Constrained public benefits from global catch share fisheries

Abdulrahman Ben-Hasan[a,b,1], Santiago De La Puente[a], Diana Flores[c,d], Michael C. Melnychuk[a,e], Emily Tivoli[f,g], Villy Christensen[a], Wei Cui[h], and Carl J. Walters[a]

[a]Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC V6T 1Z4, Canada; [b]Department of Marine Science, College of Science, Kuwait University, Kuwait City, Kuwait; [c]Intelfin Estudios y Consultoría S.A.C. (Sociedad Anónima Cerrada), San Isidro 15047, Peru; [d]Bren School of Environmental Science and Management, University of California, Santa Barbara, CA 93106; [e]School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195; [f]Vancouver School of Economics, University of British Columbia, Vancouver, BC V6T 1L4, Canada; [g]Queen's Economics Department, Queen's University, Kingston, ON K7L 3N6, Canada; and [h]Peter A. Allard School of Law, University of British Columbia, Vancouver, BC V6T 1Z1, Canada

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Across publicly owned natural resources, the practice of recovering financial compensation, commonly known as resource rent, from extractive industries influences wealth distribution and general welfare of society. Catch shares are the primary approach adopted to diminish the economically wasteful race to fish by allocating shares of fish quotas—public assets—to selected fishing firms. It is perceived that resource rent is concentrated within catch share fisheries, but there has been no systematic comparison of rent-charging practices with other extractive industries. Here, we estimate the global prevalence of catch share fisheries and compare rent recovery mechanisms (RRM) in the fishing industry with other extractive industries. We show that while catch share fisheries harvest 17.4 million tons (19% of global fisheries landings), with a value of 17.7 billion USD (17% of global fisheries landed value), rent charges occurred in only 5 of 18 countries with shares of fish quotas primarily allocated free of charge. When compared with other extractive industries, fishing is the only industry that consistently lacks RRM. While recovering resource rent for harvesting well-governed fishery resources represents a source of revenue to coastal states, which could be sustained indefinitely, overcharging the industry might impact fish supply. Different RRM occurred in extractive industries, though generally, rent-based charges can help avoid affecting deployment of capital and labor to harvest fish since they depend on the profitability of the operations. Our study could be a starting point for coastal states to consider adapting policies to the enhanced economic condition of the fishing industry under catch shares.

catch share programs | coastal states | extractive industries | fishery resources | rent recovery mechanism

A fundamental practice in the exploitation of public natural resources is the recovery of a financial return for the resource owner—the society—from extractive industries. This practice can influence wealth distribution and the general welfare of the society (1). If national agencies fail to recover a financial return, they deprive the society of a potential stream of economic benefits while at the same time leaving these benefits accumulating within the industry (1). Charging industries for the use of public natural resources is widespread, with charges generally reflecting resource rent—the surplus or above-normal profit related to the natural resource itself rather than to the actions of private enterprises (2). For example, in North America, stumpage fees are imposed on the forestry industry for harvesting timber on public lands (3), and the oil and gas industry is charged royalties for extracting subsoil minerals (4). In contrast, recovering rent from global fisheries has received limited attention from policymakers, despite the widespread harvest of marine living resources, with fish being one of the top traded food commodities in the world (5).

Fishery resources within Exclusive Economic Zones (EEZ) have the potential of generating more than $80 billion in resource rent annually for coastal states (6). Worldwide, around 96% of the annual marine capture production (102 million tons) is caught within EEZs (7). Contrary to open-access and other competitive fisheries, allocating portions of the total quota of a fish stock to a restricted number of fishing firms (individual fishers, fishing vessels, or producers) (i.e., "catch shares") effectively mitigates an inherent economic problem in fisheries management: the competitive race to fish (8). After their inception in the 1980s, mounting evidence highlighted the improved profitability of fishing firms under catch share programs in North America (9, 10), South America (11, 12), Europe (13, 14), and Australasia (15, 16). Currently, fisheries under catch share programs capture some of the largest and most economically valuable fish stocks in the world; yet, it is perceived that society is not compensated for private firms exploiting these public resources (17, 18).

