Distributional Effects of the Transition to Property Rights for a Common Pool Resource*

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Abstract

The introduction of property rights to manage common pool resources is often met by opposition from some incumbent users, despite evidence of large increases in resource rents. We introduce an analytical model with cost heterogeneity to distinguish between rents to high skill and traditional resource rent, which accrues to all owners. We show that despite large aggregate gains from property rights, some current users may prefer common pool management, demonstrating the importance of initial allocations of rights. In our empirical application, property rights generate a ten-fold increase in market capitalization and a doubling in the present value of the resource.

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Economists have long advocated the introduction of property rights to address problems pervasive in common pool resources such as fisheries (Gordon, 1954). Indeed, there is a growing theoretical and empirical literature documenting substantial gains in resource rent as a consequence of property rights. Yet proposed property rights regimes are often opposed by some incumbent resource users. Even if aggregate benefits are large, some incumbents may rationally oppose the change if, individually, they are likely to be disadvantaged. Thus, an interesting and understudied feature of institutional reform, and the one we focus on here, is the distribution of rents among resource users before, and after, the transition to property rights.

We argue that under neither regime do all users earn the same rent: Heterogeneity in skill leads to "inframarginal rent"[1] in the common property regime, which may be subsequently transferred to other users or capitalized into asset values when property rights are introduced. Thus, in order to ensure Pareto improving institutional change, or to gain the political support of incumbent resource users, the allocation of rights must compensate incumbents for the changes in rent associated with the introduction of property rights. In this paper, we develop an analytical model to separate resource rent from inframarginal rent under alternative management regimes. We use the framework to calculate empirically the magnitude and distribution of these rents across users in an important U.S. fishery that has recently transitioned to property rights.

Environmental regulations affect diverse groups through changes in wages, returns to capital, product prices, firm-level profits, and land values and rental rates. The literature has considered a broad range of impacts on different groups (e.g. Fullerton, 2011; Grainger, 2012; Parry, et al, 2005). And distributional impacts of cap-and-trade programs are believed to be largely a function of the initial allocation scheme (Parry, 2004; Stavins, 2010). While it is well-known that regulating natural resource extraction can increase overall resource rents, it may also be the case that different resource institutions affect the distribution of rent.

We develop a theoretical model to examine the changes in the distribution of rent, and

[1] Throughout this paper we will refer to "inframarginal rents" as those rents arising from heterogeneity in marginal extraction costs. These could alternatively be referred to as "racing rents", "skill rents", or following Anderson (1989) as "highliner rents".

the welfare implications of those changes, that arise due to the introduction of individual transferable quotas (ITQs) in fisheries. We use the model to analyze firm-level decisions and rent capture under two market regimes. Among other results, we derive the conditions under which inframarginal or resource rents dominate a fishery's value and the conditions under which fishermen would rationally favor (or oppose) a transition to ITQs. Because the cost structure often changes after a transition to property rights, we also derive the effects of this change on asset lease values, this distribution of rent, and the overall value of the resource.

We derive analytical results that are interesting and informative in their own right and then apply the model to parameterize an empirical application of a prominent US fishery. Our estimates for the Gulf of Mexico Red Snapper fishery suggest more than a doubling in real value of the fishery due to ITQs, and over a ten-fold increase in market capitalization. However, we find that the ITQ has important distributional effects by transferring inframarginal rent into resource rent. More generally, by assigning property rights in a common pool resource, the inframarginal rent that accrues to resource users with high skill may be capitalized into asset values and transferred to the (possibly new) owners of the resource.

Our theoretical and empirical findings offer insight into the political economy of rights-based management of natural resources. One of the barriers to the implementation of rights-based management often comes from current users who benefit from the status quo. The reason for this is clear: if skill is heterogeneous, high-skilled individuals may earn positive rent in the common pool, though marginal individuals earn little above the return to their inputs. The transition to property rights is then marked by the conversion of some of these inframarginal rent into resource rent. If the initial allocation of rights fails to take this into account, disadvantaged fishermen may rationally oppose the transition to property rights. Without political support from current users for management change, ITQs are unlikely to be implemented despite their aggregate benefits.

1 Background

Over the past three decades hundreds of prominent fisheries have transitioned from common property arrangements to individual transferable quotas. A recent database estimates 647 different ITQs in a total of 17 countries (Environmental Defense Fund, 2012).[2] These fisheries represent about 25% of global fish landings (Arnason 2012), and adoption is increasing rapidly. The transition to ITQs is almost always preceded by a system called "Limited Entry" under which a fisherman purchases a permit entitling him to participate in the fishery. Permits are generally transferable, and the market permit price will reflect capitalized profitability to the marginal fisherman. After the introduction of ITQs, since the transacted goods are units of harvest, the market price of a quota share should reflect the profitability of share ownership for a marginal unit of harvest. These market prices are generally available to researchers, and combined with other relevant variables, we show that this information can be used to estimate the economic gains of transitioning to a rights-based form of management.

The recent wide-scale adoption of property rights has been supported by ecological (Costello et al., 2008) and aggregate economic (Grafton et al., 2000) claims of success. The ecological argument rests on the premise that by providing a stake in the long run health of the stock, ITQs provide a greater stewardship incentive than does Limited Entry. The economic argument usually invokes claims of enhanced resource rent from reducing the race to fish, thereby enhancing technical efficiency and reducing costs.

Switching from common pool management, where participants race to capture the largest share possible, to an ITQ, where shares are clearly defined, may also have important distributional consequences. Distribution also plays an important role in the applied question of how to divvy up the rights in the first place. In practice, initial rights in an ITQ are almost always grandfathered for free to incumbent users. Typically a ten-year historical window defines each fisherman's catch share; new and potential entrants are simply excluded from the allocation.[3] In some rare instances quota banks or communities receive allocations to distribute, over time, to new entrants. Whatever the formula, the initial allocation, combined with the allocative effects of the institutional change, define the distributional consequences of a shift to ITQs. The main focus of this paper is to examine these distributional effects in

[2]Including lesser-known examples in places like Namibia, Cook Islands, Estonia, and South Africa. We know of only one fishery world-wide, a sea cucumber fishery in Ecuador, that adopted an ITQ and then reneged it.

[3]The allocation window is generally granted based on an historical window in order to avoid creating perverse incentives such as a race for initial allocation.

detail and to lend insight into the political economy of the transition to property rights over a natural resource.

We also contribute by deriving and estimating the aggregate value of the fishery before and after the transition to ITQs. Estimating the aggregate economic gain from a transition to property rights is regarded as a difficult task. Previous authors have assembled time series of detailed microdata to estimate firm-level costs and revenues before and after rationalization; they generally point to large gains from the introduction of property rights (e.g. Grafton, et al., 2000; Lian, et al., 2010).[4] A tempting alternative, that makes use of only market data, is to simply calculate the market capitalization: The market permit price times the number of permits (before the transition) and the ITQ quota price times the number of quota shares (after the transition). The problem with this calculation is that it ignores completely the inframarginal rents and effectively assumes all fishermen are of equal skill, in which case there are no interesting distributional effects to explore. Under this assumption, we would expect the same behavior among all fishermen (e.g. the same level of harvest every year), and all fishermen would be equally advantaged, or disadvantaged from the transition to ITQs.

Perhaps most poignantly, the market permit price in Limited Entry does not fully reflect the present value of access to every fisherman to the fishery; it reflects only profitability to the *marginal* fisherman. The value of a permit to the most skilled fisherman could be significantly higher, depending on the heterogeneity in the fishery. In these cases, inframarginal rent accrues to the permit-holders with high skill. In our model, higher skill fishermen have the largest harvests under Limited Entry. Thus firm-level heterogeneity is critical in determining the value of the inframarginal rent, as well as the overall value of the resource, prior to the implementation of property rights. Similarly, under ITQs, the present value of the fishery is higher than the aggregate value of quota shares would suggest, because inframarginal rent is excluded from that measure.

Earlier authors, such as Copes (1972) and Johnson and Libecap (1982), point to the potential importance of inframarginal rent in the presence of heterogeneous firms. Coglan

[4]In a working paper, Reimer, Abbott and Wilen (2012) examine the multiple margins of rent generation in the Bering Sea Red King Crab fishery. They focus on the difference in the intensive versus extensive margins, but because their model assumes a homogeneous fleet, there are no rents to high-skill individuals.

and Pascoe (1999) indicate the importance of measuring profits, not just resource rent, using survey data. And Johnson (1995) points to the importance of rent beyond pure resource rent in his model of taxation in fisheries. We build on this foundation by building a model with heterogeneous fishermen and compare welfare and distributional outcomes under alternative management regimes. This allows us to examine both theoretically and empirically many real-world concerns that tend to be raised by incumbents and potential entrants when considering the switch to ITQs, and to inform the design of property rights systems.

