closure on the fishery; Abbott and Wilen (2010) use variation in the choice to participate in a cooperative management structure to identify the gains from information sharing; and, more recently, Scheld, Anderson, and Uchida (2012) exploit the fact that only a share of the fishermen fishing multiple fish stocks were operating under a quota program to measure the economic effects of the program.

We use a unique (confidential) data set from the Alaska federal halibut and sablefish ITQ program. The program was implemented in 1995 (58 Federal Register 215: 59375–59413) to limit access to each of the fisheries, reduce overcapacity, and address "conservation and management problems that are endemic to open access fisheries" (69 Federal Register 84: 23681). At the same time, concern about the potential impacts of the program on the social and cultural characteristics of the fisheries and fishing communities in Alaska led to restrictions on quota trading.

The number and diversity of restrictions on the transfer of quota in the halibut and sablefish markets makes the program a unique and well-suited laboratory to measure the efficiency costs of achieving nonefficiency objectives. Furthermore, relative to other TPPs, the halibut and sablefish ITQ program has been in place for a long time, has an active and well-documented trading market, and has a large number of participants.

Using both parametric and nonparametric methods, we find that restrictions in the fisheries have decreased the present value of resource rent (as measured by quota asset prices) over the lifetime of the program by approximately $117 million for halibut and $40 million for sablefish (in US$2012). To put these numbers in context, the gross revenues for the halibut and sablefish fisheries in 2011 were $205.2 million and $128.9 million, respectively (Fissel et al. 2012).

Our findings suggest that restrictions in TPPs can have significant efficiency implications. This is a particularly important finding given that imposing restrictions in these programs is becoming more commonplace. For example, recently proposed air pollution legislation in California (see, e.g., EPRI 2013) and newly implemented programs for managing West Coast and New England fisheries impose restrictions on permit markets. In the fisheries management context, the use of restrictions is likely to grow as the National Oceanic and Atmospheric Administration's (NOAA) Catch Share Policy (NOAA 2010) discusses the key role trading rules can play in addressing multiple objectives.

The remainder of the paper is organized as follows. First, we describe the Alaska halibut and sablefish ITQ program, the restrictions we focus on in the paper, and the data used in our analysis. We then provide a brief overview of how the costs of the restrictions were measured. This is followed by estimates of the costs of the restrictions, including a set of parametric and nonparametric robustness checks. We conclude with a summary of our results and future research questions.

THE ALASKA HALIBUT AND SABLEFISH TRANSFERABLE QUOTA PROGRAM

Prior to ITQ implementation, both the halibut and sablefish fisheries were managed using season length restrictions as a means of restricting catch. However, both fisheries went through periods where significant numbers of vessels entered the fishery, causing the season lengths to be progressively shortened in an effort to avoid exceeding the annual catch limits. When ITQs were implemented in 1995, openings as short as 24 hours had occurred in the halibut fishery and seasons were as short as 20 days in the sablefish fishery.[4] The Alaska halibut and sablefish program was implemented in 1995 by the North Pacific Fishery Management Council (NPFMC), the regulatory body overseeing the management of the fishery. The NPFMC determines how much sablefish can be caught each year, while the annual amounts of Pacific halibut that can be harvested in the United States (and Canada as well) are determined by the International Pacific Halibut Commission (IPHC).

To sustain healthy fish populations, the yearly total allowable catch (TAC) of the halibut stock and the sablefish stock are capped. TACs are assigned to specific geographic areas, of which there are eight in the halibut fishery and six in the sablefish fishery (see fig. A1*A* in the appendix; appendix available online). Area-specific TACs are intended to prevent local stock depletion (Pautzke and Oliver 1997).

At the inception of the program, the NPFMC granted revocable permits, which are denoted quota share (QS), to past participants in the fisheries. The QS were allocated for a species-area combination and based on the fishing history of each participant. Prior to program implementation it was common for fishermen to fish both halibut and sablefish and to fish in multiple areas, and therefore some fishermen were allocated quota for multiple species-area combinations. Ownership of QS for a species grants the owner the privilege to fish a percentage of the species' TAC in an area each year and into perpetuity. The yearly allowances in pounds of fish are determined by multiplying the percentage of the TAC an individual is entitled to, which is based on their QS holdings, with the TAC. The annual allocations of pounds are called IFQ (individual fishing quota) pounds and are allocated to individuals who hold QS via an IFQ permit.

4. See, e.g., Homans and Wilen (1997) and NRC (1999) for more detail on the history of the halibut and sablefish fisheries and their management.

Transfer of QS and IFQ is allowed in the fishery but subject to a number of restrictions. Rather than provide an exhaustive coverage of them, we describe in detail the rules most relevant for our analysis. Specifically, we discuss the vessel class and blocking rules.[5]

Vessel Class Restriction

Limiting the use of a specific quota to certain vessel classes affects production flexibility and use of capital inputs. The restriction dictates who can own the QS and IFQ pounds and where and how they can be fished and transferred, as well as the size and type of vessel permitted to fish the IFQ pounds. Class A QS and IFQ pounds are the least restrictive, as they can be owned by a corporation or an individual, sold, and fished on a vessel with or without the owner on board.[6] All other classes of quota may be fished only when the owner of the IFQ pounds, who must be an individual, is on board.[7]

The class also dictates the type and length of the vessel on which the IFQ can be fished. In both fisheries, Class A IFQ is the only IFQ that can be fished on any length vessel, including catcher-processor vessels (large vessels that both catch fish and process it at sea). All other IFQ must be fished on catcher vessels, which are vessels that deliver their catch to shore-side processors. Classes B and C in the sablefish fishery and classes B, C, and D in the halibut fishery designate a variety of sizes of catcher vessels on which the IFQ can be fished.[8] Class B vessels are larger than Class C vessels, which are larger than Class D.

5. The program also includes accumulation caps limiting how much quota an individual or entity can hold. We do not focus on this restriction because there is evidence that fishermen find ways to circumvent these restrictions (see, e.g., Carothers 2013). Additionally, there are also criteria fishermen must meet in order to purchase quota and enter the fishery (see Pautzke and Oliver [1997] and also fishery management reports available at http://www.fakr.noaa.gov/ram/ifq.htm).