Absent a rent recovery mechanism (RRM), catch share programs could lead to fairness and distributional issues. For example, these programs entail high management costs related to administration, research, surveillance, and enforcement that are entirely or partly covered by society (19, 20). It has been reported that countries intensively adopting catch shares have some of the highest management costs per fishing boat in the world (21). Additionally, for most catch share programs, national agencies have allocated fishing quotas to firms free of charge on the basis of historical participation (i.e., grandfathering) (22). In the United

Significance

Charging industries for exploiting natural resources ensures that the owner of the resources—the public—receives compensation for their usage. Although fishery resources within exclusive economic zones constitute most of the global marine capture production, it is unclear whether fishing industries harvesting these resources are charged for harvesting fish. Our study shows that while global catch share fisheries harvest 17.4 million tons (19% of global catch) with a value of $17.7 billion, rent recovery mechanisms are lacking in 13 of 18 countries. This contrasts with the other extractive industries in the same countries, where rent recovery mechanisms are commonplace. Our findings highlight that most countries are likely forgoing a potential stream of economic revenue from fishery resources.

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[1]To whom correspondence may be addressed. Email: a.benhasan@oceans.ubc.ca.

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Kingdom, for example, the estimated total value of the grandfathered fishing quota is around $1 billion (23). Under such conditions, society fails to offset expenditures attributable to the industry and forgoes a potential stream of revenues that could be maintained indefinitely. The extent to which governments collect resource rent from catch share fisheries therefore has critical ramifications for national policies and the general public alike, particularly as catch share programs are increasingly adopted worldwide (24).

Our goal in this study is threefold. First, we evaluate the prevalence of catch share fisheries at the national and global levels through combining catch statistics from the Food and Agriculture Organization of the United Nations (FAO) with three datasets of catch share fisheries (*Materials and Methods*). Second, to determine society's compensation from the fishing industry, we examine whether RRMs—like auctions, production-based charges, or rent-based charges—occur in catch share programs. Our review focuses on 56 programs harvesting 174 fish stocks in 18 countries, comprising some of the world's largest and most valuable fisheries. Finally, we demonstrate how common rent capture schemes are in catch share fisheries compared with four major extractive industries—forestry, oil, gas, and mining—in the same countries.

Results

Magnitude of Catch Share Fisheries at National and Global Levels. Marine capture production under catch share fisheries accounted for 17.4 million tons with a value of 17.7 billion USD, amounting to 19% and 17% of the weight and value of global landings declared to FAO between 2000 and 2017, respectively (Table 1). Catch share fisheries were identified in 29 countries, 14 of which are among the top 25 largest fish-producing countries of the world (5). Among these 29 countries, the fraction of harvest obtained by catch share fisheries ranged from 0.04 to 84% of the national harvest, with greatest proportions (>50%) in Peru, South Africa, Iceland, New Zealand, Canada, Russia, Chile, and Norway (Fig. 1*A*). The harvest values are roughly proportional to the weight of fish landed in all countries (Table 1 and *SI Appendix*, Figs. S1 and S2). More than half of the resources captured in the Arctic Sea, as well as the northeastern, southeastern, and southwestern Pacific Ocean, were caught by catch share fisheries (Fig. 1*B*). Catch share fisheries target some of the most abundant and valuable target species in global fisheries (*SI Appendix*, Table S1). For example, 61% of gadids (e.g., Alaska pollock, Atlantic cod, blue whiting, and North Pacific hake) and 41% of forage fishes (e.g., Peruvian anchoveta, Atlantic herring, and capelin) landed between 2000 and 2017 were caught by catch share fisheries (Fig. 1*C* and *SI Appendix*, Table S1).

Allocation and Duration of Catch Shares. In the vast majority of catch share programs surveyed (48 out of 56 programs; *SI Appendix*, Tables S2 and S3), catch quota allocations were based on grandfathering (i.e., proportional to historical catch of individual quota holders) or were equal among fishing firms (six programs). These allocation schemes typically involve the (free) granting of access to fish, considered to be either a property right or a limited privilege, depending on the system. The allocations of two catch share programs in Chile are based on a combination of grandfathering and auction: a fraction of the total quota is allotted to the highest bidders in a public sale, while the remainder is allotted based on historical catch (*SI Appendix*, Tables S2 and S3). Over the first 10 years of the quota management system (QMS) implementation in New Zealand, the majority (61%) of the total quota was allocated to firms based on catch history (25). The rest of the total quota was retained by the Crown (39% of the total quota) and had either been sold (e.g., selling around half the quota of the hoki stock) or allocated to the Māori under the Treaty of Waitangi (25).