2 Model

We model a renewable resource, focusing on the fishery, that is initially managed as a commons and then transitions to property rights. In the commons, we assume the most prevalent form of fisheries management in the western world, the *Limited Entry* system. To participate in a Limited Entry fishery, a fisherman must own one of a fixed number of permits, which are bought and sold in a permit market. This entitles the fisherman to harvest any amount of fish during the open fishing season. The season length is adjusted to meet the fishery manager's target level of catch. Importantly, this system grants access to the commercial fishery but does not grant individual rights to levels of harvest.

In our model the fishery then transitions to property rights management. We model the most common form globally, the *individual transferable quota* (ITQ), which does not limit the number of participants and does not require a permit. Rather, individual levels of catch (more precisely, individual *fractions* of the total allowed catch) are bought and sold in a quota market. We build a model capturing outcomes under both systems, paying particular attention to the individual, fisherman-level economic effects of the two management regimes. After exploring several theoretical questions, we examine these effects empirically for a prominent US fishery that has recently switched from Limited Entry to ITQs. In the theoretical model we abstract away from transition dynamics such as fishery recovery; these nuances are treated elsewhere in the literature (e.g. Weninger and Just, 1997; Weninger, 1998; Lian, et al., 2010; Schnier, 2009). Rather, our focus is on the firm-level incentives, behavior, and rent capture under each management system. Our goal is to tease apart the rents that accrue to individual fishermen as a result of fishing skill versus those rents that accrue equally to all owners of the scarce resource. In so doing, we will be able to estimate, and characterize the important properties of, the distributional consequences of switching from common property to property rights management of a renewable natural resource.

2.1 Fisherman Behavior & Harvest Choice

Our theoretical model begins by assuming that independent fishermen can control their own fishing effort, which, within a fishing season, translates directly into the quantity harvested. Total extraction cost is quadratic in a fisherman's own harvest and we separate the marginal extraction cost for fisherman i into two components: his relative skill (represented by heterogeneous marginal extraction cost parameters), and a parameter common to all fishermen. If fisherman i harvests h_{it} fish in period t, his total cost is given by $\frac{1}{2}\eta_t\lambda_i h_{it}^2$. The skill parameter, λ_i, reflects fishermen's heterogeneous cost of extraction and will thus vary across fishermen (i). It represents a fisherman's relative ability, or his inherent marginal extraction cost absent regulatory and market conditions. Lower values of λ_i imply greater skill.[5]

To "produce" fish, fishermen adjust inputs subject to the fishery-wide harvest constraint, H_t,[6] imposed by the regulator and exogenous prices, P_t. As H_t or P_t change, costs are affected and fishing firms adjust inputs. We model the change in cost through an adjustment parameter, η_t, which adjusts to season-specific constraints in the fishery.[7] We assume that this constraint has a common, multiplicative effect on all fishermens' costs. For example, suppose that the ex-vessel price exogenously increases. Then each fisherman has an incentive to "race" to capture any marginal rent, resulting in an increase in marginal extraction cost for all fishermen (see Appendix). Similarly, an increase in the Total Allowable Catch would result

[5]In addition to inherent ability, one could also interpret this parameter as reflecting prior investment in "racing capital", as an individual could lower his marginal extraction costs through investment in alternative gear or vessels. The effort choice model in the Appendix demonstrates the dissipation of rents at the margin through this "race" to capture the resource.

[6]Sometimes this is modeled as adjusting the season length.

[7]See Appendix for a formal model of effort choice and adjustment cost. Doing so results in: (1) a race to fish in the intensity of harvest effort, (2) individual fishing effort that is increasing in the ex-vessel price of fish, and (3) individual fishing effort that is increasing in the total allowable catch, H_t.

in a decrease in marginal extraction cost inversely proportional to that change. Whatever the cause, η_t in a period will adjust costs so marginal profit for the final unit of catch for each fisherman is zero. Because we focus on period-t incentives, behavior, and market outcomes, and do not require tracking the biological status of the stock, we henceforth suppress the time subscript.

2.2 Limited Entry Management

We now apply this basic setup to a model of a Limited Entry fishery with tradable permits and a fishery-wide annual Total Allowable Catch (TAC), H. A total of N permits are transferable and allow access to the resource, but do not give the holder a right to a share of the overall harvest. Fisherman i takes H and others' harvest choices as given and seeks to maximize his own annual profits by choosing his own harvest. The market (ex-vessel) price for fish is given exogenously by P.[8] In equilibrium, fishermen compete for the harvest until marginal profit is zero:

$$P = \eta \lambda_i h_i^* \tag{1}$$

where h_i^* is the equilibrium harvest for fisherman i that year. Now the overall TAC binds, such that $H = \sum_i h_i^*$, and η adjusts such that each fisherman's first-order condition and the TAC constraint hold with equality, so $\eta = \frac{P}{H}(\sum_i \frac{1}{\lambda_i})$. For convenience we define $c_i \equiv \eta\lambda_i$. Fisherman i's annual rent is simply the difference between revenue and cost, given by $Ph_i^* - \frac{1}{2}c_i(h_i^*)^2$. We define fisherman i's equilibrium share (de facto, not de jure) of the overall harvest in a year as $\gamma_i \equiv \frac{h_i^*}{H}$; his annual rent can be rewritten as $P\gamma_i H - \frac{1}{2}c_i(\gamma_i H)^2$.

Permits are valid in perpetuity, so the present value of a permit will capitalize the expected stream of future rents. If the fishery is in steady state,[9] fishermen expect the same annual rent every year in the future and the lowest skilled harvester (to whom we refer as

[8] This assumption could be relaxed, for example if the fishery supplied a small local market, as long as fishermen do not believe they can impact the ex-vessel price and all fishermen face the same price within a season.

[9] For the calculations that follow, we assume that the fishery is in steady state so fishermen expect the same conditions to hold into the future; our model and results could easily be generalized to account for any alternative future expectations in harvest.

the "marginal" fisherman), indexed by $i = 1$, places the following value on his permit:[10]

$$v^* = \frac{1+r}{r}\left[(P\gamma_1 H) - \frac{1}{2}c_1(\gamma_1 H)^2\right], \tag{2}$$

for discount rate, r. A new entrant willing to pay at least v^* could successfully purchase a permit, so Equation 2 gives the market permit price under Limited Entry. The total *resource rent* is just the market capitalization of the fishery under any given management regime. Denote the resource rent for a Limited Entry fishery as R^{LE}. Here, it is the market equilibrium permit price times the number of permits in the market, simply

$$R^{LE} = Nv^*. \tag{3}$$

Importantly, resource rent ignores the additional rent that may accrue to individuals of high skill; we call this *inframarginal rent*. The present value of inframarginal rent for fisherman i is given by the present value of returns above the market value of a permit; it is given by

$$V_i^* = \frac{1+r}{r}\left[P\gamma_i H - \frac{1}{2}c_i(\gamma_i H)^2\right] - v^*. \tag{4}$$

This expression is positive for any non-marginal fisherman (i.e. $\forall i \neq 1$). Summing over all fishermen and rearranging gives us the fishery-wide present value of inframarginal rent:

$$V^* = \frac{1+r}{r}\left[PH\sum_{i=1}^{N}(\gamma_i - \gamma_1) - \frac{1}{2}H^2\sum_{i=1}^{N}\left[c_i\gamma_i^2 - c_1\gamma_1^2\right]\right]. \tag{5}$$

If all fishermen are identical, so $\gamma_i = \gamma_1$ and $c_i = c_1$ for all i, then the present value of inframarginal rent (Equation 5) equals zero. That is, only in the presence of firm-level heterogeneity do inframarginal rents persist under Limited Entry.

2.2.1 Welfare and Distribution Under Limited Entry

Because the marginal fisherman earns zero inframarginal rent under Limited Entry, the present value of his profits are completely offset by the market permit price: he buys a permit for v^* and expects to earn (present value) income of v^*. When skill is heterogeneous

[10] Suppose for simplicity that a person identical to the marginal fisherman is in the fishery, so that the market price exactly reflects profitability of the resource for the marginal fisherman.

the other *N-1* fishermen each earn positive inframarginal rent.[11] In the case of homogeneity, no one earns inframarginal rent, and the value of having access to the resource exactly equals the market permit price.

