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Did Processing Quota Damage Alaska Red King Crab Harvesters? Empirical Evidence

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Abstract *The Bering Sea and Aleutian Islands (BSAI) red king crab fisheries are managed with a controversial, market-based policy design, in which both individual transferable fishing and processing quotas are used. Despite the fact that the policy design maintains contestable markets, concern remains that the use of individual transferable processing quota (IPQ) damages harvesters who receive individual transferable fishing quota (IFQ). An integer, nonlinear optimization model that incorporates an empirically estimated, non-linear catch per unit effort function is developed to measure imputed IFQ values. The imputed quota values are based solely on harvesting efficiency in the absence of IPQs or potential wealth redistribution between sectors. Results are compared to a pre-rationalization optimization model and also to empirical quota trading prices in the presence of IPQs. This with and without analysis lends insight into whether and/or the extent to which IPQs damaged BSAI crab harvesters.*

Key words Crab rationalization, IPQ, IFQ, imputed quota prices, harvesting efficiency.

JEL Classification Codes Q22, Q28, D61, C61, L78.

Introduction

The most controversial fishery policy in the U.S.A., and possibly the world, was implemented fall 2005 in the Bering Sea and Aleutian Islands (BSAI) crab fisheries off western Alaska (Benton 2002). The cornerstones of the BSAI crab rationalization design were the use of individual transferable processing quota (IPQ), along with individual fishing quota (IFQ), and specific fishery-dependent community protections. These policy design elements were intended to maintain contestable markets (Baumol 1982; Baumol, Panzar, and Willig 1982; and Bresnahan and Reiss 1991), while recognizing prior economic interests and the importance of the partnership between harvesters, processors, and ultimately, fishery-dependent communities (Duffy 2002).

Until recently, individual transferable quota policies recommended by economists allocated only IFQs to harvesters, despite consequential and unintended

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redistribution of processing sector wealth to harvesters (Lindner, Campbell, and Bevin 1992; Matulich, Mittelhammer, and Reberte 1996; and Matulich and Sever 1999). Following years of intensive industry negotiations that settled on the so-called "two-pie allocation" of IPQ and IFQ, the North Pacific Fishery Management Council (Council) broadened the policy design to include specific community protection elements. On June 10, 2002, the Council unanimously passed a "three-pie voluntary cooperative" policy that recognized the economic interests of all three sectors, mindful of the tradeoffs between maximum efficiency and maximum efficiency subject to various social goals. The Council motion was enacted into law January 2004 (16 U.S.C.S. § 1862(j)(1), (2) (Supp. IV 2004)).

The policy design promised to increase economic returns and stability for harvesters, processors, and communities and to enhance overall efficiency by encouraging voluntary industry cooperation, so each of the three partners look beyond simple self-interest to the synergistic benefits of mutual interests (Duffy 2002). Nevertheless, the plan is not without a long list of critics. Some crab harvesters, economists, individuals in state and federal fishery agencies, the U.S. Department of Justice, members of Congress, fishermen from around the country, fishery conservation organizations, and even editors of major newspapers across the country reviled the plan. A common theme among the critics is that IPQs increase antitrust risks and will damage the economic welfare of harvesters.

Despite rhetoric that equated the crab rationalization policy with slavery (Young 2004 and Tillion undated), communism (McCain 2004), and Stalinism (Bromley 2005), the Council took a circumspect, wait-and-see view of this novel policy. The Council required unprecedented socio-economic data collection from all quota recipients; they also required an early, 18-month policy review, a three-year review, and five-year review for the purpose of assessing whether the policy was achieving its intended goals. Upon passing the policy, the Council notified industry and the public that it would modify the policy if the Council's intent/goals were not achieved.

The research reported in this article was initiated at the request of the Commissioner of the Alaska Department of Fish and Game, two years prior to plan implementation. Commissioner Duffy recognized that the economic data would likely provide scant empirical evidence for the early 18-month review and may not be adequate for the three-year review. He asked that the research, which was initiated prior to fall 2005 implementation, provide insight into expected rationalization benefits and, in particular, address whether the use of IPQs has detrimental effects on harvesters that the critics claimed were inevitable.

Economic performance of the Bristol Bay red king crab fishery is modeled with and without rationalization. The analysis abstracts from the many detailed elements of the policy, though still captures the expected efficiency benefits or losses to harvesters. Harvesters, for example, were allocated 100% of their qualified catch history as IFQ, while processors received only 90% of their corresponding qualified processing history as IPQ. Ninety percent of the catch has to be delivered to any processor holding IPQ. The residual 10% IFQ allocated to harvesters has no delivery restrictions; *i.e.*, does not have to be delivered to a processor holding IPQ. This unbalanced quota allocation between sectors was fiercely negotiated by harvesters as a means to increase ex-vessel price leverage over processors who, some argued, would derive market power from IPQs. The intended effect of the 90:10 split was to allow both sectors and fishery-dependent communities to benefit from rationalization, and to maintain opportunities for new entrants into processing (National Marine Fisheries Service 2004). Formation of voluntary cooperatives, community protection measures, binding arbitration, skipper shares, use caps, and inclusion of community development quota are also omitted from the analysis.

None of these elements are essential to determine whether harvesters were damaged from IPQs relative to the license-limited policy state. It is only necessary to establish whether qualified harvesters (vessel owners) who were allocated IFQ in the Bristol Bay red king crab fishery were better or worse off following plan implementation, absent any cross-sector redistribution—intended or otherwise. This goal is achieved by measuring pure harvesting efficiency gains with and without rationalization at precisely the same ex-vessel price; *i.e.*, by removing any possible influence of IPQs from the analysis. Although the Council and Congress were silent on the distribution of rationalization benefits between harvesters and processors, providing both benefitted, the analysis lends insight into whether the policy design might have skewed the benefits toward one sector or the other. To this end, a comparison of the equilibrium imputed quota price and the empirical market price of quota indicates whether harvesters benefitted more or less than the pure efficiency value of rationalization. No attempt is made to measure the impact of the program on processors or communities, though all communities are assured their historic share of landings and, thus, landings taxes.