The duration of catch share allocations vary across programs: 65% of programs have medium (6 to 12 y) and indeterminate (unspecified) duration terms (36% and 29%, respectively); 14% long-term (16 to 25 y); 11% short-term (1 to 5 y); and 11% have permanent allocations (*SI Appendix*, Table S2). While medium and short-term durations may be viewed as less-secure fishing opportunities, historical allocations have most often been consistently allocated to the same fishing firms. For example, although the duration of quota allocations in the United Kingdom catch share fisheries are officially short-term, quota allocations have experienced minimal changes since 1999; the French, Polish, and Peruvian catch share programs undergo similar allocation processes (23, 26). While permanent fishing opportunities are less common, they have been granted for valuable fishery resources: all New Zealand and Iceland catch share fisheries and Australia's rock lobster and abalone fisheries (*SI Appendix*, Table S2).

RRMs in Catch Share Fisheries versus Other Extractive Industries. RRMs (which we distinguish from a cost-recovery [CR] scheme, because the latter is imposed on extractive industries to recover management costs paid by the government) (27) were characterized for 56 catch share programs (174 stocks) in 18 countries (Fig. 2 and *SI Appendix*, Tables S2 and S3). These mechanisms were levied on catch share programs in five countries: they are fully imposed on catch share programs in Argentina, Iceland, Peru, and Russia and are partially imposed on Australia's catch share programs (Fig. 2 and *SI Appendix*, Table S2). In these countries, RRMs levied as a fee proportional to the amount of landings or landed value (*SI Appendix*, Table S4). Of the six catch share programs examined in Chile, the state only receives a financial return from auctioning a portion of the total allowable catch (TAC) set for two catch share programs (*SI Appendix*, Tables S2 and S3). In New Zealand, currently, the Crown auctions off fish quota if 1) there is a remaining quota after allocating quotas of a new fish stock entering the QMS to Māori (20% of the total quota) and commercial fishers and if 2) fishers surrender their quota or the quota is forfeited by the Crown (28). However, rent generated by these auctions represent only a small fraction of total quota value in the New Zealand catch share system. In total, of the 174 stocks (covered by 56 catch share programs), RRMs are imposed on harvesting 36 of them (15 programs); half of these 36 stocks are located in Russia (*SI Appendix*, Table S2).

RRMs are commonplace in other extractive industries (Fig. 2). Overall, among 18 countries, RRMs for oil and gas resources occur in 17 (94%) and 16 (89%) countries, respectively, for mineral resources occur in 13 (72%) countries and for forest resources occur in eight (44%) countries (Fig. 2 and *SI Appendix*, Tables S3 and S4). For some natural resources that are insufficient or underexplored, policies that specify RRMs are in place; this is the case for the oil and/or gas resources in Chile, France, Iceland, Portugal, and South Africa (Fig. 2 and *SI Appendix*, Tables S3 and S4). RRMs linked to production (e.g., money per amount extracted) or value (e.g., percentage of value extracted) occur in all resource industries while mechanisms sensitive to the profitability (e.g., a resource rent tax, which targets the above-normal profit) of firms occur in fossil fuel and mining industries (*SI Appendix*, Table S4). Auctions are commonly applied to the forestry industry in the United States, France, Russia, and, to a lesser extent, Canada (29–32) (*SI Appendix*, Tables S3 and S4). In some circumstances, a rent recovery regime can combine both auctions and rent charges; for instance, leases for the federal onshore oil and gas resources in the United States are awarded to the highest bidders, who also pay charges as a proportion of the production value during operation (*SI Appendix*, Tables S3 and S4).