Equations 3 and 5 provide compact expressions for the present value of resource and inframarginal rents that will accrue in a Limited Entry fishery. The overall fishery value is the sum of these terms. In perfectly competitive markets it is common to measure the value of an asset by its market capitalization (here, resource rent). But this measure ignores heterogeneity across resource owners, and thus ignores a potentially significant contribution to overall value. Indeed, we will show that if skill is sufficiently heterogeneous under Limited Entry, a fishery's total value may be dominated by inframarginal rent. To analyze that problem, we refer to the annual value of rents. The single-period resource rent is: $\frac{P^2}{2c_1}$, which determines the equilibrium permit price. Single period inframarginal rent is calculated by recognizing that fisherman i catches P/c_i fish, must pay permit price $\frac{P^2}{2c_1}$, and thus earns inframarginal rent $\frac{P^2}{2}(\frac{1}{c_i} - \frac{1}{c_1})$. Fishery-wide inframarginal rent is given by

$$\sum_{i=1}^{N} \frac{P^2}{2} \left[\frac{1}{c_i} - \frac{1}{c_1} \right]. \tag{6}$$

To compare the relative magnitude of inframarginal and resource rent, it will be convenient to define a term capturing the degree of skill heterogeneity in the fishery. Let $\bar{C} \equiv \frac{1}{N} \sum_{i=1}^{N} \frac{c_1}{c_i}$ which captures the average ratio of the marginal extraction cost parameter between the marginal fisherman and the non-marginal fishermen. The comparison is then summarized as follows:

Result 1. *Under Limited Entry, inframarginal rent exceeds resource rent if and only if*

$$\bar{C} > 2. \tag{7}$$

Proof. Inframarginal rent exceeds resource rent if and only if $\frac{P^2}{2} \sum_{i=1}^{N} [\frac{1}{c_i} - \frac{1}{c_1}] > \frac{NP^2}{2c_1}$, which reduces to $\frac{1}{N} \sum_{i=1}^{N} \frac{c_1}{c_i} = \bar{C} > 2$. □

Result 1 states that inframarginal rent exceeds resource rent if, on average, the low skill fisherman's cost parameter is at least twice as high as the cost parameters of other fishermen.

[11] We assume for convenience that there is exactly one marginal fisherman.

As $\bar{C}$ grows, the relative size of inframarginal rent to resource rent also grows. The greater the difference between the lowest-skilled individual and the average skilled fisherman in the fishery, the greater the inframarginal rent and the more likely inframarginal rent is to dominate resource rent as a source of value.

2.3 Individual Transferable Quotas

The purpose of this paper is to compare the distributional outcomes of common pool resource management (Limited Entry) with those under property rights (ITQs). Under an ITQ, fishermen exchange shares of H in a market and the fixed number of permits is relaxed. H is still set by the regulator, and the market ex-vessel price for fish is still given exogenously. The number of active fishermen may change under ITQs, e.g. if consolidation occurs due to ITQ management. Define the equilibrium number of fishermen under ITQs as M.

Because incentives for investment and the race to fish may change under ITQs, we allow for the possibility that fishermens' marginal extraction costs may change following the transition. Each fisherman's cost (c_i) is defined as before, but we allow the marginal cost of extraction to change multiplicatively by the firm specific factor $\alpha_i \in [0, 1]$.[12] This allows for technical efficiency gains under ITQs (e.g., due to changes in racing behavior). Given tradable and divisible quota shares, the marginal extraction cost across fishermen will be equalized, with the equilibrium lease price of quota shares given by $\pi^* = P - \alpha_i c_i h_i^*$. Then the present value of resource rent for the fishery is simply $R^{ITQ} = \frac{1+r}{r}\pi^* H$.

The annual inframarginal rent for fisherman i under ITQs is now given by:

$$\Pi_i = \frac{1}{2}(P - \pi^*)h_i^*. \tag{8}$$

One consequence of Equation 8 is that inframarginal rent will persist under ITQs, even in the presence of a homogeneous fleet. In steady state, the present value of all inframarginal rent under ITQs is given by:

$$\Pi_i^* = \frac{1+r}{r}\left[\frac{1}{2}(P - \pi^*)H\right]. \tag{9}$$

[12] We assume that an individual's marginal extraction cost cannot increase under ITQs, as their input decisions and behavior are allowed to remain as under Limited Entry.

2.3.1 Welfare and Distribution under ITQs

As shown above, the quota share lease price in an ITQ fishery determines the annual resource rent. Total annual resource rent is given by $\pi^* H$. And total annual inframarginal rent is given by $\frac{1}{2}(P - \pi^*)H$, which leads to our next result.

Result 2. *Under ITQs, resource rent exceeds inframarginal rent if and only if*

$$\pi^* > \frac{1}{3}P. \tag{10}$$

Proof. Resource rent exceeds inframarginal rent if and only if $\pi^* H > \frac{1}{2}(P - \pi^*)H$. Rearranging gives the desired result. □

If the lease price of a quota share is more than three times as large as the ex-vessel price, then resource rent dominates the value of the fishery under ITQs. This will certainly be the case in our empirical example, and is often (though not always) true generally.[13]

2.4 Comparing Limited Entry to ITQs

While ITQs may change several aspects of a fishery's economic performance, we focus on changes in cost, through the parameter α_i, and thus assume that P and H are unchanged following the transition. To roll out an ITQ, quota shares are typically allocated for free to fishery incumbents. In our model, fisherman i is freely allocated the harvest level $h_i^A \geq 0$.[14] As shown above, the lease price for a quota share is just the wedge between the ex-vessel price of fish and the marginal extraction cost. Intuitively, if costs do not change as a consequence of the ITQ, then nothing changes and the marginal unit of harvest would earn zero rent, just as it does under Limited Entry. This is formalized as follows:

[13] Using data from hundreds of ITQ fisheries in New Zealand, Canada, and the United States, we calculated that this condition holds in about 80% of North American ITQ fisheries and in about 20% of New Zealand ITQ fisheries. Thus, according to Result 2, resource rent seems to dominate an ITQ fishery's value in North America while inframarginal rent seems to dominate an ITQ fishery's value in New Zealand. This may suggest that the marginal harvest cost in New Zealand is more elastic, i.e. smaller α and/or c_i, than in North America. We also note that in the New Zealand data we do not directly observe ex-vessel prices, but use a proxy based on the export value of an individual species (the "green weight price").

[14] Technically, fisherman i is allocated a *share* that is equivalent to harvest level h_i^A.

Result 3. *If costs are unchanged under ITQs ($\alpha_i = 1 \; \forall i$), then the equilibrium lease price is zero: $\pi^* = 0$.*

Proof. If costs are unchanged after the implementation of ITQs, $h_i^* = P/(\alpha_i c_i)$. It follows directly that $\pi^* = P - c_i h_i^* = 0$. □

Result 3 establishes that the lease price under an ITQ is directly related to the decrease in cost from an ITQ. If costs do not decrease, then the marginal unit of harvest earns zero rent and so the quota price is zero.[15] In that case, fishermen will still earn inframarginal rent accruing to skill, but they do not have to pay for a Limited Entry permit. Thus, we find the following result:

Result 4. *If costs are unchanged under ITQs ($\alpha_i = 1 \forall \; i$), fisherman i's profit is higher under ITQs than under Limited Entry, regardless of his initial allocation h_i^A.*

Proof. Under Limited Entry, i earns $\frac{P^2}{2}(\frac{1}{c_i} - \frac{1}{c_1})$, and under ITQs i earns $\pi^* h_i^A + \frac{1}{2}\frac{(P-\pi^*)^2}{\alpha_i c_i}$. Invoking the condition $\alpha_i = 1$, using Result 3, and rearranging, fisherman i prefers the ITQ if and only if

$$\frac{1}{c_1} > 0, \tag{11}$$

which always holds regardless of h_i^A. □

Intuitively, if costs do not change and the permit requirement is lifted, the inframarginal rent for all fishermen (including the marginal fisherman) increases because individuals need not pay the opportunity cost of a permit.