Data and Methods

Optimal fishing behavior under license-limited access management is contrasted with transferable quota management and attending fleet consolidation. Two integer, nonlinear optimization models are constructed to evaluate policy-induced behavioral changes. The license-limited access optimization model developed by Briand *et al.* (2004) for the Bristol Bay red king crab fishery is extended to better reflect fleet heterogeneity, updated cost of production data, and a revised objective function that more accurately captures actual returns to individual vessels and the fleet. Relatively little detail is presented for the license-limited access model because the modifications required to accommodate these few changes were relatively minor. Interested readers should consult Briand *et al.* (2004) for a complete model description. An overview of the transferable quota management model is presented below, following introduction to the nonlinear catch per unit of effort (CPUE) function. Policy-induced behavioral changes are highlighted.

A centerpiece of both optimization models is a nonlinear CPUE function relating the time a crab pot soaks (soak time) to CPUE. A generic representation of that logistical, von Bertalanffy-type function is $CPUE_V = \beta_0(1 - e^{-\beta_2 ST_V})$, where ST_V is the vessel specific soak time, β_0 is the asymptotic catch, and β_2 is the catch rate.[1] The CPUE function was empirically estimated from state and federal fishery time series data for the Bristol Bay red king crab fishery and recalibrated to conditions reflecting the 2004 season. Conceptual and estimation details regarding this CPUE specification are detailed in Briand, Matulich, and Mittelhammer (2001). Calibration is discussed below.

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[1] The relationship between CPUE and soak time is extensively reviewed in Miller (1990). Collectively, the literature provides evidence that CPUE (generally measured as total catch of crabs or fish per trap) increases asymptotically with soak time due to a progressive reduction in both bait effectiveness and the density of the species being fished. Additional factors found in the experiment-based literature to affect the shape of the asymptotic CPUE-soak time relationship include: size and effectiveness of the gear (*e.g.*, Munro 1974); inter- and intra-species behavioral interactions (*e.g.*, Miller 1979); local stock density (*e.g.*, Sinoda and Kobayasi 1969); and general environmental conditions such as temperature, time of day, and current (*e.g.*, Bennett and Brown 1979). Zhou and Shirley (1997) found an asymptotic catch model to be particularly appropriate to describe the CPUE-soak time relationship for short fishing seasons, like red king crab. Ability to move gear during a rationalized fishery similarly avoids localized stock depletion.

The 2004 fishery not only was the last license-limited access crab fishery, it had the dubious distinction of being the quickest race-for-fish on record. A fleet consisting of 243 catcher vessels (CVs) plus eight-catcher processors (CPs) harvested 13,889,067 pounds of red king crab, in just three days-eight hours. The CV fleet harvested 95.7% of the total catch.

Fleet heterogeneity is approximated in this study by disaggregating it into five-vessel size classes (<100 feet, 100–109 feet, 110–125 feet, 126–139 feet, and >139 feet). Harvesters in each vessel class were surveyed prior to the 2004 season to obtain cost of production data similar to the economic data collection required by the policy. Thirty-eight mostly independent vessels participated in the survey to reflect the behavior, catch, and cost structure across the heterogeneous fleet. Each vessel-length class is assumed to consist of homogeneous, representative vessels, the number of which conforms to the fleet structure in the year being modeled or the policy scenario. All fleet data, including total catch-by-vessel-class and initial quota allocations were compiled by the Alaska Department of Fish and Game (ADF&G) from confidential fish ticket files.[2]

Abbreviated Optimization Model

The rationalized fishery model integrates quota-trading elements of Matulich, Mittelhammer, and Reberte (1996) and Matulich and Sever (1999) into a variant of the license-limited access optimal fishing behavior model of Briand *et al.* (2004). Like Briand *et al.*, this optimization model is constructed in the context of a complete description of the fishing process and the policy-induced incentives harvesters have to adjust the fishing process.

Individual harvesters are assumed to adopt optimal fishing strategies. Optimum amounts of gear and soak times that maximize quasi rents (revenues in excess of variable costs) define the individual vessel catch for an expected or given season length. Each harvester's optimization problem is subject to a variety of constraints. A common season length across all harvesters aggregates vessel-specific catch to fleet-wide catch.

Regardless of policy state, vessels retain a portion of the gross revenue after deducting the crew's share of operating expenses (fuel and bait costs, and in the case of a rationalized fishery, the annual rental cost of acquired quota). Though crew payment practices differ somewhat across the fleet, the most common practice is that the crew is paid a share of the gross revenues, net of bait and fuel expenses, and the annual rental cost of acquired quota. Typically there is no deduction for the initial quota allocated to the vessel. The vessel is responsible for paying a constant $25 per crewday for food and P&I insurance costs, plus all variable pot costs, though this practice also differs somewhat across the fleet. Some vessels, for example, require crew to pay for all food so as to lessen food waste. Inactive vessels that rent their initial quota allocation to another vessel earn quasi rents equal to the quota payment they receive. A consolidated representation of the fleet-wide constrained optimization problem is given in equation (1).

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[2] The initial quota allocations compiled by ADF&G may not be identical to the official allocations made by the National Marine Fisheries Service (NMFS). However, any error should be small because the NMFS official allocations were based on ADF&G fish ticket data.

$$\underset{n_{Vi}, m_{Vi}, ST_V, SL_V, T_V, \omega'_V}{Max} \sum_{V=1}^{5} \sum_{i=1}^{N_V} QR_{Vi} = \sum_{V=1}^{5} \sum_{i=1}^{N_V} (1 - \gamma_V)\big[P * Catch_{Vi}(n_{Vi}, m_{Vi}, ST_V, SL_V) \tag{1}$$

$$- CVC_V(n_{Vi}, m_{Vi}, T_V)$$

$$- s\omega'_{Vi},\ s = \begin{Bmatrix} (1 - \gamma_V)S,\ \omega'_{Vi} \geq 0 \\ S,\ \omega'_{Vi} < 0 \end{Bmatrix}$$

$$\begin{aligned} st \quad & SL_{Vi} \leq T_{MAX} \\ & n_{Vi} \leq PotLimit_V \\ & \sum_{V=1}^{5} \sum_{i=1}^{N_V} Catch_{Vi} \leq TAC \\ & Catch_{Vi} = \omega_{Vi} + \omega'_{Vi},\ \omega'_{Vi} \underset{>}{\leq} 0. \end{aligned}$$