While reasons are rarely explicitly stated in the reviewed documents, generally the scarcity or absence of resource rent mechanisms in the mining and forestry industries in some countries could be ascribed to the state of the natural resource or ownership. Mineral resources in some countries are generally inadequate, economically nonviable to extract, or have been depleted. For example, France generally has scarce nonfuel minerals with

Table 1. **Mean fisheries yield and value of marine living resources by country, 2000 through 2017**

Country	Mean yield (10^3 t)	Mean value of yield (10^6 USD)	Mean yield under catch share programs (10^3 t)	Mean value of yield under catch share programs (10^6 USD)
Argentina	894	1,099	314	288
Australia	191	669	31	141
Belgium	26	71	2	7
Canada	972	1,944	601	1,028
Chile	3,205	2,771	1,940	1,831
Denmark	912	480	384	182
Estonia	88	41	27	6
France	525	853	40	72
Greenland	230	438	111	201
Iceland	1,456	1,220	1,062	876
Ireland	262	254	28	6
Italy	305	477	23	22
Japan	4,115	5,383	75	121
Mauritania	328	287	43	11
Mexico	1,619	1,842	1	13
Morocco	1,131	995	121	90
Namibia	504	379	2	11
Netherlands	451	365	105	90
New Zealand	486	560	350	433
Norway	2,411	1,796	1,277	1,179
Peru	6,752	7,070	5,700	5,805
Poland	198	109	22	2
Portugal	211	264	10	14
Russian Federation	3,891	3,986	2,369	2,446
South Africa	653	659	515	509
Spain	977	1,307	4	23
Sweden	237	99	104	46
United Kingdom	671	926	157	288
United States	4,853	6,195	1,971	1,956
Other countries*	54,512	64,650	0	0
World†	93,066	107,189	17,388	17,697

Individual countries listed are those with catch share programs in place. Countries in bold are among the world's top 25 countries in terms of landed tonnage (5).
*Other countries include data from 205 countries and territories.
†World includes data from all countries and territories (n = 234) that reported marine catches to FAO between 2000 and 2017.

metallic minerals that are no longer commercially viable for mining (Fig. 2 and *SI Appendix*, Table S3). Iceland has few proven mineral resources and currently lacks metallic mines. Metallic mineral resources in the United Kingdom have either been exhausted or substituted by cheaper imported minerals, though the country is a major producer of other types of minerals. Most mining rights in the United Kingdom are generally privately held with entitlement to all mineral deposits in the subsoil, excluding those owned by the Crown like silver and gold (*SI Appendix*, Table S3). In Sweden, the ambiguity of ownership of minerals covered by the Mineral Act is likely complicating the implementation of an explicit royalty on the mining industry for exploiting minerals (33). With respect to forestry, public ownership of forestland and/or the size of forest resources are apparently insignificant in some countries. In Portugal, Norway, and Denmark, for example, the percentage of forest area under public ownership is ∼3%, 12%, and 24%, respectively, and the total area allocated for production is much smaller than the forest area (*SI Appendix*, Table S3). Forest resources and location are insufficient in Iceland, and so they do not sustain extensive forestry industry (the share of the forest area to land area is 0.5%; *SI Appendix*, Table S3).

Discussion

Catch share fisheries often have exclusive access to fishery resources in coastal waters of national EEZs. Yet, the vast majority of catch share programs are not charged resource rent for the capture of public resources; this contrasts with other extractive industries, in which RRMs are commonplace.

Our findings at the global level are consistent with studies that indicated that mechanisms to recover rent (e.g., auctions, production-based charges, or rent-based charges) are uncommon in catch share fisheries (18, 22, 34). Our findings are also consistent with work that highlighted, though anecdotally, fairness issues stemming from the absence of economic compensation from catch share fisheries to society, especially considering that quota shares are largely allocated free of charge. For example, Smith (35) pointed out that even though the fishing industries in countries like the United States, New Zealand, and Australia have been allocated quota shares for free and that they generally have the flexibility to use, sell, or lease them to new entrants, society receives no compensation. This situation is compounded when society bears the costs of fisheries management, which may include administration, research, surveillance, and enforcement (20, 27, 35). While various forms of CR, usually as license fees, exist in most catch share programs around the world, they often only partly cover management costs paid by society (18, 36).