So far we have assumed no changes in costs from the implementation of ITQs ($\alpha = 1$). Lower values of α decrease a fisherman's marginal extraction cost and thus alter his equilibrium harvest. However, if all fishermens' costs decrease by the same proportion, then the structure of our model gives rise to the following result:

Result 5. *If costs under ITQs decrease for all fishermen proportionately ($\alpha_i = \alpha \in (0, 1) \forall i$), then equilibrium harvests are unchanged.*

[15] Empirically, we always observe positive lease prices, and can thus infer that costs are indeed decreasing as a result of the ITQ.

Proof. Under Limited Entry, i's harvest share is

$$\frac{\frac{P}{c_i}}{P\sum_{i=1}^{M}\frac{1}{c_i}}, \tag{12}$$

which can be simplified as $\frac{1}{c_i\sum_{i=1}^{M}\frac{1}{c_i}}$. Under ITQs, if cost proportionately decrease, i's share of the total harvest is given by:

$$\frac{\frac{P}{\alpha c_i}}{\frac{P}{\alpha}\sum_{i=1}^{M}\frac{1}{c_i}}, \tag{13}$$

which simplifies to the same harvest share as under Limited Entry. □

Result 5 will prove useful in the empirical example because we can use the distribution of harvests across fishermen to infer their cost structure (and thus, their skill). Under the assumption of a proportional cost decrease, we can compare the total value of a fishery under Limited Entry and ITQs for any value of α, as follows:

Result 6. *Provided $\alpha_i = \alpha \in (0,1)$ $\forall i$, the fishery-wide benefit from adopting ITQs increases as α decreases.*

Proof. The total annual value of the fishery under ITQs is given by the sum of inframarginal and resource rent: $\pi^*H + \frac{1}{2}(P - \pi^*)H = \frac{\pi^*H}{2} + \frac{PH}{2}$, so the aggregate fishery value depends positively on the ITQ lease price, π^*. But π^* is given by the aggregate supply of harvest, as follows:

$$\pi^* = P - \frac{\alpha H}{\sum_{i=1}^{M}\frac{1}{c_i}}. \tag{14}$$

Clearly $\frac{d\pi^*}{d\alpha} < 0$, which proves the result. □

Result 6 is intuitive: the lower are costs, the greater will be the willingness to pay of fishermen to harvest a marginal unit of fish ($\frac{d\pi^*}{d\alpha} < 0$), and the more valuable will be the fishery as a whole. We can also see from Equation 14 that as costs go to zero, the lease price approaches the ex-vessel price for fish: $\lim_{\alpha\to 0}\pi^* = P$. Finally, we can analyze how the initial allocation affects a fisherman's welfare:

Result 7. *Provided $\alpha_i = \alpha \in (0,1)$ $\forall i$, fisherman i's profits are higher under ITQs than under Limited Entry, provided that his free allocation exceeds half his Limited Entry harvest ($h_i^A > \frac{1}{2}h_i^*$).*

Proof. Annual profit under ITQ is: $\pi^* h_i^A + \frac{1}{2}h_i^*(P - \pi^*)$. Profit under Limited Entry is $\frac{1}{2}h_i^* P - \frac{r}{1+r}v^*$, noting that, by Result 5 the harvests between the two regimes are equal. Expanding and rearranging gives an expression for the net benefit of ITQs over Limited Entry:

$$\pi^*(h_i^A - \frac{1}{2}h_i^*) + \frac{r}{1+r}v^* \tag{15}$$

which is clearly positive under the stated condition that $h_i^A > \frac{1}{2}h_i^*$. □

Result 7 suggests that if the free allocation is at least half as large as historical harvests, all incumbent fishermen will prefer ITQs to Limited Entry. In fact, this allocation condition is sufficient but not necessary for all fishermen to prefer ITQs. There exists a range range of smaller free allocations over which fisherman i prefers ITQs. Extending fishery-wide, this implies that the regulator need not freely allocate the entire TAC in order to leave all incumbents better off under ITQs. We define by $\bar{h}_i^A$ the free allocation such that fisherman i weakly prefers ITQs to Limited Entry. Rearranging Expression 15 it is clear that $\bar{h}_i^A = \frac{1}{2}h_i^* - \frac{r}{1+r}\frac{v^*}{\pi^*}$, which provides a simple benchmark for the initial distribution of quota shares.

It may be tempting to think that the more valuable are quota shares (i.e. the higher is π^*) the smaller would be the required allocation, $\bar{h}_i^A$. This is incorrect. When the allocation is less than the historical harvest (and thus less than the desired current harvest), a fisherman must compete in the quota market (and pay π^*) for his desired quota. The net effect is that higher values of π^* require *larger* free allocations, as summarized below:

Result 8. *Provided $\alpha_i = \alpha \in (0, 1)$ $\forall i$, higher ITQ quota values require larger free allocations to ensure fishermen are at least as well off under ITQs compared to Limited Entry: $\frac{d\bar{h}_i^A}{d\pi^*} > 0$.*

Proof. $\bar{h}_i^A = \frac{1}{2}h_i^* - \frac{r}{1+r}\frac{v^*}{\pi^*}$ from Expression 15. Differentiating with respect to π^*, and noting that h_i^* is unaffected by π^* (by Result 5), gives the desired result. □

Taken together, Results 6-8 suggest that incumbent fishermen face two competing objectives when considering a switch from common pool to property rights based management. If allocations are free, and are "close enough" to historical harvest levels, fishermen will always prefer ITQs. But if free allocations are sufficiently low, then fishermen may prefer the status quo, even if resource rents, and the value of the fishery, will rise substantially.

The analysis thus far has focused on a proportional cost decrease shared by all fishermen. Instead, suppose the cost decrease is itself heterogeneous. This may occur, for example, if some fishermen are able to compete well in the race to fish (under Limited Entry), but are unable to retool their fishing operations to thrive under ITQs. If another firm is successful at reducing cost, it turns out that this imposes a positive externality on all other fishing firms through the quota share lease price, as summarized below, but this hinges critically on whether the fisherman in question is a net seller, or a net buyer, of ITQ rights.

Result 9. *Let h_i^* be the harvest level chosen by fisherman i under ITQs for cost decreases $\{\alpha_1, ..., \alpha_M\}$ and suppose $h_i^A \geq h_i^*$. Then, a cost reduction given by $\alpha_j < 1$ strictly increases welfare for fisherman i.*

Proof. We allow for a any cost decrease α_j. Let $\Delta\pi^* > 0$ and $\Delta h_i^* < 0$ be the associated changes in ITQ lease price and fisherman i's harvest. We would like to prove that the net benefit of the change to fisherman i is positive:

$$\Delta\pi^* h_i^A - \Delta\pi^* \frac{2h_i^* - \Delta h_i^*}{2} > 0 \tag{16}$$

which reduces to $\Delta\pi^*(h_i^A - h_i^* + \Delta h_i^*/2) > 0$. Noting that $\Delta\pi^* > 0$, it is sufficient to show that

$$h_i^A > h_i^* - \frac{\Delta h_i^*}{2}, \tag{17}$$

which is clearly positive under the stated condition since $\Delta h_i^* < 0$. □

When a fisherman receives a sufficiently large allocation to ensure that he will be a *net seller* of ITQ rights, then the increase in lease price benefits him. On the other hand, a firm who receives a low allocation, and so must purchase permits from the market, is disadvantaged by a decrease in cost for another firm because it drives up his cost. If the inequality in Equation 17 was reversed, owner i would be disadvantaged by the drop in α_j. This suggests that incumbents who receive large free allocations are made better off when others' costs are reduced in an ITQ transition. On the other hand, new entrants, who receive little or no free allocation, prefer competitors whose costs do not decrease following ITQ adoption.