The indices V_i denote the *i*th vessel in vessel-length class V; N_V is the number of vessels in class V; QR_{Vi} denotes quasi rents retained by the vessel; $(1 - \gamma_V)$ denotes the vessel share of revenues net of shared operating expenses; γ_V is the crew share; P denotes the ex-vessel price of crab, net of taxes and fees; $Catch_{Vi}$ is the total harvest by the vessel, which is derived from the CPUE function scaled by the number of pots fished (n_V) and the number of times they are picked (m_V) during the fishing season of length (SL_V); crew variable costs (CVC_V) is the fuel and bait cost that is shared by the crew and the vessel; vessel variable costs (VVC_V) is the daily cost of food, P&I insurance, and the variable pot costs, which are borne solely by the vessel; ω_{Vi} is the initial quota allocation; ω'_{Vi} is the amount of quota bought ($\omega'_{Vi} > 0$), held ($\omega'_{Vi} = 0$), or sold ($\omega'_{Vi} < 0$); S is the equilibrium quota price defined by the unit quasi rents (UQRs) earned by the marginal active and inactive vessels; and TAC is the total allowable catch.

The shared fuel and bait cost is a function of the number of pots fished, the number of times they are picked, and the vessel-specific elapsed time (T_V). The elapsed time is the sum of time spent in preseason activities ($PreT_V$), the non-uniform rotation of fishing activities that are systematically updated to define the optimal season length (SL_V), and post-season activities ($PostT_V$). Systematic linkage of time-dependent activities is explained in the next subsection. VVC_V is a function of the number of pots fished and the elapsed time, T_V.

Conceptually, the model is constructed around two clocks. The first clock accumulates time within the fishing season, SL_V, as catch accumulates, and the second clock accumulates time from the beginning of preseason activities and ends with completion of all post-season activities, T_V, as operating costs accumulate. Note that the vessel-specific season length is determined by the soak times of the pots fished, as well as the choices of n_V and m_V.

The final term in the objective function is the cost/revenue from quota trading, following current industry convention. The crew pays a share (γ_V) of annual quota cost ($S\omega'_V$) on all rented quota at the time of delivery, like bait and fuel expenses, so that active vessels pay $s\omega'_{Vi} = (1 - \gamma_V)S\omega'_{Vi}$, $\omega'_{Vi} > 0$ on rented quota. Exiting vessels retain the full value of quota that is rented to another vessel ($s\omega'_{Vi} = S\omega'_{Vi}$, $\omega'_{Vi} > 0$).[3] Optimal quota holding behavior of profit maximizing firms is given by:

$$\text{if } UQR_{Vi}\begin{Bmatrix} > \\ = \\ < \end{Bmatrix} s, \text{ then } \begin{Bmatrix} \text{acquire quota } (\omega'_{Vi} > 0) \\ \text{optimal quota } (\omega'_{Vi} = 0) \\ \text{sell quota } (\omega'_{Vi} < 0) \end{Bmatrix}. \tag{2}$$

The term $-s\omega'_{Vi}$ is removed (along with the last constraint) when modeling the license-limited access policy state.

The first constraint establishes the season length. Vessels trade quota so that the fleet consolidates until the *TAC* is harvested in the longest season length that allows completion of all integer-fishing activities (not including the pre- and post-season activities) within T_{MAX} days. This consolidation to the core fleet minimizes variable operating costs and maximizes quasi rents. The second constraint defines the maximum number of pots, n_V, that the operator fishes as less than or equal to the regulatory pot limit, $PotLimit_V$.[4] The third constraint prevents fleet-wide catch from exceeding the *TAC*. The last constraint limits catch per vessel in a rationalized fishery to its quota holding. The third and fourth constraints together serve as the market equilibrium condition that supply of quota equals demand.

Systematic, Non-Uniform Fishing Rotation

The abbreviated model in equation (1) is expanded primarily by delineating the systematic, non-uniform fishing rotation and then expressing $Catch_V$ in terms of the updated nonlinear CPUE function. The length of each rotation is a function of time-dependent decision variables and the duration of the prior rotation.

The crab fishing process is assumed to begin in Dutch Harbor, Alaska, where pre-season activities occur. Pre-season activities include stacking pots aboard the vessel, up to the lesser of the VCC_V or the regulatory pot limit. Vessels wishing to fish more pots than their VCC_V must haul gear to designated wet storage areas near the fishing grounds before the season. These pots may be retrieved only after the season commences.[5] Immediately before the season, loaded vessels travel to the fishing grounds, where they wait for the season to commence; *i.e.*, when in-season

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[3] The last two constraints assure supply of quota equals demand. These constraints prevent vessels from renting out their initial quota allocation at S and then acquiring all quota at $(1 - \gamma_V)S$. More importantly, crew refuse to work for a payment equal to γ_V ($P * Catch_V - CVC_V - S * Catch_V$). Vessels that deducted the cost of quota on all quota, both their initial allocation and rented quota, lost their crew. The current convention of treating the cost of rented quota like bait and fuel may change over time. A deduction on all quota equal to the opportunity cost of capital, an amount considerably less than the crew share, seems likely, especially after the first generation of quota recipients retires from the fishery. Achieving a quota pricing equilibrium may take many years. The now 13-year-old North Pacific halibut IFQ program still uses a crew-share deduction convention on quota.

[4] In 2004, vessels less than or equal to 125 feet in length were allowed to fish 200 pots, whereas vessels greater than 125 feet were allowed to fish 250 pots. Rationalization in 2005 increased the pot limit regulation to a common 450 pots per vessel.