6. IFQ transactions are akin to leases. These leases are restricted to emergency circumstances only (such as a death or military deployment) for quotas associated with all classes of vessels, except Class A quotas.

7. Companies grandfathered in at the beginning of the program are exempt from this restriction. Additionally, participants who were initially allocated QS at the beginning of the program are permitted to hire skippers.

8. In the sablefish ITQ program the vessel lengths associated with the classes are as follows: Class A IFQ pounds can be fished by any length and by either type of vessel, Class B must be fished by catcher vessels and the vessels can be greater than 60 feet in length, and Class C must be fished by catcher vessels 60 feet or less. The vessel classes in the halibut fishery are the same except that Class C must be fished by vessels between 35 and 60 feet in length, and there is also a Class D designation, for which the IFQ pounds must be fished on catcher vessels 35 feet in length or less.

Blocking Restriction

The blocking restriction makes some QS only transferable as an indivisible block and places limits on the number of blocks one can hold. Blocked QS was established at the beginning of the program for the purpose of ensuring a minimum fleet size (Pautzke and Oliver 1997); in other words, there were concerns that the total number of vessels fishing would drastically decrease. In conjunction with other restrictions, the intention was to prevent overconsolidation and ensure that the fishery would not end up dominated by only a few firms (Pautzke and Oliver 1997). Whether the initial issuance of QS was blocked depended on the amount of QS a participant received;[9] participants receiving a relatively small amount of QS received quota in an indivisible "block."[10]

Blocked quota also results in a restriction on the total amount of quota a participant can hold. Specifically, the number of blocks a participant can hold is limited, and the size of each block is capped, restricting total QS units and associated yearly IFQ pounds that can be owned. Furthermore, owning blocked quota can limit the ability to own unblocked quota. Specifically, holding more than one block of QS disqualifies a participant from holding unblocked QS.

Data

We acquired primary confidential data on quota transactions from the National Marine Fisheries Service, Alaska Regional Office. The data set covers all market transactions since the program's inception in January 1995 through the end of the 2011 fishing year (the final year for which we have complete data).[11] Information describing the transactions includes the transaction date, names and identification numbers for the buyer and the seller, addresses of the buyer and the seller, information on the price paid/received, the amount of IFQ pounds and QS in the transfer, the reason for the transfer, information on how the buyer and seller found one another, details on the relationship (if any) between the buyer and seller, and details of the quota transacted (e.g., species, area, vessel class, blocked or unblocked, and "fishdownable").[12]

9. See Pautzke and Oliver (1997) for details on how the initial allocation of quota was determined.

10. Other examples of blocking restrictions include the West Coast sablefish limited entry endorsed sector permit stacking scheme (Kroetz and Sanchirico 2009) and "locking" of quota in the British Columbia trawl program (Grafton, Nelson, and Turris 2005).

11. Our primary results use transaction data from the 2000–2011 fishing seasons due to different reporting requirements than the earlier data. As a robustness check, we did the analysis using the period from 1995 to 2011. Overall, the results are consistent with the shorter time period. The full set of results is available upon request.

12. As Newell et al. (2005) found in the New Zealand ITQ fisheries, individual-level market data can include transactions that are not arm's length (transactions where both par-

Because of limitations on IFQ pound trading (i.e., leases) and the resulting small number of leases, we use the QS (asset) price data that consist of 4,870 transactions for halibut and 2,160 for sablefish. Specifically, we use data from transactions that include both QS and IFQ pounds, and where the number of pounds is equal to the yearly issuance of IFQ pounds associated with the quantity of QS in the transaction.[13] These transactions represent 78% of the transactions in each fishery, and the prices are less likely to be confounded by other factors, such as adjustments to the price for IFQ pounds not included in the transaction.

The observed transactions in the final set are relatively evenly distributed across the years, although the transactions are more heavily concentrated in the spring relative to the rest of the fishing year (the open season runs from late February/March through November). See table 1 for a summary of the breakdown of the total quota by restriction type, and see table 2 for a summary of the transaction data. Also see the appendix for more details.

IDENTIFYING THE COSTS OF RESTRICTIONS

In a well-functioning quota market, the QS price (asset price) is equal to the discounted present expected value from fishing the yearly allocation of pounds into the future. The annual return (dividend) to holding a share is the resource rent and represents "the surplus value, i.e., the difference between the price at which fish can be sold and the respective production costs which include a normal return" (NOAA 2010). The asset price, therefore, is a function of the future expectations of profitability in the fishery, discount rates, and expected TAC allocations in the future (for more detailed discussion of quota prices and examples, see Clark 1980, 1985, 2005; Newell, Papps, and Sanchirico 2007).

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ties act strictly in their own best interest). Given the detailed nature of our transaction data, specifically the fields in the data set describing the reason for the transfer, information on how the buyer and seller found one another, and details on the relationship (if any) between the buyer and seller, we are able to eliminate non–arm's length transactions (8% of priced observations were removed for halibut and 14% for sablefish).

13. We observe three types of transactions in the data. The first is QS-only transactions. These transactions do not include any IFQ pounds. In the halibut fishery these transactions made up approximately 14% of the transactions, and in the sablefish fishery the percentage is approximately 15%. The second type of transaction includes both QS and IFQ pounds, and the amount of pounds is equal to the yearly issuance of IFQ pounds, which varies by year, associated with the quantity of QS in the transaction. These "Full-IFQ" transactions are the majority of the transactions we observe: 78% of halibut transactions and 78% of sablefish transactions are this type. Finally, there are also transactions that include both QS and IFQ pounds, but the number of IFQ pounds is fewer than the yearly issuance associated with the quantity of QS in the transaction. These transactions make up 7% of halibut transactions and 8% of sablefish transactions.

Table 1. 2011 TAC by Vessel Class and Blocking Combination (%)

	Halibut			Sablefish		
Vessel Class	Unblocked	Blocked	Total	Unblocked	Blocked	Total
A	2	1	3	20	2	22
B	32	10	42	35	6	41
C	21	27	48	29	8	37
D	1	6	7	. . .	. . .	. . .
Total	55	45	100	84	16	100

Note.—The vessel sizes that correspond to the classes differ between the fisheries, where in halibut A is unrestricted, B is length >60 feet, C is length 35–60 feet, and D is length <35 feet. In the sablefish fishery there are only three classes: A is unrestricted, B is >60 feet, and C is <60 feet.