The absence of RRMs in some catch share fisheries may be ascribed to multiple reasons. Upon implementing many catch share programs, selling quotas to fishers or imposing charges on the industry was not considered feasible as some fisheries were already in financial distress due to declining fish stocks and overcapacity. Consequently, the gratis allocation of quotas for initial holders and the absence of rent charges were considered necessary costs for the government to create an efficient management system (13, 37). In addition, many countries with strong

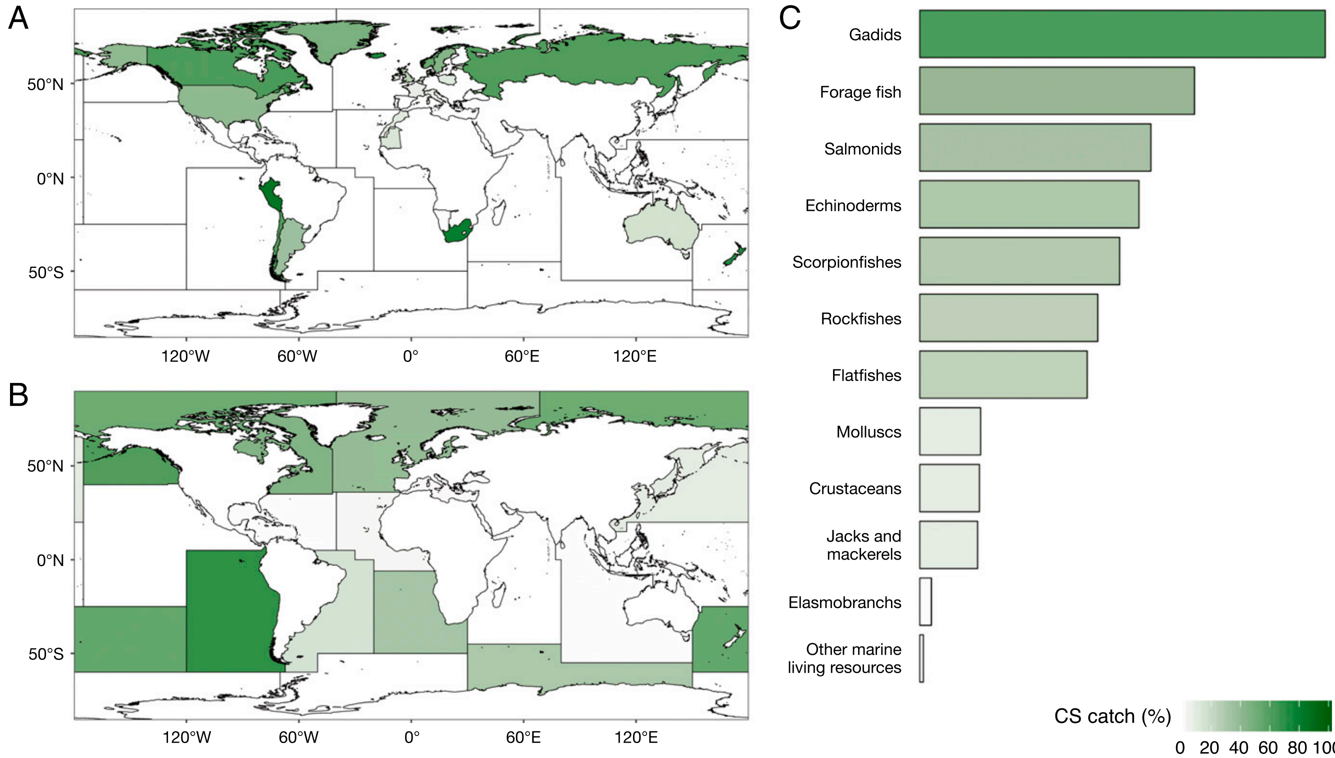

Fig. 1. Proportion of marine capture production under catch share programs. Data are means of annual proportions between 2000 through 2017, separated by fishing country or territory (*A*), FAO major fishing area (*B*), and taxonomic group (*C*).