[5] Elongated seasons due to rationalization also allow vessels to retrieve additional gear from onshore storage, at or near the dock. This alternative is not modeled. The crab rationalization policy also allows vessels to join fishing cooperatives that may share gear, which can alter the preseason decision to set and retrieve additional gear from wet storage. This feature of fishing behavior cannot be included in this model, possibly resulting in a slight overstatement of fishing costs.

fishing activities start. In-season activities involve the general fishing process of sequentially setting and picking pots. In its simplest form, the fishing process involves setting a baited pot on the seabed and soaking it a unit of time (ST_V). The pot is then picked from the seabed; legal male crabs are retained; and the pot is re-baited and re-set or stacked on deck and moved to a new location, where it is re-baited and re-set. This simplified pick/set cycle is repeated for all pots, one at a time, until season closure. In reality, however, the optimal soak time and thus CPUE, depends upon when in the season it is being measured, the ultimate season length, the number of pots being fished, whether or not the pots that are soaking are influenced by a prior delivery to a processor, and/or whether the vessel stopped actively fishing to allow a period of sleep. Soak time and CPUE are dependent on what occurred in the prior time period. Post-season activities involve delivering the final load of crab to a processor, returning to the fishing grounds as many times as necessary to pick up all gear, and unload it at onshore pot storage.

There are three distinct fishing periods within a season. Behavioral differences stemming from the two management regimes are most easily contrasted by first describing the general crabbing process in the context of the license-limited fishery. Period 1 consists of the initial unstacking/baiting/setting, picking/emptying/stacking/running, and baiting/resetting all pots. Vessels that choose to fish pots in excess of their vessel carrying capacity take an in-season trip from the fishing grounds to a wet storage area in order to retrieve additional pots. These vessels first set all pots initially carried to the grounds before retrieving additional pots. It is assumed that vessels set all pots retrieved from wet storage before picking, re-baiting and re-setting the gear, and that all pots are picked in the order that they were set. All pots soak a different amount of time throughout Period 1. The soak time for the first pot that is set is determined by the amount of time it takes to set all remaining pots in the first period, including any time spent obtaining gear from wet storage. The initial soak time of any other pot is determined by its exact position in the fishing sequence. Period 2 is characterized by a constant per pot soak time; the pick-set process is repeated for all pots, possibly multiple times. Anticipation of season closure may require vessels to rebait and reset only a subset of the pots at the end of Period 2. The remaining pots are picked/emptied and reset back on the seabed, unbaited, with doors open for post-season collection. The third and last period under the race-for-fish consists only of the final pick of those pots that were baited and set at the end of Period 2. Period 3 ends with all baited pots picked/emptied and set back on the seabed, unbaited with doors open.[6] Season compression to just a few days when racing for fish means the crew works around the clock, without sleep. Vessels simply cycle through gear until the season is closed by emergency order. The first delivery of live crab to a processor occurs after season closure.

Quota trading under rationalization elongates the season, which adds three dimensions of systematic but non-uniform rotational complexity to the problem. First, daily sleep becomes critical to crew safety. Based on conversations with industry members, it is assumed the crew sleeps six hours per 24-hour day, regardless of vessel size. Vessels stop working during this sleep period and “jog” in a low fuel consumption mode. The work-sleep cycle impacts the optimal soak time, CPUE, and number of pots fished in a particular day. It also requires that the total number of pots fished be divided into an integer number of pots that are actively fished each 18-hour workday. The crew first sleeps after all pots have been set and a workday’s complement of gear has been picked and reset. Thus, the first six-hour sleep occurs

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[6] This assumption simplifies the decision to stack a subset of the n_V pots, which has vessel stability implications, given full or partially full tanks of crab. All pots are picked, stacked, and returned to dry storage after the final crab delivery of the season.

either in Period 1 if the integer number of days required to pick and reset all gear exceeds 1; otherwise the first sleep begins Period 2.

A second consequence of elongated seasons is that vessels must leave the fishing grounds, with their gear soaking, to make in-season deliveries of live crabs to a processor. Fuel consumption rises but so does catch per unit of effort ($CPUE_V$) due to longer, delivery-influenced soak times.[7] The first of potentially multiple deliveries occurs in Period 2. The inclusion of in-season deliveries requires dividing Period 2 into two distinct sub-periods, each with different soak times and CPUEs. Period 2.1 is linked to Period 1 in that no in-season delivery has occurred. However, unlike Period 1, all pots soak an identical amount of time in Period 2.1. The first in-season delivery occurs at the beginning of Period 2.2. Soak times and thus, catch rates vary across Period 2.2; some of the catch rates are delivery influenced, some are both delivery influenced and sleep influenced, and some are only sleep influenced. There may be many repetitions of Period 2.2, depending on the class-specific, optimal season length. Period 3 always commences with the one and only in-season delivery during that period. The final delivery is made after the end of Period 3; *i.e.*, at the beginning of post-season activities.

The third consequence of season elongation is that all pots are assumed to soak a minimum of 12 hours prior to being picked. If 12 hours has not elapsed since the first pot is set, the vessel must *Wait* in a jog mode.

Solution Procedure

The solution procedure is dictated by two considerations. First, the real-valued decision variables (ST_V, SL_V, T_V) are actually intermediate variables that are functions of only integer variables, *e.g.*, n_V and m_V. Thus, the optimization problem is *de facto* an integer, nonlinear program. Second, some integer variables, like the optimal vessel-specific number of pots, n_V, are also unknown upper limits on associated index sets $\{1, 2, \ldots, n_V\}$. The optimal numerical value of this integer is determined by the optimization program. Accordingly, optimization programs, such as GAMS, were not used. Instead, a complete enumeration algorithm was written in the C++ programming language and run under a Windows operating system. The enumeration algorithm searches among all feasible fishing strategies to maximize accumulated quasi rents, given that harvesters trade quota so that the fewest, most efficient vessels harvest the TAC within the maximum season length. The set of feasible fishing strategies is delimited by the vessel-specific, end-of-season closure condition for Period 3. That condition is:

$$SL_V \in \left[T_{MAX} - \frac{Del_V}{24} - \alpha_V^T,\ T_{MAX}\right],$$

where $Del_V/24$ is a real-valued parameter defining the number of days required to deliver a load of live crab to the processor; and $\alpha_V^T \in [k_V, \alpha_V]$ is the integer number of fishing days in the terminal period, exclusive of the initial and only delivery. The terminal number of fishing days (α_V^T) must equal or exceed the time to pick and set all n_V pots (*i.e.*, is at least k_V days long) and may not exceed the maximum number of

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[7] In reality, delivery frequency is dictated by catch rate, capacity of the live tanks, and weather conditions. The decision to make in-season deliveries is simplified in this analysis because live tank capacities are unknown. In-season deliveries are assumed to occur every six days for vessels less than or equal 125 feet and every eight days for the two larger vessel size classes that have larger live tank capacities.

days before the last delivery must be made, α_V days. Parameter definitions and values are given in Appendix 1 for the five vessel-length classes.