We set out to answer the question of whether or not restrictions led to lower resource rent than would have existed in the hypothetical case where the ITQ program was implemented without restrictions in place. Our focus is on estimating the differential in the QS price between restricted quota and unrestricted quota. The basis of our identification strategy is that potentially binding trading restrictions distort the price signals in the permit market. That is, a market where rules restrict production processes is likely to lead to the TAC being fished at higher costs and/or at lower per unit revenue than when the trading market is unrestricted. We exploit the policy experiment that restrictions only apply to segments of each fishery, and

Table 2. Summary of Transactions

	Halibut	Sablefish
Buyers:		
Unique	1,269	491
Yearly average	165	65
Min.	82 (2009)	43 (2009)
Max.	225 (2001)	104 (2003)
Sellers:		
Unique	1,921	584
Yearly average	197	69
Min.	92 (2009)	50 (2009)
Max.	258 (2001)	104 (2003)
Transactions:		
Average size (lbs)	6,678	9,997
Median size (lbs)	4,975	3,545

we observe the quota prices associated with both the unrestricted and restricted segments of the fisheries.[14]

Our estimates represent the long-run marginal value of moving one unit of quota from a restricted operation to an unrestricted one. For example, we consider the situation where one unit of Class C blocked quota was instead unblocked or where one unit of Class C quota is fished on vessels with lengths in the Class B category. We do not attempt to model the transitional dynamics that would occur if a restriction is relaxed at a point in time and the fishermen and markets readjust.[15]

The success of our identification strategy rests on the assumption of a competitive market for quota where no one fisherman can influence the quota price. This assumption is supported by work in other fisheries quota markets showing that the markets are well functioning (see Newell et al. 2005) as well as by characteristics of the specific fisheries and quota markets we analyze. Specifically, there are a large number of individuals owning quota in the fisheries we examine (over 2,600 individuals in the halibut fishery and over 800 individuals in the sablefish fishery are allocated pounds of quota each year; RAM 2012), and brokers have been active in the markets facilitating trades since the inception of the program.

While we estimate the marginal value of moving one unit of quota across restrictions, from a policy perspective primary interest is likely to be on the difference in total resource rent in the restricted versus the unrestricted scenario. For this, we compare the total resource rent in the restricted scenario to that in the counterfactual scenario where one or more restrictions did not exist. In the case where the equilibrium without restrictions would consist of vessels similar to the vessels in the unrestricted segment of the fishery, we measure the total resource rent as the product of the observed unrestricted quota price and the total TAC in the counterfactual. Similarly, the total restricted scenario resource rent is the sum of the products of the restricted prices and the corresponding restricted TACs.[16]

14. Note that because we estimate a difference between restricted and unrestricted quota prices we do not view our estimates as either an upper or lower bound. In other words, there is no reason to expect the difference to be higher or lower over time as it is possible the time frames and impacts of transitions of capital would differ between restricted and unrestricted markets.

15. There is evidence, for example, that capital in fisheries may be slow to turn over after a policy change (see, e.g., Weninger and Just 1997). The path of adjustment to a new management regime (with or without restrictions) is interesting to consider, and a structural econometric model that incorporates capital dynamics is one method to measure the full dynamic costs of the restrictions but is beyond the scope of this paper.

16. Using observed quota prices, we can estimate what the total resource rent in the fisheries would have been without one of the restrictions (rent equals unrestricted quota price × TAC) and with the restriction (rent equals unrestricted quota price × unrestricted

ECONOMETRIC ANALYSIS

Before developing our reduced form model to measure the long-run impact on resource rent of the blocking and vessel class restrictions, we present summary statistics that show how prices across the restricted categories have varied over time. Specifically, figure 1 illustrates average quota prices by vessel class; the percentages of priced transactions we observe in each vessel class are 1% A, 23% B, 45% C, and 31% D in the halibut fishery. For sablefish, the observed percentages of priced transactions are 6% A, 37% B, and 56% C. The shortest halibut vessel class (Class D) tends to have prices below the other classes, but the other class prices are close to one another and the ranking changes year to year in some cases. There are several possible reasons for why quota prices may differ by vessel class. For example, Haynie and Layton (2010) provide empirical evidence that profitability varies by length of vessel in the Bering Sea pollock fishery (e.g., due to different technologies and variable cost structures, and ability to travel further distances).

Figure 2 illustrates the average real quota prices over time based on the blocking status, where blocked quota comprises 80% of the halibut transactions and 57% for sablefish. The average blocked quota prices are lower than the unblocked prices in both the halibut and sablefish markets. Blocking has the potential to affect quota prices through mechanisms similar to other restrictions that limit production flexibility, including impacts on size of the operation, variables costs, and access to credit and interest rates.

These summary statistics are limiting, however. For example, the price of quota may depend on the area designation of the quota and the class *and* blocking restrictions jointly.[17] Therefore we investigate potential price differences using a regression analysis to control for other potential factors influencing quota prices. Ideally, we would observe restricted and unrestricted quota prices for species k and quota attributes j at the same point in time t, and could calculate the difference, which can be written as:

$$D(k, j|t) = P(k, j|R, t) - P(k, j|U, t), \tag{1}$$

where U and R are used to distinguish between unrestricted and restricted quota prices, respectively. The estimate is a reduced form estimate in the sense that we cannot ascribe the difference to particular factors that may influence profitability, including differences in ex-vessel price received, inputs used, or input prices.

Estimation of $D(k, j|t)$ is complicated by the fact that we only observe restricted and unrestricted quota prices when a quota trade occurs and transactions often do

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TAC + restricted quota price × restricted TAC). Differences between these estimates are the costs due to the restrictions.