fishing lobbies are generally sensitive to the industry's interest because of the central role that the industry plays in the success of new management regimes (22, 38). Governments in New Zealand and Denmark, for example, sought to secure the industry's endorsement in catch share systems by assigning quotas on the basis of participation in years leading up to implementing the program (38). However, it is generally recognized in the literature that at least in fisheries in which efficiency has been realized, the continued lack of RRMs in catch share fisheries is unwarranted (17, 38–41). Another possible reason could be the unique history of exploiting fishery resources relative to other extractive industries and the associated impact on the generation of resource rent. Prior to the establishment of EEZs in the late 1970s and early 1980s, fishery resources were considered "common pool" resources largely open for exploitation to all (42). Even after EEZ establishment, resource rent was largely dissipated under management systems that did not address the race to fish (43). Catch share programs began to be

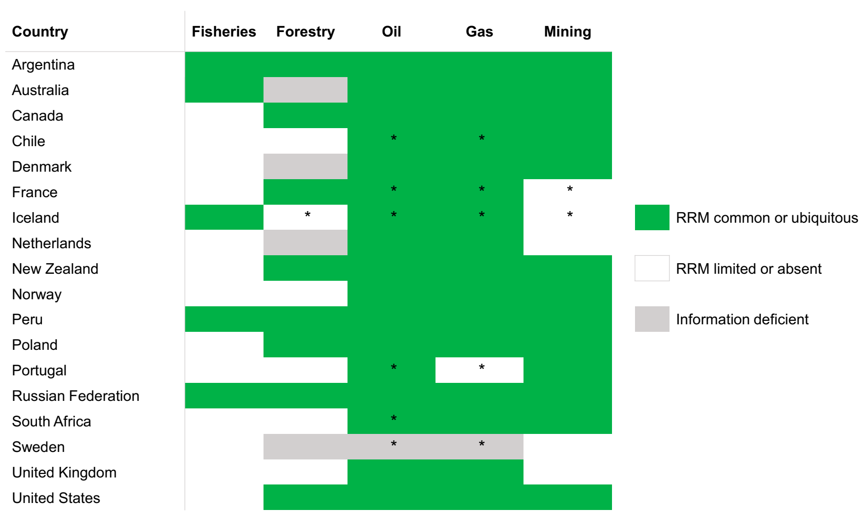

Fig. 2. Occurrence of RRMs by major extractive industries in selected countries. "Fisheries" comprise firms operating under catch share programs (*SI Appendix*, Table S2). The categories "RRM common or ubiquitous" and "RRM limited or absent" indicate the extent to which RRM occurs at the national level or by the administrative entities and its prevalence within an industry (*Materials and Methods*). Asterisks indicate natural resources that are insufficient or underexplored (*SI Appendix*, Table S3).

adopted after this period by a few countries aiming to maximize resource rent (44, 45). While RRMs remain relatively scarce in fisheries, they are currently under consideration by some countries with well-established catch share programs (e.g., Norway) (46).

Although the recovery of resource rent is possible, determining and imposing an RMM on extractive industries is not straightforward. In fisheries, the size of resource rent depends on available fish biomass and on fish prices (47). While catch share fisheries are expected to generate resource rent, this outcome may not be immediate (48). Setting excessive rent charges could affect landed tonnage and may result in bankruptcies or job losses. Nevertheless, for catch share fisheries with quotas already allocated, rent-based charges like a net cash flow can have minimal distortive effects, because they depend on the profitability of the operations: resource rent is generally recovered after deducting all significant capital and operating costs from the revenue (Table 2) (4, 27, 49). During years when firms' expenditures exceed income, rent-based charges can be designed such that losses are carried forward at an interest rate—that is, a loss in one year decreases the charges paid on profits in future years. While in principle, fishing firms subjected to rent-based charges would still be able to earn normal profits even if governments recover all the rent, a partial recovery can be important in minimizing the impact on firms' incentive for innovative investment (Table 2) (4, 27, 47, 49). Sharing rents between the government and firms is common practice in several petroleum and mining industries, in which resource rent tax rates generally range between 10 and 40% (4, 49). Rent-based charges have been recommended or implemented in oil and gas (4, 49), mining (50), forestry (3), developed and developing catch share fisheries (47), and more recently in growing resource industries like aquaculture (51). However, a rent-based charge is but one of many possibilities to capture resource rent, and for some extractive industries, governments do not use it in isolation from other charges and taxes (49). For underdeveloped catch share fisheries in which quotas have not been fully allocated, special models of auctions—possibly in combination with a production-based charge or rent-based charge—have been proposed instead of grandfathering to allocate quotas and recover revenue while considering the economic condition of firms entering the fishery (17, 47). Because auctions entail recurrent sales of publicly held quotas, which necessitates that quotas be retained and reallocated by the government, their application might be politically contentious in developed catch share fisheries whereby quotas have already been assigned based on historical participation. Further, in many catch share fisheries with transferability, new entrants have purchased fishing quotas from the original owners by paying the price that reflected the potential profits without an RRM. Imposing an RRM after such a purchase could decrease the value of these quotas and so may be perceived as unfair to these new entrants. Ultimately, the choice of a RRM heavily depends on critical factors such as the circumstances or historical context of the fishery, governance capacity of the country, political acceptability, potential revenue, and administrative costs.