The optimization problem is solved in two steps. First, all feasible fishing strategies for each vessel class and associated initial quota allocation are enumerated for a given T_{MAX}. Quasi rent-maximizing strategies among the finite feasible set are chosen for each vessel class. Second, quota is traded according to the equilibrium conditions specified in equation (2). The model is re-optimized with the upper-bound season length tightened until the fleet structure resembles the 2005 fleet.

Analytical Framework

Assessing both the economic efficiency benefits of rationalization and the distribution of those benefits among the initial IFQ recipients requires simulating with- and without-rationalization policy scenarios. The "without-rationalization" simulation establishes the race-for-fish baseline against which the "with-rationalization" simulation is contrasted.

The first step in measuring the net benefits to harvesters involves calibrating the econometrically estimated CPUE function in the context of the race-for-fish optimization model. Simulation 1 models fleet behavior for the last year (2004) of license-limited access management. In 2004, a fleet of 243 CVs plus eight CPs harvested 13,889,067 pounds of red king crab in just three days-eight hours. The CV share of this catch was 95.7%. Only the CV portion of this fishery is modeled, assuming the CV fleet structure is identical to the actual 2004 fleet. Vessels less than or equal to 125 feet in length were limited by regulation to fish at most 200 pots; larger vessels were limited to 250 pots.

Model calibration followed Briand *et al.* (2004). The season- and day-specific CPUE function parameters estimated by Briand, Matulich, and Mittelhammer (2001) were compressed into an average CPUE function that conformed to the actual 2004 fishing conditions and regulations. Four benchmarks were used to calibrate the 2004 CPUE function: (*i*) actual catch by the CV fleet, (*ii*) actual catch by vessel class, (*iii*) actual season length, and (*iv*) an estimate of CPUE that was developed by the Alaska Department of Fish and Game from observers onboard a subset of the fleet. The CPUE function parameters were adjusted to yield optimization model results consistent with these four calibration benchmarks.

Ideally, this calibration model could serve as the without-rationalization benchmark for policy comparison. However, fleet structure changed between 2004 and 2005 policy implementation, as did the TAC and prices. Prior to initial quota allocation, 25 qualified CVs exited the fishery in a government-sponsored industry buyout program. Some of the remaining vessels did not fish in 2004, and some that did fish in 2004 did not qualify as quota recipients. Ultimately, 227 vessels were awarded quota share (QS) based on their catch history during qualifying years. The QS is converted annually to IFQ, once the TAC is set.

With- and without-policy analysis requires comparison across an identical initial fleet structure in both policy contexts. The without-rationalization context is modeled by overlaying the 2005 post-buyout, pre-trade fleet structure and initial QS allocation on the race-for-fish calibration model. All prices, TAC, and fishery regulations were fixed at the 2004 level. Thus, without-rationalization catch per vessel equals the product of the post-buyout, pre-trade, initial QS allocation times the 2004 TAC; UQRs are pegged at the 2004 calibration level, yielding total quasi rents per vessel that conform to the without scenario catch. This without-rationalization scenario allows for meaningful comparison of gains and/or losses arising from rationalization that is due solely to quota trading.

Several factors militated against modeling the with-rationalization policy scenario as the 2005 season, per se. Quota trading among the CVs that received an initial allocation reduced the fleet to 89 active vessels that participated in the first-ever rationalized red king crab fishery. The 2005 season elongated to more than two months, though this extensive season elongation misrepresents efficiency-driven behavioral changes that derive from quota trading. Few of the 89 vessels fished on any given day during the 2005 season because of three predominant factors: (*i*) internal decisions of 15 "operational" fishery cooperatives (not limited anti-trust exempt cooperatives) that were encouraged to form under the rationalization policy, (*ii*) the unprecedented high Pacific cod prices that diverted crab vessels into the concurrent pot cod fishery, and (*iii*) dangerous weather conditions during some of the 2005 season. None of these factors could be modeled.

Accordingly, the with- and without-rationalization analysis is conducted in the context of the 2004 simulated TAC and the 2004 prices. The analysis essentially asks, What would have happened had the 2004 fishery been rationalized, given the initial quota allocations and no opportunity to change ex-vessel price due to policy design; *i.e.*, no price influence of IPQs? See Appendix 1 for parameter values.

Consolidation of the post-buyout, 227-vessel CV fleet is allowed to accommodate a nearly 10-fold season length extension from the actual 3.3-day, 2004 license-limited access fishery to $T_{MAX} \leq 30$ days. This upper bound is then tightened to maximize fleet-wide quasi rents for a fleet size similar to that in 2005. Additionally, the pot limit is revised in accordance to regulation to at most 450 pots per vessel, regardless of length. The with-rationalization analysis abstracts from certain cost saving behavioral changes that undoubtedly followed from rationalizing the fishery. Survey participants could only speculate about cost reductions like reducing engine RPMs while running and fishing or tuning engines to conserve fuel.