17. See table A1 in the appendix for a breakdown of transactions by area.

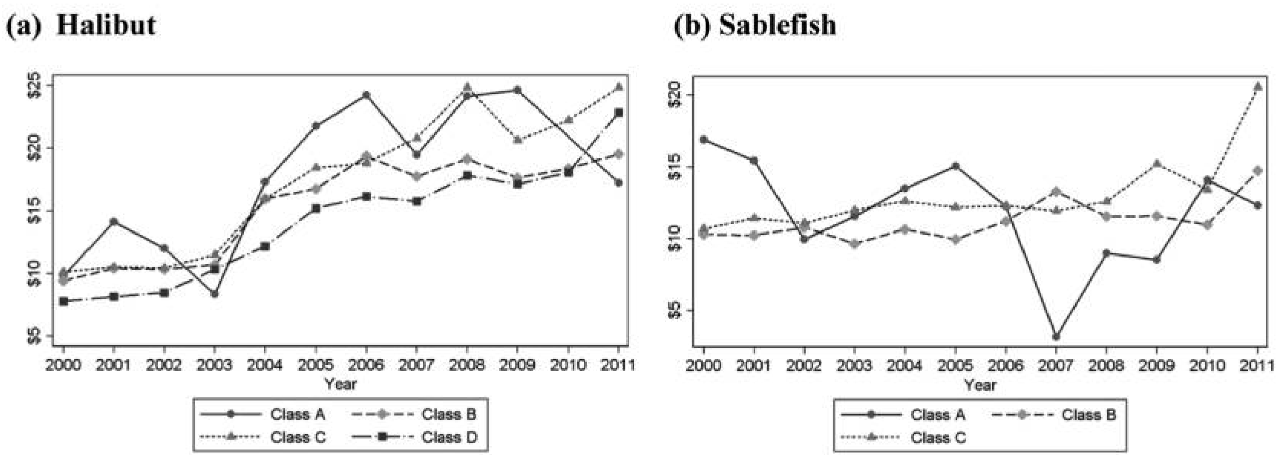

Figure 1. Average quota price by vessel category ($2012). These are unweighted averages by year.

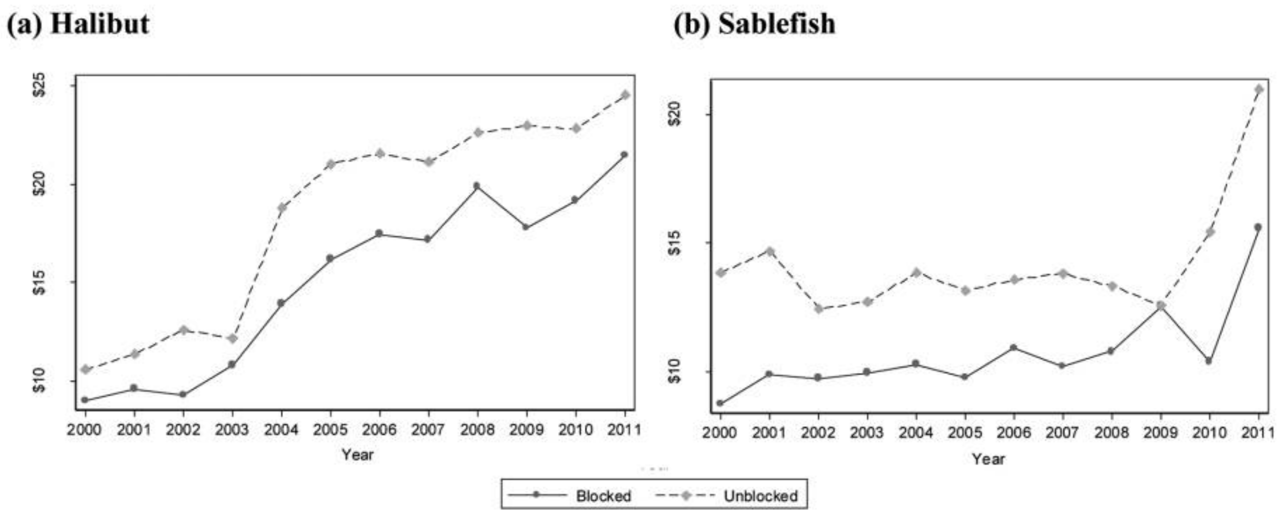

Figure 2. Average quota price by blocking status ($2012). These are unweighted averages by year.

not occur in the same window of time or at regular intervals throughout the season. Furthermore, because factors influencing quota prices change over time, we cannot condition on t (measured in days), and we do not use this simple framework to directly compare quota prices observed at two different points in time.

Instead, we rely on the fact that factors influencing prices tend to be correlated through time (e.g., current fish stock size is a function of fish stock size in the previous period; similarly prices such as ex-vessel prices and fuel prices tend to be correlated through time). Therefore, we expect the difference between restricted and unrestricted prices that are observed close to the same day to be a good approximation of the difference $D(k, j|t)$. This allows us to use a reduced form regression model, with controls for factors other than the restrictions that influence QS prices, to estimate the difference in prices.

For our analysis we construct a separate model for each species, using observed quota prices as our dependent variable. Specifically, we estimate:

$$f(\text{Quota price})_{i,s,y} = \alpha + \mathbf{R}'\beta + \mathbf{D}'_{y*\text{area}}\gamma_{y*\text{area}} + \mathbf{D}'_{\mathbf{s}}\gamma_{\mathbf{s}} + \mathrm{D}_{pol}\gamma_{pol} + \varepsilon_{i,s,y}. \qquad (2)$$

The i subscripts index the observed market transactions, s indexes season, and y indexes year. Because there are multiple restrictions, a fully interacted set of vessel class and blocking dummy variables (***R*** vector) is used to measure the impact of restrictions. We use the coefficients on these variables, β, to estimate the reduction in quota price due to each of the restrictions.

We also include multiple control variables in the analysis, represented by ***D***. A policy dummy variable is included to capture the change to the regulations that occurred in the halibut fishery, where the limit on the number of blocks held increased from two to three. Seasonal dummy variables are also included to capture seasonality in processing and/or potential costs associated with the weather that varies throughout the season.[18] Other variables include controls for year to capture changes in the fishery at a yearly time scale, which are interacted with area dummy variables specifying where the quota can be fished.[19]

The area of fishing can affect the profitability of fishing and quota prices, and therefore we control for area differences in our model. Specifically, ex-vessel prices

18. For our analysis, the year is divided into five periods, a pre-fishing season, three approximately 3-month fishing seasons (spring, summer, and fall), and a post-fishing season. Alternative seasonal time period specifications were tried, such as monthly dummies, but none affected the restrictions coefficients of interest.