2.5 New Entrants & Political Economy of a 'Zero' Allocation

Taken together, the theoretical results above suggest that incumbents will always benefit from a transition to ITQs if there are no cost changes. When costs proportionately decrease due to ITQ management, incumbents are strictly better off under allocations at least half as large as historical harvests (and for some range of smaller allocations). Similarly, if allocations are grandfathered equal to historical harvests, a decrease in costs for one individual benefits everyone in the fishery. But what happens if a fisherman k receives no free allocation, so $h_k^A = 0$? This may occur for several reasons. First, there is often strong political opposition to free allocation from constituents who feel that a public trust resource ought not be freely distributed to private agents. In that case, even incumbents would receive no free allocation and must compete in the market for ITQ rights.[16] Another possibility is that incumbents are allocated shares for free, but new entrants are not. Whatever the mechanism, requiring owner k to purchase all rights will change owner k's preference for ITQs versus Limited Entry. When $h_k^A = 0$ and making use of Expression 15, owner k will (weakly) prefer Limited Entry if he is of sufficiently high skill. That is, if

$$h_k^* \geq \frac{2rv^*}{\pi^*(1+r)}. \tag{18}$$

Consistent with Result 4 if costs do not change under ITQs (so $\alpha_i = 1 \ \forall i$) then $\pi^* = 0$, so all fishermen prefer ITQs. But if costs are substantially reduced under the ITQ, many of the inframarginal rents that would have accrued to fishermen, are translated into resource rents which (under no free allocation) accrue to the government. In that case some fishermen, particularly the high-skilled ones, are better off under Limited Entry. This becomes particularly extreme when costs go to zero under ITQs, as summarized below:

Result 10. *If $\alpha_i = 0 \ \forall i$, then any non-marginal fisherman k who receives no free allocation ($h_k^A = 0$) prefers Limited Entry to ITQs.*

Proof. By Equation 18, it is those fishermen with high harvest (i.e. those with high skill) who might prefer Limited Entry to ITQs. Since all fishermen have harvest greater than fisherman 1, if the result holds for fisherman 1, it must hold for all fishermen. Applying

[16] In this case, the initial allocation would likely be by auction.

Equation 18 to fisherman 1 and substituting the definition of v^* from Equation 2, yields the inequality:

$$h_1^* \geq \frac{2\left[Ph_1 - \frac{1}{2}c_1 h_1^2\right]}{\pi^*}. \tag{19}$$

If this holds, then fisherman 1 prefers Limited Entry to ITQs (under the stated conditions). Since $\alpha_i = 0 \ \forall i$, we know that $\pi^* = P$ by Equation 14. Substituting into Equation 19 and rearranging gives the inequality $h_1 \geq \frac{P}{c_1}$, which is true by equality: Fisherman 1 weakly prefers Limited Entry. Since fisherman k has strictly larger harvest than fisherman 1, then fisherman k will strictly prefer Limited Entry to ITQs. □

In the extreme, when costs under ITQs go to zero, the value of the fishery is maximized, but it is all manifested as resource rent. Under no free allocation, this rent is captured by the auctioning government, so fishermen actually capture zero rent under ITQs but positive rent under Limited Entry. This result has a strikingly crucial implication: In the best of all possible worlds, where ITQs reduce all costs of fishing to zero, and thus the value of the fishery rises dramatically from the transition to ITQs, every single fisherman would rationally oppose the transition, provided there is no free allocation.

For less extreme assumptions about cost, but still assuming no free allocation, there will be a split: the highest skill fishermen will prefer Limited Entry and the lowest skill fishermen will prefer ITQs. These findings can help inform the political economy and distributional implications of the allocation process when switching to property rights management of a natural resource. For example, given assumptions about the cost decrease for each individual (i.e. values for each α_i), the model could be used to determine the minimum share of the overall quota that must be freely allocated to each participant in order to make all incumbents at least as well off under ITQ management as they were under Limited Entry. This framework could also be used to analyze the allocation rules that are necessary to achieve alternative distributional goals. Similarly, if management change requires a referendum, one could calculate how ITQ shares would need to be freely allocated in order to make 51% (or some other proportion) favor management change. In the end, these question of allocation and distribution are empirical, so we now proceed to a numerical application of our model.

3 Empirical Application

Our model can be used to calculate the distributional and overall economic effects of transitioning to property rights management of a common pool resource. In order to empirically estimate the gains from property rights management and to separate resource rent from inframarginal rent across fishing firms, we need only ex-vessel prices, limited-entry permit prices, ITQ share prices, and the harvest distribution over time. A significant advantage of our approach is the availability of these data. We illustrate our model using data from the Red Snapper fishery in the Gulf of Mexico.

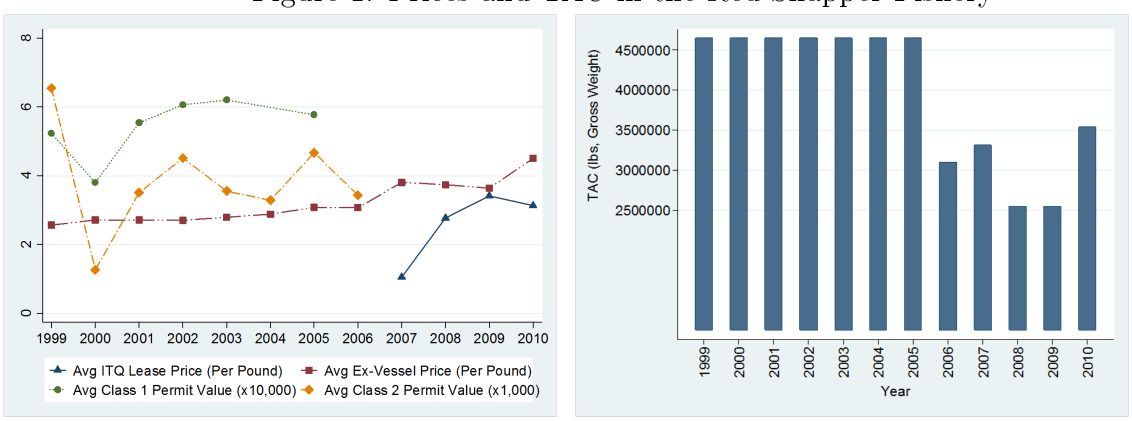
3.1 Gulf of Mexico Red Snapper

The Gulf of Mexico Red Snapper fishery has been exploited commercially for over 100 years. While the fishery declined substantially in the 1990's from overfishing, it has recently been rebuilt. Fishery-wide catch is approximately 8 million pounds/yr., half of which is allocated to the commercial sector. In accordance with our model, the fishery transitioned to ITQs in 2007 following years of limited-entry management. Here, we briefly describe the data and apply the theoretical results derived above to calculate inframarginal and resource rent over time, by fishing firm. Data come from a variety of sources, including government reports and classified advertisements in the leading trade publication. Ex-vessel prices were collected by the Gulf of Mexico Fisheries Management Council and the National Marine Fisheries Service; they were deflated using the Consumer Price Index. IFQ share and lease prices for the years 2007-2010 come from management reports from the Gulf of Mexico Fisheries Management Council.

Limited entry permit prices are not compiled by any public or private entity, so we extracted them from historical issues of the leading trade publication, called *Boats and Harbors*. Bid and ask prices were both used in the calculation of the median permit price each year, and in cases where the listing was repeated in subsequent months (based on the contact information provided), only the last listing was used in the analysis. In cases where multiple goods were listed for one price (such as multiple permits), the permit price was calculated by subtracting the average price of the second permit, when possible. When this was not practicable, those listings were excluded. To our knowledge, this is the first study to use these data to estimate the change in rent due to changes in management.

Figure 1 shows average ex-vessel prices, median permit prices and average quota lease prices over time. The figure shows Class I and Class II permit values, which allow permit holders to harvest 2,000 and 200 pounds per trip, respectively. The average value for a Class I permit is generally more than ten times as high as a Class II permit, and harvest levels for the fishery are generally dominated by Class I permit holders. The ex-vessel prices (product prices) are relatively flat in real terms, with a modest increase in value after the implementation of ITQs in 2007. This is consistent with the literature on ITQs, which generally shows a product premium post-rationalization (e.g. Grafton, et al, 2000). Finally, lease prices for ITQs increased after the initial implementation in 2007, which suggests an increase in annual profitability.[17] In 2010, the lease price is about 70% of the ex-vessel price, far greater than the 33% required for resource rent to exceed inframarginal rent under ITQs (see Result 2 above).