Total policy net benefits are calculated as the difference between what is earned under the rationalized fishery minus what is earned under the 2004 license-limited access fishery that is normalized to reflect the 2005 pre-trade, post-buyback fleet configuration. Following trade, acquisitive or active vessels benefit two ways. They earn any efficiency differential between policy states on their initial quota allocation. On all purchased quota, active vessels also earn the efficiency differential between their reservation price and the equilibrium quota price, plus an additional return equal to the crew share times the equilibrium quota price. Thus, the annual policy benefit to an efficient vessel is: $(UQR_V^R - UQR_V^L)\omega_V + [(UQR_V^R - S) + \gamma_V S]\omega'_V$, $\omega'_V \geq 0$. The superscript R refers to the rationalized policy state, and the superscript L refers to the license-limited policy state. The policy benefit to exiting vessels, exclusive of opportunity costs in alternative use, is the differential between the quota price and their license-limited access UQRs earned on their initial quota allocation: $(S - UQR^L)\omega_V$, $\omega'_V < 0$. Any alternative use for the vessel, including any salvage value, raises net benefits for exiters.

Results

Calibration

Calibrated model results reflecting the 2004 race-for-fish are given in table 1. The calibrated optimization model deviated little from three of the four calibration benchmarks. Simulated CV fleet catch (13.271 M lbs.) underestimated actual catch (13.286 M lbs.) by only 0.11%, in a virtually identical season length (3.34 days simulated versus 3.3 days actual). Total catch by vessel-length class deviated less than 2.8% for each of the five length classes. Only the CPUE observer estimate and

Table 1
2004 Calibrated Model Results for the Catcher-Vessel Fleet, Race-for-Fish Policy

		Vessel-length Class (feet)				
	Fleet	<100	100–109	110–125	126–139	>139
No. Vessels	243	69	57	62	30	25
Catch						
Actual	13,286,318	2,762,450	3,069,158	3,786,459	1,979,158	1,689,073
Simulated	13,271,451	2,804,829	3,113,414	3,681,689	2,002,646	1,668,872
% Error	–0.11%	1.53%	1.44%	–2.77%	1.19%	–1.20%
Season Length (days)						
Actual	3.3					
Simulated	3.34					
% Error	1.2%					
CPUE (lbs.)						
Observed	23					
Simulated	18.5					

the simulated CPUE deviated much. The CPUE estimate from ADF&G observer data was 4.5 crab per pot lift more than the simulated CPUE (23 versus 18.5 crab per pot lift). This difference is not important for two reasons. First, observed crab vessels tend to be larger than the fleet average so as to accommodate observer living quarters. Larger vessels fish more pots with longer soak times and higher CPUEs. Second, unlike the other three calibration benchmarks, CPUE is an ADF&G estimate and not a certain parameter value. It is used in calibration only to assure the asymptotic catch parameter, β_0, exceeds observed performance.

Fishery Performance With and Without Rationalization

A comparison of the 2004 simulated fishery without and with rationalization is given in table 2. Although the rationalization policy was examined initially with $T_{MAX} \leq 30$ days, the results reported here reflect a season length of only 13 days. A 30-day season would allow processed crab to enter the Japanese end-of-year gift giving market, thereby maintaining the highest possible price. But a 30-day season would also result in excessive consolidation *vis-à-vis* the actual fleet size. $T_{MAX} = 13$ days captures the first full increment of differential efficiency, where both the TAC and season length are binding for the most efficient vessel class.

Quota trading elongates the season four fold, resulting in fleet consolidation from 227 post-buyout vessels to 72 vessels. Sixty-eight vessels from the most efficient vessel class (110 to 125 feet) and four vessels from the next most efficient class (126 to 139 feet) harvest the TAC. The equilibrium quota price falls in the \$2.46–\$2.54 interval defined by the reservation prices of the most efficient inactive vessels and the most efficient active vessels. The most efficient, active vessels nearly triple their catch, while the four active vessels in the next most efficient category more than double their catch. All other vessels rent out their quota to the 72 active vessels.

Table 2

2004 Simulated Performance: Without Rationalization versus With Rationalization[1]

		Per Vessel, by Length Class (feet)[2]				
	Fleet	<100	100–109	110–125	126–139	>139
No. Vessels						
2004 (actual)	243	69	57	62	30	25
Without	227	63	43	68	25	28
With	72			68	4	
Season Length						
Without	3.49 days					
With	13 days					
Catch (lbs.)						
Calibrated 2004	13,271,451	40,650	54,621	59,382	66,755	66,755
Without (initial quota)	13,271,451	41,049	60,597	66,424	74,612	60,597
With	13,271,451			184,418	182,751	
Quasi Rents ($)[3]						
Without	32.709 M	97,449	148,594	168,738	185,215	145,544
With (total)	41.868 M					
With (inactive)	21.138 M	102,621	151,494		186,530	151,494
With (active)	20.730 M			287,262	299,075	
Unit Quasi Rents ($)						
Without[4]		2.37	2.45	2.54	2.48	2.40
With (selling)		2.50	2.50		2.50	2.50
With (initial quota)				2.54	2.46	
With (royalty quota)				1.01	0.97	
Quota Price ($/lb.)	2.46–2.54					
Policy Net Benefits ($)	9.160 M					
With (inactive)		5,172	2,900		1,315	5,950
With (active)				118,524	113,860	

[1] All dollars denominated "with-rationalization" results assume no gain in fuel efficiency.

[2] All results reported by vessel class are per vessel, except the number of vessels.

[3] All quasi rents and unit quasi rents are based on an assumed quota trade price of $2.50/lb.

[4] UQRs under the without scenario were set equal to the calibrated UQRs for the 243-vessel fleet applied to the 227-vessel, pre-trade quota.

Assuming a quota price of $2.50 and without any of the inevitable benefit of reduced fuel consumption, the pure harvesting efficiency gains from rationalization are estimated to be $9,159,822 per year—a total net benefit increase from $32,708,643 to $41,868,465. Net benefits increase for every vessel class. Notice that even the four marginal active vessels (126 to 139 feet) benefit substantially, despite earning UQRs from fishing equal to four cents less than the price of quota. These vessels earn $0.97 per pound (39% crew share times the quota cost) on all acquired quota.

All results are based on a simplifying and obviously false assumption that rationalization provides no opportunity to conserve fuel. Vessel owners that participated in the cost of production survey prior to the first year of rationalization could only speculate that fuel savings would be likely—they could not quantify the savings. A

10% fuel savings would increase total net benefits less than $82,000 in total and have no perceptible impact on the imputed quota price.