The scope of our study does not cover all considerations relevant to resource rent and catch share fisheries. We did not consider whether the resource rent charges paid by catch share fisheries and other extractive industries are adequate, excessive, or insufficient. Economic assessments that use fishery-specific data are essential to determine the magnitude of resource rent and set an appropriate charge that 1) ensures adequate compensation for the public, 2) avoids affecting the deployment of capital and labor to harvest fish, and 3) has minimal impacts on the innovation incentive of firms (Table 2). Nor did we consider all possible financial transfers between industries and governments. In all extractive industries examined, the presence of resource rent charges does not necessarily lead to net revenue for the government. In the United States, for example, the forestry industry is charged for cutting timber on public lands, but policies related to who bears the cost of building roads are diverse. These may require that the state pays all construction costs, that industry is responsible for the costs, or that costs are shared between the state and industry (29). The lack of RRMs in catch share fisheries may have serious consequences within the fishing industry. Allowing fishing firms to fully retain the resource rent would lead to high quota values, because the value of the uncollected or inadequately collected resource rent becomes capitalized into the quota value. Consequently, the cost of purchasing quota could form a major hurdle for potential participants, limit income diversification for fishers, and, in conjunction with the concentration of ownership, force fishers to lease fishing quotas that in some cases may cost 70 to 80% of their total revenue in high-value fisheries (52), though in most cases, lease rates are much lower. Some studies have suggested that the absence of RRMs may lead to such consequences (41, 47). However, case studies addressing this issue are limited and represent a fruitful direction for future research.

By highlighting that resource rent capture is a consistent practice across most extractive industries, our findings bolster calls for national agencies to consider collecting rent from profitable catch share fisheries (41, 53, 54). As many catch share fisheries are now well established, prosperous, and expanding (13, 25, 26), depriving society of a potential income stream contradicts the coherent practice of redistributing a share of private gains to the public purse.

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Materials and Methods

Data Sources. Marine fisheries landings data as reported by countries to the FAO were accessed from the FAO Global Capture Production dataset through FishStatJ (55). Landed quantities of live weight (in tons) were separated by country, species, FAO area, and year. The following taxa were excluded as they are not typically fished in wild-capture fisheries managed under quota systems: mammals, reptiles, amphibians, sponges, corals, pearls, shells, and plants. Listed species are occasionally at higher levels of taxonomic aggregation such as Genus, Family, or Order, and are occasionally pooled into "nei" (not elsewhere included) miscellaneous species groups such as "Marine fishes nei." Mean landings over years 2000 through 2017 were calculated for unique entities of country, FAO marine area, and species, here termed "$stock_{C,F,S}$."

Table 2. Selected elements of a rent recovery regime considered for catch share fisheries

Element	Clarification	Importance
State ownership	The right to recover rent springs from the ownership of natural resources.	• Recovering rent represents a source of revenue for the national treasury. • Recovering rent allows for more equitable distribution of wealth between industry and the public.
Rent-based charge	Intends to capture only rent by considering major capital and operating costs, including normal returns.	• Have least distortions on firm's operations since it only targets above normal profits.
Rent sharing	Rather than absorbing all rent, including the portion related to entrepreneurship, the government shares it with the industry.	• Help preserve the firm's incentive for innovation while still ensuring a return to the government.