Figure 1: Prices and TAC in the Red Snapper Fishery

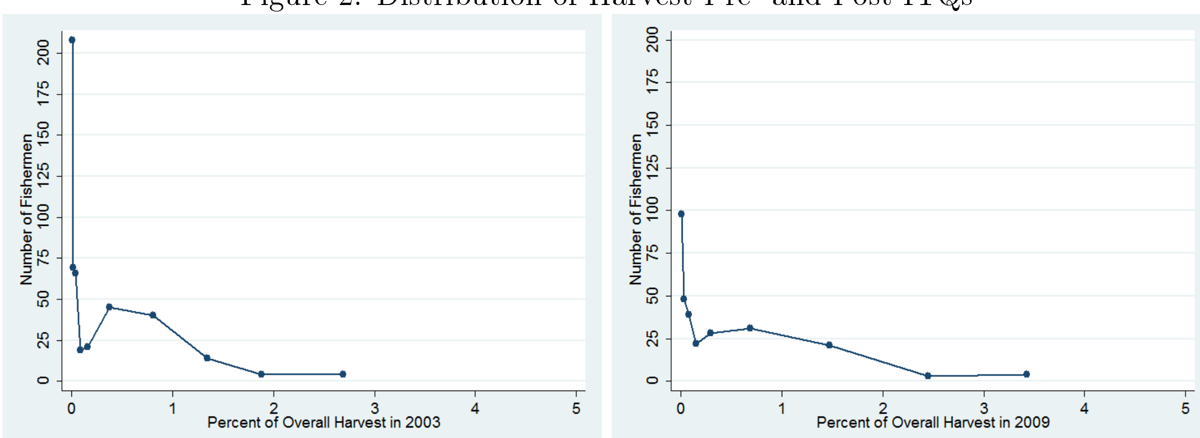


Note: All prices are in 2010 US Dollars. License prices have been scaled by 10,000 and 1,000 for the class 1 and class 2 permits, respectively. The figure on the right is the annual total allowable catch over time (gross weight).

[17] Not shown here are the average values of reef fish permits, which must be held in addition to ITQ rights in order to land red snapper post-2007. These values (roughly $3,500 per permit) are not used in the calculation because a reef fish permit allows access not only to red snapper, but also to other reef fish in the Gulf of Mexico. To the extent that part of the value of the Red Snapper ITQ program is capitalized into reef fish permits, our estimates will lead to an undervaluation of the resource rent.

To estimate the distributional impacts of the transition to ITQs, we need to estimate firm-level skill parameters. Under our model, skill also translates one-to-one to harvest (a fisherman harvests more if and only if he is of higher skill - see Equation 1). We obtained the year-by-year distribution of harvest across fishermen in this fishery. Due to privacy concerns, data on the distribution of harvest are binned.[18] The distributions of harvest under Limited Entry (2003) and ITQs (2009) are shown in the Figure 2. The distribution of harvest under Limited Entry is far from uniform. Prior to ITQs, many fishermen had very small harvest levels, while a few (the exceptionally highly skilled incumbents) enjoyed extremely large catches. This pattern suggests that inframarginal rents may have dominated the value of the fishery under Limited Entry (Result 1). A few years after ITQs, once some consolidation has occurred (captured by $M < N$ in our model), there are fewer fishermen in the extreme ends of the distribution.

Figure 2: Distribution of Harvest Pre- and Post-ITQs



Note: The figures show the number of individuals by harvest levels (as a percentage of the overall quota) in each bin, pre- and post-ITQs. The years shown are 2003 and 2009, respectively.

[18] We assume that the harvest for each fisherman within that bin is the midpoint. This assumption seems reasonable; summing across fishermen within any given year yields roughly the total allowable catch for that year. Through a separate Freedom of Information Act request, the maximum harvest each year was also collected, which is used to estimate the value of a permit for the highest harvester.

3.1.1 Assumptions and Estimates

In this numerical application, we continue to assume that prices are exogenous and costs depend on skill. The cost function, combined with the data on the distribution of harvest, allows us to estimate the cost parameters by fishing firm and calculate the annual inframarginal rent for each fisherman and year. The market permit price under Limited Entry equals the present value of the stream of expected rent for the *marginal* fisherman (Equation 2). Given the assumptions above, we can calculate the annual rent for the marginal fisherman. Ordering the fishermen according to their marginal extraction cost, with i=1 being the marginal fisherman, the annual surplus for the marginal fisherman under Limited Entry management is given by $\frac{h^*_{1t}P_t}{2}$. The market permit price is then given by the present value of all future rents for the marginal fisherman:

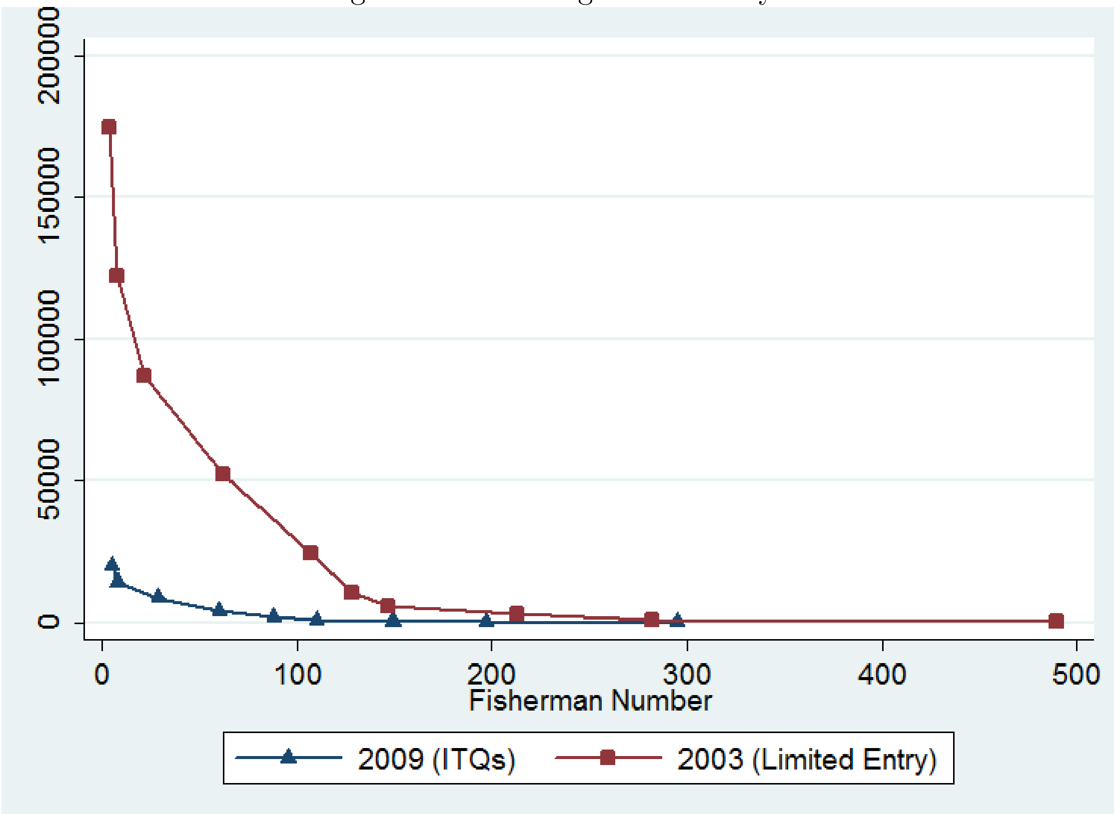
$$v^*_t = \frac{(1+r)}{r}\frac{h^*_{1t}P_t}{2}, \tag{20}$$

Assuming that the expected future rent in each year equal the rent this year, we can calculate the discount rate that rationalizes the market for permits. The median discount rate for the years 1999-2006 that result from this calculation is 11.5%.

We then assume that this discount rate is the same across fishermen within any given year, which allows us to calculate the latent permit value for each fisherman in each year. The present value of resource rent is given by the market capitalization: the permit price times the number of permits. And the present value of inframarginal rent can be calculated using the latent permit value for each fisherman. The sum of the present values of inframarginal rent and resource rent yields the present value of the fishery in any given year. We can then repeat this process to estimate the present value of inframarginal rent, resource rent and the fishery in each year for which we have data. Whether the fishery's value is dominated by inframarginal rent or resource rent under Limited Entry will depend on the degree of heterogeneity in the fishery (Result 1). In this fishery there is considerable heterogeneity in harvest ($\bar{C} \approx 9.77$ for class I participants in 2005) so we expect inframarginal rent to dominate.