19. We take the area TAC (cap) as given and control for it in our analysis, as the area-specific TACs "reflect the biological distribution of the stocks of fish . . . retaining these separations was intended to prevent local stock depletion" (Pautzke and Oliver 1997, 9). Whether the combination or further splitting of TACs could increase economic efficiency is beyond the scope of this analysis.

vary by port in the Alaska halibut and sablefish fisheries (NMFS 2010a, 2010b). Costs may also be region specific due to differences in distance to the fishing grounds, fuel prices, the prices of other supplies, and fish abundance levels. We expect fishing costs to be lower where stocks are higher, ceteris paribus.

We estimated a number of different specifications, including unweighted and weighted models, using both a logged dependent variable (hereafter the LLM model) and an untransformed dependent variable (hereafter the LM model). Because we have no economic rationale for preferring one dependent variable formulation over the other, we use comparable R^2 statistics to identify the preferred specification and find that the LM is preferred (Wooldridge 2012).[20] Therefore, in the remainder of the paper, we present the results of the LM model but include a parallel set of results in the appendix for the LLM model.

In terms of weighting, we focus our discussion on the estimates that put greater weight on the larger transactions in the larger markets.[21] Smaller markets are less important for the fishery both from an economic and ecological point of view and often have few transactions. To put more weight on the transactions from the larger markets, we weight the quota prices by the size of the potential market (IFQ pounds in an area/class/blocking combination). Because there are reasons to think that the price signals from larger (relative) trades within a market might be more reliable in any given year, we also weight by size of the transaction relative to the size of all transactions in that submarket in a year.[22] The weighting approach provides a good approximation of the value/pound reduction due to restrictions to each pound in the fishery.

For comparison purposes, we also illustrate the unweighted regression results (specification II). The coefficients of the unweighted regression can be interpreted as the average observed difference in transacted quota prices, after controlling for interacted year and area fixed effects, policy changes, and seasonal effects.

By multiplying the per-pound-equivalent reductions with the size of the market (i.e., amount of restricted TAC pounds in each category in 2011), we obtain es-

20. Parameter estimates for both models are provided in the appendix.

21. Specifically, the total weight assigned to an observation is the product of a within submarket weight and a between submarket weight. To arrive at the within submarket weight, we begin by calculating the total pounds transferred via all the transactions in each class/blocking/area submarket. This is just the sum of the pounds in each of the transfers in the submarket. Within the submarket, we give each transaction a within submarket weight that is proportional to the pounds in the transaction. The between submarket weight is proportional to the class/blocking/area share of the TAC.

22. For example, with one restriction the weight a restricted transaction would receive would be

$$\frac{\text{Restricted } TAC}{\text{Restricted+Unrestricted } TAC} \times \frac{\text{Pounds in transaction}}{\text{Total restricted pounds transferred}}.$$

timates of the total efficiency loss. In the remainder of the paper, we focus on describing the costs of the restrictions based on the regression results for the restrictions individually and in aggregate.

Costs of Vessel Class Restriction

In table 3 and figure 3, we break down the effect of the vessel class restriction by blocking status. In the halibut market, the results suggest that the Class A unblocked quota trades for higher prices than Class B, C, and D unblocked quota by $2.63, $3.04, and $5.24, respectively. Recall that Class A quota is the least restrictive quota across a number of dimensions, including that it can be fished on any size of vessel, can be leased, and can be owned by a company or individual. In fact, during our time frame, we find that all Class A quota was landed by the same length and type of vessels as Class B quota. Therefore, the large and significant difference that we estimate between Class A and Class B unblocked QS prices in the halibut fishery is a measure of the economic efficiency gains associated with having an essentially unrestricted use of the quota.

Within each vessel class, there is also blocked quota. In the halibut blocked market, we find that the difference between the value of A blocked quota and D blocked is $4.48 and the difference between A blocked quota and C blocked quota prices is $1.92. The difference between halibut Class A blocked quota and halibut Class B blocked quota is not statistically significant. This result could stem from a number of factors but most likely is due to the limited Class A blocked halibut quota allocated and even fewer trades.

In the sablefish market, we find that unblocked Class B and C quota trades approximately $1.39 and $1.61 lower per pound than Class A unblocked quota, respectively. Blocked B and C quota trade $2.52 and $3.07 below A blocked quota. Within both the halibut and sablefish unblocked and blocked categories there is overlap in the confidence intervals between the Class B and Class C coefficients (fig. 3). It could be that there is not a large difference in profitability between the two sizes of vessel.

Costs of Blocking Restriction

Table 3 and figure 3 also include statistics summarizing the effect of the blocking restriction broken down by vessel class. We find for the halibut market that Class A blocked quota trades at approximately $3.31 less than Class A unblocked quota, B blocked is lower than B unblocked by $1.55, C blocked lower than C unblocked by $2.19, and D blocked lower than D unblocked by $2.54. In the sablefish market, we find that B blocked quota is $1.90 lower than B unblocked, and C blocked trades $2.23 lower than C unblocked.

Generally, our regression results suggest that blocked quota trades at lower prices relative to unblocked quota. The one exception is in the sablefish Class A market.

Table 3. Change in Quota Prices due to Blocking and Vessel Class Restrictions (in $2012): LM Model

	Equal Weight for each Pound Transacted within an Area/Class/Blocking Combination[a] (I)		Unweighted (II)	
	Halibut	Sablefish	Halibut	Sablefish
	Impact of Class Restriction on Unblocked Quota Prices			
B unblocked	−2.627***	−1.389***	−3.537***	−1.862***
	(.412)	(.530)	(.757)	(.389)
C unblocked	−3.042***	−1.613**	−1.814**	−1.523***
	(.435)	(.650)	(.762)	(.390)
D unblocked	−5.239***	NA	−7.13***	NA
	(.746)		(.914)	
	Impact of Class Restriction on Blocked Quota Prices			
B blocked	−.869	−2.518***	−1.768	−2.804***
	(.603)	(.261)	(1.160)	(.344)
C blocked	−1.92***	−3.071***	−2.539**	−3.637***
	(.617)	(.296)	(1.160)	(.356)
D blocked	−4.475***	NA	−5.897***	NA
	(.624)		(1.166)	
	Impact of Blocking Restriction			
Class A	−3.308***	−.771	−2.65*	−.959**
	(.713)	(.470)	(1.365)	(.467)
Class B	−1.55***	−1.899***	−.882***	−1.901***
	(.195)	(.195)	(.277)	(.213)
Class C	−2.185***	−2.229***	−3.376***	−3.072***
	(.257)	(.249)	(.258)	(.189)
Class D	−2.543***	NA	−1.417**	NA
	(.665)		(.574)	

Note.—The coefficients should be interpreted as absolute changes in real quota price. A negative coefficient implies that the restricted quota price is below that of the unrestricted quota price. The unblocked (blocked) class restriction coefficients represent the difference between unblocked (blocked) Class B, C, and D unblocked (blocked) quota relative to Class A unblocked (blocked) quota. The blocking restriction coefficients represent the difference between blocked and unblocked quota in each vessel class. The standard errors of the coefficients are below the coefficients.