Rationalization benefits the crab fishery in additional ways than captured by changes in quasi rents. Soak times, for example, increase from an average of 12–22 hrs. per pot under the without-rationalization scenario, to a minimum of 15–33 hrs. per pot and a maximum of six days per pot, depending primarily upon whether the pot is sleep and/or delivery influenced. Longer soak times translate into reduced handling mortality and improved conservation. Rationalization also reduces the amount of gear on the grounds by 71%, from 27,903 pots to 8,208 pots. At an assumed 1% pot loss rate, this reduction in gear translates into additional conservation benefits from less ghost fishing. No vessels pick up extra gear from wet storage; only the 126–139 foot vessel class fishes sufficient gear to soak each pot a minimum of two days (except for the first picks in Period 1). Perhaps most important though, is rationalization improves crew safety. Not a single crew member died since policy implementation.

An additional with-rationalization simulation was conducted to evaluate the implication that fleet consolidation might increase CPUE, given a constant TAC. Average variable costs drop, and both unit and total quasi rents increase. The asymptotic catch parameter, β_0, was doubled from 27 to 54 crab per pot lift, and the with-rationalization quota trading model was re-run. Equilibrium quota price increases to $2.61 per pound. The fleet consolidates to just 53 active vessels in the 110–125 foot vessel class, while the season length drops from 13 to 10 days.

Discussion

The BSAI crab rationalization policy was designed for a variety of purposes, not the least of which was to assure both harvesters and processors participated in the economic benefits of rationalization. The Council was silent on the relative distribution of those benefits. Some argued that the use of individual processing quota would harm harvesters. The Council responded to these concerns by requiring early, periodic reviews that focused on whether specific elements of the policy need to be modified in order to assure both harvesters and processors participated in the policy benefits. The analysis contained in this article addresses that goal from the harvesting perspective, while abstracting from many of the detailed policy elements. Additional, if not more important factors, like elimination of four to five deaths per year, are not considered in this article.

The with- and without-policy analysis presented here isolates purely efficiency-driven harvesting benefits from red king crab rationalization. Fleet-wide net benefits exceed $9.2 million per year, and all vessel classes participate in those benefits. No vessel class is damaged. Of equal importance, however, is the fact that the imputed quota price of $2.46–$2.54 per pound is less than the empirical quota rental price. Quota brokers and vessel owners reported that 2005 quota rented for 70% of the ex-vessel price, after deducting 5.5% for fees and taxes. This rental or royalty rate establishes the empirically based, equilibrium market price for quota of $3.11/pound, based on a 2004 ex-vessel price of $4.70. It should be noted that actual royalty rate includes any discount or premium harvesters applied because of IPQs. The fact that harvesters actually paid 22% to 26% more for quota than supported purely by the imputed efficiency gains affirms they were not damaged by IPQs. Had IPQs disadvantaged harvesters, they would have paid less, not more than the imputed efficiency value. This observation supports the conclusion that omitted policy elements, like IPQs, skipper quota, and community protection, do not alter the finding that the BSAI crab rationalization program benefits harvesters. Doubling the potential CPUE under the rationalized policy state does not alter this conclusion.

There are several reasons why the empirical quota market exceeded efficiency-based imputed prices:

1. Crab rationalization is new. Harvesters may not know how to value quota. The high prices could reflect speculative behavior, though this seems unlikely in an annual rental context. The fact that the quota royalty rate softened to the 66–70% interval in 2006 might be partially attributed to learning, though a 40% increase in the cost of fuel surely contributed to the lower royalty rate. Regardless, the 2006–07 empirically based quota price range still exceeds the imputed price by at least 15% to 19%.

2. The 10% asymmetry between IFQ and IPQ was intended to provide price leverage to harvesters on the 10% open-delivery quota (B-shares). Harvesters should be able to capture the joint quasi rents (the composite contribution value from harvesting plus processing) on B-shares. In fact, harvesters did capture higher ex-vessel prices on most open delivery shares in 2005. The falling red king crab market during the 2006 season makes such an unequivocal statement tenuous for that year.[8] The intended leverage raises the net benefits of the rationalization program, thereby raising the equilibrium quota value, though it is impossible to make a direct comparison of A-share and B-share prices because B-shares could be used to raise the average (A+B)-share price.

3. The threat of binding arbitration and the associated nonbinding formula price that is prepared prior to the season may have increased the share of wholesale price paid to harvesters above the target historical level.[9] This possibility tends to lessen the difference between A- and B-share prices but raise the overall premium on A-share quota.

4. Vessel class-specific, representative firm analysis may understate net benefits in the acquisitive vessel class/classes. This would occur if the survey participants in that class were less efficient than the true class average.

Perhaps the most important limitation of this analysis concerns the representative firm approach. A typical vessel in each of five vessel-length classes approximates heterogeneity across a fleet that ranges in length from under 70 feet to more than 170 feet. Obviously, heterogeneity exists within each of the five length intervals. This is one reason the post-trade simulated fleet does not mirror the currently active fleet. Another reason is that the decision to buy, hold, or sell quota is dependent on a variety of factors, including efficiencies in other activities, especially the winter opilio crab fishery and age of the quota recipient. While the 110–125 foot vessel class is estimated to be most efficient in the rationalized red king crab fishery, it may not be as efficient as the 126–139 foot vessel class is in bigger seas of the more dangerous winter opilio fishery. The small efficiency differ-

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[8] Vessels that made open deliveries late in the 2006 season and without forward contracts assumed all price risk. Open delivery (B-share) prices established at the end of the season were often less than A-share prices on deliveries that had to be made to a processor holding IPQ. Simple comparison of A-share and B-share prices is not an indicator of price leverage.

[9] John Sackton, the individual who prepares the binding arbitration pre-season price formula and market report, acknowledged this point during his testimony to the NPFMC's 18-month review, April 2007 (North Pacific Fisheries Management Council 2007).

ential between these two classes might be reversed and overshadowed by the relative efficiencies in the opilio fishery.