Under ITQ management, the annual rent for a marginal unit of harvest is given by the lease price of a quota share. Given the distribution of harvest in each year, we use our

Figure 3: Inframarginal Rents by Fisherman



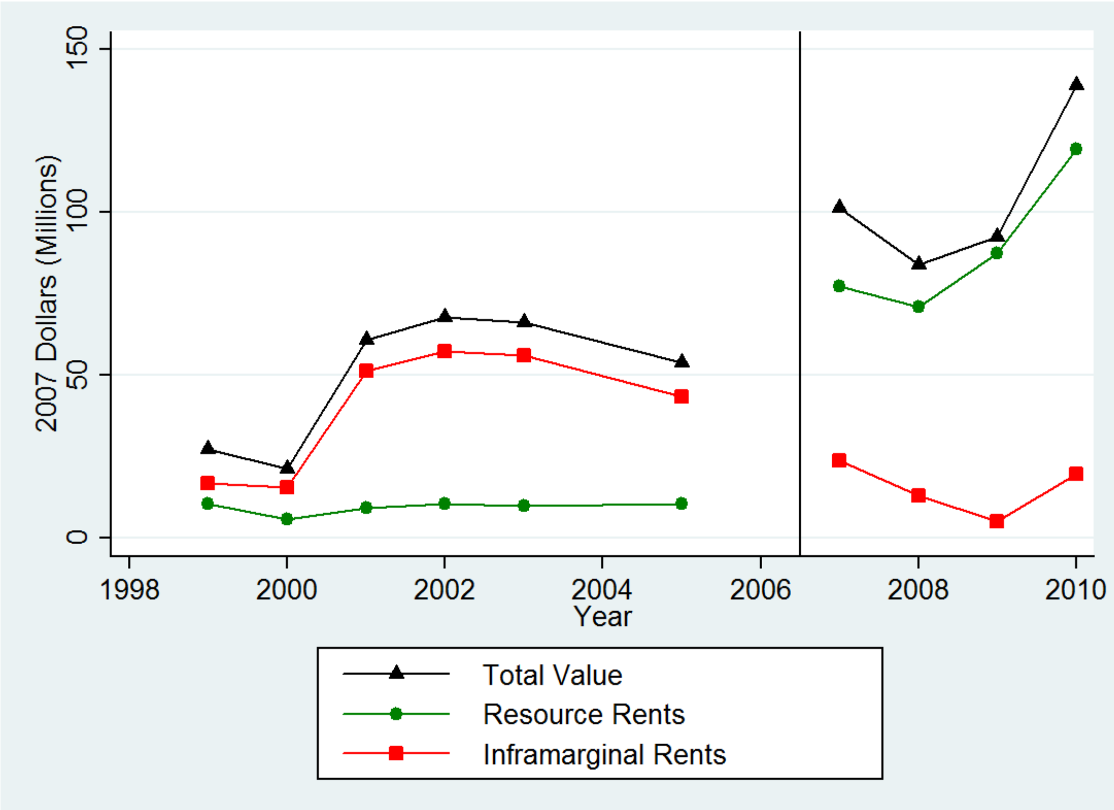
Note: Calculations by the authors using the model described in the text. The vertical axis (2010 Dollars) represents inframarginal rent accruing to an individual. There are 490 fishermen in the data, ranked by harvest levels; 1 represents the highest harvest in that year, and 490 represents the lowest. Two years, 2003 and 2009, are shown, representing pre- and post-ITQ management, respectively.

theoretical model to calculate the implied rent to each fisherman.[19] Figure 3 shows the fisherman-level inframarginal rent in two representative years with different management, Limited Entry (2003) and ITQs (2009). The highly skilled fishermen under Limited Entry earn almost $200,000/yr. in inframarginal rent, while the best fishermen under ITQs earns less than $50,000/yr in inframarginal rent. The earnings by less-skilled fishermen are commensurately smaller. Of course, one of the key messages of this paper is that much of this inframarginal rent is transferred to resource rent under an ITQ. Indeed, the market capitalization (resource rent) under Limited Entry was about $10 million, while the market capitalization under ITQs is about $120 million by 2010. These aggregate results for both

[19]These calculations assume that the discount rate under ITQs is the same as the median rate calculated from our permit equation (20), 11.5%.

kinds of rent and the full value of the fishery are shown in Figure 4. Figure 4 shows an

Figure 4: The Present Value of Rents in the Gulf of Mexico Red Snapper Fishery



Note: Authors' calculations using the model described above. Values in 2007 Dollars. The vertical line denotes a change to property rights (ITQs) in 2007. Data are not available for all permit values in 2006.

overall increase in the value of the fishery due to ITQ management of about 140%. This increase in real value comes despite decreases in the TAC post-rationalization to rebuild the fishery.[20] By assigning property rights in the common pool resource, the return to being skilled under the race for fish is diminished and much of that value is transferred to the owners of the scarce resource. This emphasizes the importance of the initial allocation to compensate incumbent users of the resource for inframarginal rent they might have earned under the status quo regime that they stand to lose under ITQs.[21]

[20]This is consistent with findings in Newell, Sanchirico and Kerr (2005), who study asset values after the implementation of ITQ fisheries in New Zealand. They find that an initial TAC decrease after rationalization led to a subsequent increase in the value of quota in those fisheries.

[21]An interesting point of comparison is the South Atlantic Snapper Grouper Fishery, which we discuss in

3.1.2 Allocation & Distribution

The parameterized model above can be used to determine the initial allocation of quota shares that would be necessary to make each individual as well off (or better off) under ITQs. We use the years 2005 and 2010 (pre- and post-ITQs, respectively) as an example. Suppose that every individual fisherman saw the same proportional decrease in cost due to ITQs (so $\alpha_i = \alpha \ \forall i$). In 2010, the average lease price was \$3.13, and the ex-vessel price was \$4.50. This strongly suggests that costs decreased following the ITQ $\alpha < 1$ (Result 3). Based on the assumptions in our model, this suggests that the social marginal extraction cost decreased significantly–this would correspond to roughly a 70% decrease in cost, or $\alpha \approx 0.3$.

To determine how much free allocation would be required to just compensate every individual fisherman, note that the top harvesters in 2005 earned an average of almost \$200,000/yr. in inframarginal rent. In order to compensate those individuals they would need about 1% of the annual harvest in 2010 freely allocated, substantially less than the 3% they harvested under Limited Entry. One could then follow this line of reasoning to distribute quota shares to each fisherman, based on their inframarginal rent in 2005. The shape of this distribution will follow the shape of the distribution of inframarginal rents, with a total of about 30% of the fishery being freely allocated to just compensate every individual in the fishery (Results 6-8). In fact, the Red Snapper Fishery allocated 100% of the catch to incumbents, who (consistent with our model) generally supported the move to ITQs.

These calculations could be repeated under alternative assumptions about which fishermen are able to decrease their cost by more (or less). For example, if the high-skilled individuals from 2005 could decrease their cost by more than low-skilled individuals, the amount of freely-allocated quota shares required to compensate the high-skilled individuals would decrease; these cost decreases would benefit all fishermen through the permit market (Result 9).

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the Appendix. This fishery is managed by a multi-species permit program, so a direct application of our model is not possible. However, evidence suggests that permit prices and ex-vessel permit prices have been similar between the South Atlantic and the Gulf of Mexico prior to the Gulf's transition to property rights. Furthermore, the harvest distribution over individuals is unchanged over the past decade, whereas the Gulf of Mexico saw a significant shift post-ITQ.

4 Discussion

The main focus of this paper has been to analyze theoretically and empirically the distributional consequences of a transition from common pool to property rights management of natural resources. We do so primarily by distinguishing theoretically and calculating empirically resource rent vs. inframarginal rent. The former accrues equally to all owners of a scarce natural resource. The latter accrues in proportion to heterogeneous skill. Along the way we have developed and implemented a method that uses simple market-level prices, combined with firm level harvest data, to estimate the aggregate effects of the transition to property rights management.

While economists generally favor market-based approaches for managing natural resources, some incumbents often oppose rights-based management. This has often perplexed economists, who point to significant increases in resource rent accruing from the "rationalization" of fisheries. While the gain in resource rent can indeed be large, inframarginal rent under current management (such as Limited Entry management in fisheries) could also be significant. We have shown theoretically and illustrated empirically how the adoption of rights-based management in natural resource settings can lead to a transfer of inframarginal rent to resource rent, and thus may lead incumbents to *rationally* oppose the transition.[22] An important empirical question here is whether the increase in resource rent can more than offset any decrease in inframarginal rent that arises from rationalization. We found conditions surrounding heterogeneity in skill and free quota allocations under which all fishermen would prefer the transition and estimated empirically the net gain from moving to ITQs. The magnitude of this increase will depend on fishery-level variables, so this model could be applied to calculate these value changes in other fisheries.