[a] The combination is weighted by the average yearly percentage of the TAC.

* $p < .1$.

** $p < .05$.

*** $p < .01$.

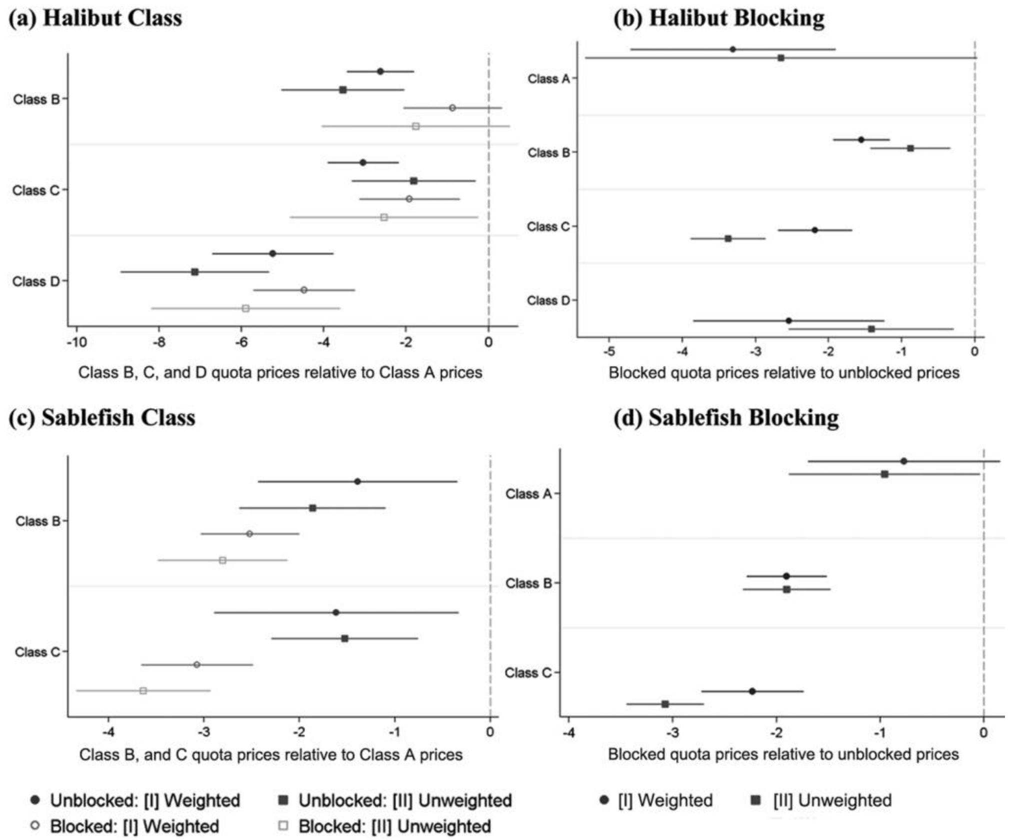

Figure 3. Difference between restricted and unrestricted quota prices ($2012). Impact of the class and blocking restrictions. A color version of this figure is available online.

This result is not surprising given that there is so little blocked quota allocated and, similarly, so few transactions. Furthermore, because every participant may hold up to one block of quota and still hold unblocked quota, it is possible the blocking restriction on Class A quota has little impact.

Total Cost of Restrictions

In addition to calculating the cost of the blocking and vessel class restriction for each possible combination, we can aggregate these costs based on the size of the market to arrive at estimates of the total efficiency loss due to the set of restrictions (see table 4). We do this by calculating a linear combination of the coefficients on the restriction dummy variables and the associated restricted TAC.

We estimate that including restrictions in the ITQ program design decreased the present value of resource rent over the lifetime of the program by approximately $117 million for halibut and $40 million for sablefish (in US$2012), relative to a hypothesized case where the restrictions were not included in the program design. To aid in the understanding of these numbers we also present the total costs of restrictions as a percentage of total resource rent.[23] We find that including the restrictions resulted in a reduction in resource rent of 25% (36%) and 9% (10%) in the halibut and sablefish fisheries, respectively, when calculated for the year 2011 (2000).

Additionally, we provide separate estimates for the total impact of the class restriction and for the total impact of the blocking restrictions (table 4). In the halibut fishery we estimate a reduction in resource rent due to the class restriction equal to US$73 million. We estimate the impact of the blocking restriction on resource rent to be a reduction of approximately $28 million, or about 40% as large as the impact of the class restriction.[24] In the sablefish fishery the impact on resource rent due to restrictions is dominated by the class restriction, with a total reduction in resource rent associated with these restrictions of $36 million relative to an $8 million reduction in resource rent attributable to the blocking restriction.

ROBUSTNESS CHECKS

In this section, we explore the robustness of our results to different weighting schemes under similar parametric assumptions and in a nonparametric analysis (local linear regression).[25] Our intent is to present results that follow directly from several sets of

23. We estimate the total resource rent using the mean values of variables such as the area and season where appropriate. We then calculate the percentage reduction in resource rent as the estimated resource rent with restrictions in place divided by the total estimated unrestricted rent.

24. Note that the total impact does not equal the sum of the class and the blocking impacts due to the presence of significant class × blocking interaction terms.