It is clear that the BSAI crab rationalization program did not damage harvesters, in either an absolute or relative distribution sense. In fact, the contrary is implied by the empirical royalty payment in excess of estimated harvesting efficiency benefits. Harvesters either captured more than their pure efficiency gain; *i.e.*, the harvesters' share of composite quasi rents increased relative to the processors' share, or harvesters are behaving in an irrational manner. Irrational behavior seems an unlikely explanation for renting quota above the efficiency value since the actual quota royalty has persisted at 66–70% of the ex-vessel price (net of fees and taxes) for three seasons.

The net per pound efficiency benefit plus the $0.57–$0.61 premium above the efficiency-based quota price implies an annual net benefit of $16.7–$17.3 million. The capitalized value of this annual net benefit to vessel owners, assuming a 35-year horizon and 2.25% real interest rate (Federal Reserve Board of San Francisco 2005), is $399–$415 million. This capitalized value excludes both the additional net benefits to catcher-processors and from the improved Bristol Bay red king crab stock abundance that was, in part, an expected by-product of rationalization.[10]

The empirical quota market corroborates the numerical results of this study. Brokers report red king crab quota sells at roughly a seven-fold multiple of the gross ex-vessel value. At the 2004 TAC and ex-vessel price, post-rationalization market valuation is $436 million. The relatively small premium above the capitalized net benefit estimate of $399–$415 million suggests the fleet was teetering on the brink of financial ruin prior to rationalization.

The conclusion that harvesters were made better off from a crab rationalization policy design that included IPQs should not be surprising; the BSAI crab policy was designed to maintain contestable markets. Nor should one be surprised by the rhetoric surrounding crab rationalization, when so few firms stand to gain so much from political redistribution of wealth. The Council's admonition that it would conduct early and periodic program reviews and fix unintended consequences—in particular, demonstrable damage to harvesters, processors, or fishery-dependent coastal communities (Duffy 2002; North Pacific Fisheries Management Council 2002)—unfortunately served to encourage rent seeking. Separating fact from rent seeking remains the Council's greatest challenge.

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[10] The TAC increased one-third between 2004 and 2007.

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Appendix

Parameter Definitions and Values

Appendix Table 1.1

Pre- and Post-buyout Fleet Structure and Initial Quota Share (QS) Allocation, by Vessel-length Class

		Parameter Values by Vessel-length Class (Feet)				
Parameter	Definition	<100	100–109	110–125	126–139	>139
License-limited access (243 vessels)						
V	# of vessels per class	69	57	62	30	25
Post-buyout pre-trade (227 vessels)						
V	# of vessels per class	63	43	68	25	28
ω	Original quota share/vessel[1]	0.003093	0.004566	0.005005	0.0056222	0.004566

[1] Initial per-vessel quota share allocation reported as CV portion of the TAC equals 100%.

Appendix Table 1.2

Parameter Definitions and Values for Vessel-specific Characteristics and Activities

		Parameter Values by Vessel-length Classes (feet)				
Parameter	Definition	<100	100–109	110–125	126–139	>139
VCC_V	Vessel carrying capacity (7'x7'x3' pots)	75	126	135	218	215
$Crew_V$	Number of crew	5	6	6	6	7
γ_V	Crew share	43%	41.5%	39%	40.5%	42%
$Sleep_V$	Min. sleep time race/ rationalized (hrs.)	0 / 6	0 / 6	0 / 6	0 / 6	0 / 6
$RunFuel_V$	Fuel while running (gph.)	22	29	42	45	48
$JogFuel_V$	Fuel while jogging (gph.)	7	15	23	23	24
$FishFuel_V$	Fuel while fishing (gph.)	16	23	32	33	35
$DockFuel_V$	Fuel while at dock (gph.)	3	6	10	11	11
$DFuel_V$[1]	Fuel while delivering (gph.)	18	23	33	34	36
Pre-season Activities						
$Load_V$	Stack pots from shore (min./pot)	3.5	3.0	2.5	2.0	2.8
$WetTrip$	Round trip to wet storage (hrs.)	20	20	20	20	20
$WetSet$	Set gear in wet storage (min./pot)	2.5	2.5	2.5	2.5	2.5
$RunGrnds$	First run time one way to grounds with gear (hrs.)	18	18	18	18	18
In-season Activities						
$IntTrip$	Round trip grounds to wet storage (hrs.)	13	13	13	13	13
$Retr_V$	Wet storage pot retrieval (min./pot)	3	2.4	2.4	2.4	2.4
$Pick_V$	Pick-empty time (min./pot)	3.7	3.5	3	3	3
Set_V	Stack-run-bait-set (min./pot)	8.3	7.5	7.0	7.0	7.0
Del_V	Round trip delivery + dock time (hrs.)	47	48	50	53	53
Post-season Activities						
$RunGrnds$	One way run grounds to dock (hrs.)	18.0	18.0	18.0	18.0	18.0
$PickStack$	Pick and stack gear (min./pot)	6	6	6	6	6
$Unload$	Unload/store onshore (min./pot)	3	3	3	3	3

[1] Weighted average fuel consumption while running and at dock.

Appendix Table 1.3

Common Parameters, Definitions, and Values

Parameter	Definition	Parameter Value
TAC	Total allowable catch (M lbs.)	13.826
Tmax	Maximum season length (days)	
	License-limited access	N/A
	Rationalized	≤ 30
β_0	CPUE asymptote	27
β_2	CPUE pot fill rate	–1.6
P	Crab price before fees and taxes ($/lb.)	$4.70
BaitPrice	Bait price ($ per pot)	$10
Regist	Pot registration fee ($/pot)	$2
PotPrice	Pot + buoy + line cost ($/pot)	$850
FuelPrice	Fuel price ($/gal.)	$1.50
PctLoss	Percent of pots lost	1.0%
Imaint	Pot maintenance cost ($/pot)	$20
PctMaint	Percent of pots maintained	100%
DailyCost	Food ($25) + P&I Insurance ($60) per crewday	$85