Our estimates from the Gulf of Mexico Red Snapper fishery offer new insight into the political economy of ITQ programs. One of the political barriers to the implementation of ITQs is often from highliners in a fishery, who support ITQs only under a generous free allocation. The reason for this is clear: under Limited Entry these fishermen enjoy

[22]Moreover, our empirical findings are consistent with arguments as early as Copes (1972), who argued that resource policy should stop the "single-minded" pursuit of resource rent capture.

substantial inframarginal rent. Upon the transition to ITQs, some of this rent is transferred to resource rent, which is either shared equally among all asset owners (if rights are freely allocated) or completely captured by the government (if rights are auctioned). Only by providing a sufficiently large initial allocation can the regulator ensure that all incumbents are advantaged by the transition.

As indicated by Johnson and Libecap (1982), the heterogeneity in skill is critical in understanding the problems facing regulators in natural resources. Other papers point to the importance of heterogeneity in determining the distribution of profits. It has been argued that grandfathering permits is important for economic efficiency (Anderson, Arnason and Libecap, 2010). Our approach sheds light on the importance of both resource and inframarginal rent in determining the aggregate value of a fishery, and shows that firm-level heterogeneity is a substantial contributor to the overall value of a natural resource.

This analysis lends insight into a complex political economy problem. The allocation of rights in catch share programs, or similarly in the allocation of water or forestry rights, determines the allocation of future profits. But it also can take away potential inframarginal rent from those who are very skilled at extracting resources under current management rules. While these distributional implications are not new in resource economics, this model shows conditions under which we would expect these problems to be especially prevalent.

This paper also provides a useful empirical tool, based only on prices and the harvest distribution, for estimating the change in rent due to changes in management. Historically it has been difficult to estimate the change in economic value of a resource like a fishery, mainly because data limitations preclude the estimates of revenues and cost at the micro level. We propose a new method, based solely on publicly-available data, to estimate the change in rent due to management changes. Our model is based on assumptions about the functional form of marginal extraction cost and well-functioning markets for permits and fishing quota. Our estimates suggest more than a doubling in the real value of the fishery due to rights-based management (and more than a 1000% increase in market capitalization, or resource rent). This is similar in magnitude as some estimates using microdata (e.g. Grafton, et al, 2000; Weninger, 1998; and Weninger and Waters, 2003).

To maintain analytical tractability, and to facilitate the empirical calculations, we have made a number of simplifying assumptions. Many of these specifics could be modified or relaxed if better information were available on the resource in question (e.g. if the cost function were known to be other than quadratic). Nevertheless, several caveats are in order. First, in fisheries where skill is easily duplicable, returns to skill will be reduced. This would drive down our estimates of inframarginal rent. Second, in some fisheries heterogeneity in harvest may arise due to unobserved investment (such as in racing capital), independent of skill. In that case our model would identify returns to that capital as inframarginal rent, which would overstate the total rent under Limited Entry and understate the gains from the introduction of ITQs. Finally, it is reasonable to question whether some exogenous factor was responsible for the large gain in market capitalization following the transition to ITQs. While we have attempted to control for known factors, it is impossible to know whether we have captured all relevant variables. As a counterfactual point of comparison, we collected a similar dataset for a similar fishery (South Atlantic Snapper Grouper, see Appendix). Unlike the Red Snapper fishery analyzed above, that fishery did not transition to ITQs. Over the period of our analysis, the South Atlantic fishery maintained a roughly constant harvest distribution, permit price, and rent, suggesting that no macro-level exogenous factor was responsible for the large gains our model attribute to ITQs.

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Appendix: A Model of Effort Choice

There are N permit holders $(i = 1, ..., N)$. Each fisherman i chooses effort, E_i, allocated to fishing. The marginal cost of effort varies across individuals to reflect heterogeneity in skill. Let ϕ_i be i's marginal cost of effort. Let E be the total amount of effort in the fishery, and E_{-i} is the total amount of effort by the other *N-1* fishermen excluding i.

We assume that fisherman i can increase his share of the harvest through greater effort, but that this comes with decreasing returns. Furthermore we assume that an increase in others' effort leads to a decrease in i's share. Specifically, let $s_i(E_i, E_{-i})$ be fisherman i's fraction of the overall harvest where $\frac{\partial s_i}{\partial E_i} > 0$, $\frac{\partial^2 s_i}{\partial E_i^2} < 0$, and $\frac{\partial s_i}{\partial E_{-i}} < 0$. Fishermen take the total allowable catch (H) and ex-vessel price (P) as given.

Fisherman i chooses his effort to maximize his profits, given by

$$Ps_i(E_i, E_{-i})H - \phi_i E_i \tag{21}$$

Differentiating with respect to E_i gives us the (interior) first-order condition for i:

$$P = \frac{\phi_i}{\frac{\partial s_i}{\partial E_i} H}. \tag{22}$$

Fishermen apply effort until the marginal benefit equals the marginal cost of effort. Put another way, we can rearrange as we have in Equation 2, which states that fishermen continue harvesting until the marginal benefit of harvest equals the marginal extraction cost.

There are N fishermen and N corresponding first-order conditions. Since the optimal harvest levels are defined as shares, the TAC binds with equality.

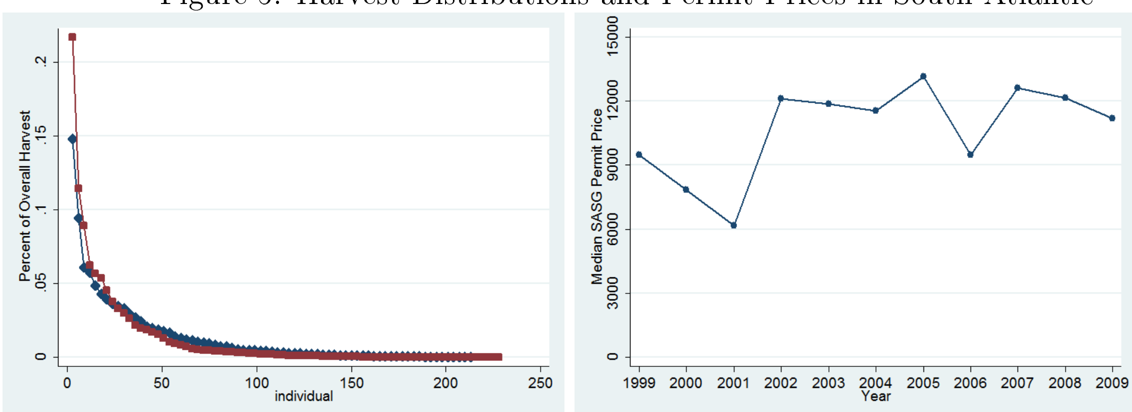
This basic model gives us the intuitive "race for fish" in the intensity of harvest effort. An individual's harvest is determined by the effectiveness and marginal cost of his effort. Moreover, an individual's marginal extraction cost are increasing in his own harvest. Importantly, an individual's effort is increasing in both the ex-vessel price (P) and the total allowable catch (H). Thus, exogenous increases in either P or H lead to more effort exerted by all fishermen.[23]

[23] To see this, first note that $s_i(E_i, E_{-i})$, the fraction of harvest for fisherman i, is increasing in E_i. Assuming some regularity conditions hold, define a function $g()$ as the inverse of $\frac{\partial s_i}{\partial E_i}$. Then $E_i = g(\frac{\phi_i}{PH})$,

Appendix: South Atlantic Snapper Grouper Fishery

The South Atlantic snapper-grouper fishery provides an interesting point of comparison to the Gulf of Mexico's red snapper fishery. Unlike the Gulf of Mexico red snapper fishery, the South Atlantic counterpart has not moved to ITQs. Here we show the distribution of harvest over the past decade and estimates of market permit prices for this fishery. While the South Atlantic provides an interesting point of comparison, that limited entry fishery is managed by a multi-species permit, which makes rent calculations based on our model difficult. Anecdotally the harvest distributions have not changed over this period, and there is no clear trend for permit prices, lending credence to our claim that changes in the Gulf of Mexico red snapper fishery studied in this paper were due to movement to property rights.

Figure 5: Harvest Distributions and Permit Prices in South Atlantic



Note: Harvest distributions are from a Freedom of Information Act data request to National Marine Fisheries Service and include harvests from class 1 permit holders in the snapper-grouper fishery of the South Atlantic. 2003 harvests are represented with a diamond, 2009 with a square. Prices are the median value from classified advertisements in historical issues of *Boats and Harbors*, a trade publication. Details are available from the authors. Prices are in real 2010 dollars.

and $\frac{\partial g}{\partial P} = \frac{-\phi_i H}{(PH)^2} \frac{\partial g}{\partial P}$. Both terms on the right-hand side are negative, so E_i is increasing in P. Showing that E_i is increasing in H is analogous.