25. An alternative model is to formulate a regression without the year and area interacted dummy variables and instead include variables related to the underlying factors that change

Table 4. Aggregate Change in Resource Rent due to Restrictions (in $million)

	Point Estimate (95% Confidence Interval)	
	Halibut	Sablefish
Total (class and blocking):		
(I) Equal weight for each pound transacted within an area/class/blocking combination[a]	−117.3	−39.5
	(−139.7, −94.9)	(−62.7, −16.3)
(II) Unweighted	−120.5	−45.7
	(−162.8, −78.2)	(−60.9, −30.5)
Class only:		
(I) Equal weight for each pound transacted within an area/class/blocking combination[a]	−73.1	−36.2
	(−93.2, −53.0)	(−56.1, −16.3)
(II) Unweighted	−85.1	−41.6
	(−122.8, −47.4)	(−54.4, −28.8)
Blocking only:		
(I) Equal weight for each pound transacted within an area/class/blocking combination[a]	−28.3	−8.2
	(−33.4, −23.1)	(−9.4, −7.1)
(II) Equal weight per transaction	−33.8	−10.2
	(−38.7, −28.8)	(−11.3, −9.0)

Note.—Negative numbers imply lower resource rent.
[a] The combination is weighted by the average yearly percentage of the TAC.

valid justifications and explore the robustness of our results. We find that the preferred model results are robust to a number of specifications and approaches.

Parametric Robustness Checks

We explore weighting schemes based on two different criteria: the first is market size and the second is the size of the transaction. Additionally, for each weighting scheme, we test the assumption that there is a statistically significant change in the difference throughout the program.[26]

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through time that may influence quota prices. We present the results with year and area interacted dummy variables as our primary results because they are more parsimonious and the fit is similar.

26. Specifically, we rerun the analysis using subsets of the data corresponding to early and later periods in the program. We find that the signs and magnitudes of the coefficients are generally similar and the overall estimates of the costs of the restrictions do not differ significantly.

Market Size Only

We explore the impact of assigning each transaction within a submarket equal weight; the between submarket weight is proportional to the class/blocking/area share of the TAC and is the same as in the preferred specification. There are differences in some cases in the magnitude and statistical significance of the parameter coefficients and point estimates of the costs of the blocking and vessel class restrictions (see table A3 in the appendix). However, we find that the confidence intervals for this and our preferred specification of the total impacts are overlapping (see table A4 in the appendix).

Transaction Size

To account for the volume transacted (including exploring the impact of block size) on our estimates of the costs of restrictions, we estimate a model weighting each observation according to the number of pounds in the transaction (with no between submarket weights). The rationale for pound-weighted models is that if the quota price differs according to transaction or block size, then changing the weight given to the transactions will change the coefficient estimates on the blocking dummy variables. The result is that the coefficients on the restriction dummy variables represent the average difference in the price per pound per pound transacted. As with the submarket size weighting scheme, we do find differences in the estimated impacts for the blocking and vessel class restrictions, but they are all the same sign and similar magnitude as our preferred model (table 3), and confidence intervals for the total costs of restrictions overlap with those of the preferred model (table 4).

Nonparametric Analysis

Our assumption that average differences in restricted and unrestricted quota prices are sufficient to characterize efficiency losses would fail if there is a clear trend in the difference over time (for example, the difference systematically increases or decreases over time). To explore this assumption we concentrate on the densest submarkets in order to generate nonparametric estimates of the restricted and unrestricted quota prices over time using a local linear regression with epanechnikov weights and a fixed bandwidth (window) of 12 months.[27]

We present the restricted and unrestricted quota prices along with 95% confidence intervals in figure 4 for two example markets: 3A Class C blocked versus

27. When estimating the nonparametric fitted curve at a particular point, this choice of kernel and bandwidth gives higher weight to observations that occur closer in time within the window and zero weight outside the window. Using a window of 12 months provides a nice balance between the comparability of the prices and having a large enough window to ensure adequate market activity.

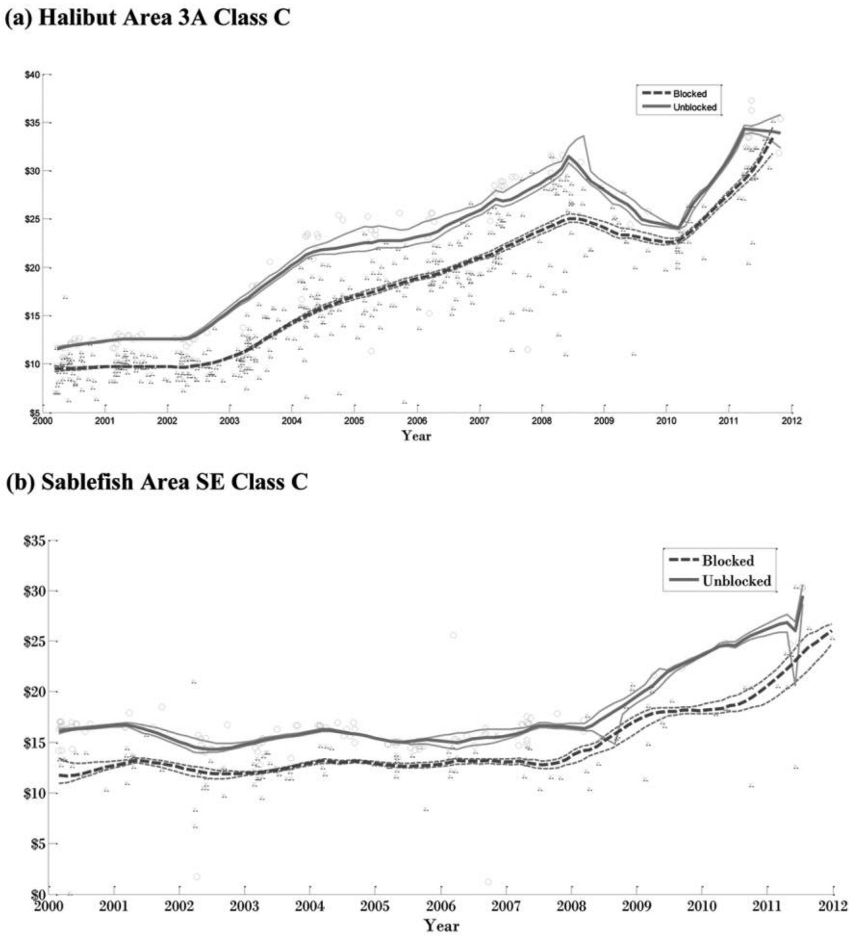

Figure 4. Nonparametric estimation of restricted (blocked) and unrestricted (unblocked) quota prices ($2012). A color version of this figure is available online.

unblocked and SE Class C blocked versus unblocked.[28] The nonparametric curves were fit at 100 equally spaced points during the 2000–2011 time period. The confidence intervals were constructed by reestimating the nonparametric curve after removing a random subset of observations. For the results we present, we randomly

28. We also include estimates for the 2C Class C blocked versus unblocked, 2C blocked Class C versus Class D, and 3A unblocked Class B versus Class C markets in figure A2 in the appendix.

chose 10% of observations to remove and replicated the procedure where we remove 10% of the observations randomly 5,000 times.[29] The confidence bands are calculated for each point of the function evaluation and are calculated as the observation in the lowest 2.5th percentile of the fitted values of the replicate curves and the 97.5th percentile observation. Figure 4 also includes the original quota prices that are used to estimate the two (restricted and unrestricted) curves.

The nonparametric results suggest that there are not significant changes to the differences in restricted and unrestricted prices over time. Figures 4*a* and *b* corroborate our regression results; the 95% confidence interval of the difference in prices attributable to the blocking restriction implied by the fitted curves contains the point estimates from the parametric models.[30] Furthermore, our nonparametric modeling (fig. A2*c* in the appendix) is also suggestive of the fact that there may not be a significant difference between Class B and Class C prices.

CONCLUSIONS AND DISCUSSION

TPPs are policy instruments that have the potential to achieve economic efficiency. However, theoretical efficiency gains may not be realized in practical applications, which necessitates evaluation of the actual performance of TPPs (Hahn 1984).

On their own, TPPs can create additional economic value; however, as we have shown, the design can influence returns. Across all of our models and the time period 2000–2011, the estimated total cost of including restrictions in the ITQ program design is on the order of 10%–35% of the total resource rent. Better-informed decisions can be made if estimates of the costs of various types of restrictions are available and can be weighed against the potential benefits.

Several important areas of research remain that could help refine estimates of the costs of restrictions in the halibut and sablefish TPP. First, we estimated the equilibrium cost but the total costs of the restrictions needs to consider the costs in each year, which is dependent on how the restrictions affect the adjustment path of capital in the fishery. Developing the necessary counterfactual (what the adjustment path would have looked like without the restrictions) will entail estimation of a dynamic

29. Our result that the difference between restricted and unrestricted quota prices does not show a significant trend over time is robust to the choice of the percentage of observations to omit, although obviously we cannot omit relatively large percentages and still estimate the curve. Our result is also robust to the number of points of evaluation.

30. We calculate the difference between the two fitted curves and bootstrap, with replacement, to estimate an average difference and a 95% confidence interval. We find that halibut 3A Class C blocked quota trades for approximately US$4.22 lower than unblocked (95% CI –$6.41, –$1.69). Sablefish SE Class C blocked quota trades for approximately $2.90 USD lower than unblocked (95% CI –$5.13, –$0.92).

discrete choice model of entry/exit decisions of quota owners. Such a model will also allow for the quantification of potential benefits such as the change in number of vessels and crew fishing, and crew income. Second, in this paper we examine several types of restrictions but do not go into detail about how the restrictions may interact with one another and how these interactions may also influence economic efficiency. Third, while we focused on direct impacts of restrictions, restrictions may also affect economic efficiency indirectly through increased transaction costs (Hahn 1984; Stavins 1995; Fowlie and Perloff 2013). How transaction costs affect participation in and subsequently the efficiency of these markets seems like an important area for further study.

Furthermore, we control for the area in our analysis, but we do not attempt to estimate its impact on current and future fishery profit. Other contexts where spatial heterogeneity in location (of extraction or pollution) is important include groundwater use, water quality, and air pollution (see, e.g., Seskin, Anderson, and Reid 1983; Farrow et al. 2005; Lankoski, Lichtenberg, and Ollikainen 2008; and Muller and Mendelsohn 2009). In the fisheries context, a spatially differentiated management structure may outperform a homogeneous management structure (one area) in terms of efficiency, if the population is indeed spatially differentiated and depending on the degree to which the area designations account for the underlying population structure. We leave for further analysis a quantitative assessment of optimal management area choice, optimal setting of TACs, and the impact of these choices on profitability.

Our results are relevant for the design and assessment of TPPs attempting to achieve multiple objectives through the imposition of trading restrictions. One common type of restriction is the creation of sectors (akin to vessel classes in our analysis) within a broader trading scheme for the same resource or pollutant, between which there are barriers to trade (or between which trading is completely restricted). Sectors can include industrial sectors; for example, in recently implemented Chinese carbon programs sectors, including transportation, water, hotels, restaurants, and public institutions, are included in some but not all of the programs (see, e.g., Munnings et al. 2014).

Additionally, new potential applications of TPPs are being proposed, including the management of habitat (Wissel and Watzold 2010), biodiversity (Gunningham and Young 1997), and agrobiodiversity losses associated with land cover changes (Pascual and Perrings 2007). With more TPPs being proposed and implemented worldwide, it is likely that the implementation of restrictions within TPPs will continue in the future.

This work is also relevant in light of the emphasis in fishery management programs on nonefficiency objectives, including vibrant coastal communities, maintaining the culture of fishing communities, and healthy ocean ecosystems. Nonefficiency goals often relate to the distribution of the benefits and costs of management changes (see, e.g., Wilen [2013] for a discussion of the political economy of small-scale artisanal fishery management reforms). Recent policies such as a mandate under the Magnuson Stevens Act National Standard 8 have begun to require that the design and evaluation of management policies take into account the impact of management changes on fishing jobs and communities. In turn, researchers have begun to evaluate nonefficiency goals. For example, community-level changes are being evaluated by creating indices of vulnerability, resilience, and participation (see, e.g., Sethi, Reimer, and Knapp 2014; Himes-Cornell and Kasperski 2015).

When multiple management goals exist, using a single policy instrument to accomplish all of the goals simultaneously poses challenges for policy design and can reduce the economic efficiency of the policy (see, e.g., Péreau et al. [2012] for a general discussion and analysis of the challenge of designing ITQs to meet multiple objectives). Empirical analyses, such as the analysis in this paper, are necessary to provide decision makers with quantitative estimates of trade-offs between economic efficiency and nonefficiency goals.

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