Mean landed tonnages at the stock level, $\overline{C_{C,F,S}}$, were multiplied by mean ex-vessel prices of corresponding species, $\overline{P_S}$, to estimate mean landed values at the stock level, $\overline{V_{C,F,S}}$. Predicted time series of nominal ex-vessel prices, back-calculated from export prices of fish commodities based on FAO databases and predicted for all taxa in the FAO landings database (56), were extracted for years 2005 through 2012. The mean ex-vessel price for each species over this period was paired with the mean catches of corresponding stocks. Although the ranges of years for $\overline{C_{C,F,S}}$ (2000 through 2017) and for $\overline{P_S}$ (2005 through 2012) only partly overlap, the interannual variability within stocks or species is generally much less than the variability among stocks or species, for both catches and prices. For Antarctic krill and Norwegian krill, $\overline{P_S}$ was instead based on years 1990 through 1994 as those were the most recent available predicted prices. Of the 21,271 unique stock$_{C,F,S}$ entities, 124 (0.6%) did not have paired prices available, but were relatively small, all with mean landings of <2,200 t.

Information about the exclusivity of catch share sectors fishing unique stocks was assembled from several datasets. Catch share fisheries are those in which a proportion of a TAC is allocated to individuals. These individuals may be fishers, vessels, companies, communities, or, in some cases, fishing cooperatives. The catch share units vary in their degree of transferability among individuals. For each stock assessment unit, the mean proportion of the stock's total catch fished by catch share fleets ($\%C_{CS}$) was calculated. For some stocks, $\%C_{CS}$ was based on allocation of TACs among sectors instead of on catches by sector. Values were drawn from the following three datasets in preferential order: 1) Data collected under the Science for Nature and People Partnership program's working group "Fisheries Measures," hosted by the National Center for Ecological Analysis and Synthesis, included 297 assessed stocks from around the world, primarily reflecting the period 2011 through2015 (45); 2) "Fisheries Status and Attributes" expert surveys included 258 stocks from the United States, western Canada, and the United Kingdom, primarily reflecting the period 2005 through 2011 (57); and 3) "Catch share programs" expert surveys included 439 stocks from around the world, primarily reflecting the period 2000 through 2010 (58). Some stocks overlapped among these three datasets; a total of 533 stocks had an available estimate of $\%C_{CS}$. Although the focal periods differed across these three datasets, the proportional allocation of catches or TACs among fleets, including $\%C_{CS}$, generally remains similar over time in the absence of major changes to the management system.

Detailed information about characteristics of catch share fisheries were compiled in the "Catch Share database" by the University of California, Santa Barbara (UCSB) and Environmental Defense Fund (EDF) (59), which used the EDF database as a core source (fisherysolutionscenter.edf.org/database). Values were drawn from two versions of the database in preferential order: 4) a more detailed dataset of 251 catch share fisheries from 20 countries and 5) a dataset of 377 catch share fisheries from 24 countries. Some fisheries overlapped between these two datasets; in total, 412 catch fisheries were contained in either dataset. These fisheries were each linked to one of 316 unique combinations of country, FAO area, and species (i.e., more than one catch share fishery was often linked to a given stock$_{C,F,S}$).

Data Preparation. For later pairing with FAO landings data and landed values, the biological stock-level data for $\%C_{CS}$ were restructured to acquire the same definition as "FAO stocks": unique entities of country, FAO area, and species (stock$_{C,F,S}$). Datasets 4 and 5 above were already defined at this level, so they did not require restructuring. For datasets 1 through 3, unit stocks as defined in stock assessments, stock$_b$, were assigned a primary country of capture and a primary FAO area of capture, here termed $stock_{b_{C,F}}$. This allowed each biological stock to be assigned to a single stock$_{C,F,S}$ of the same species (or other taxonomic level). For most analyses, this structure for stock$_{C,F,S}$ was later pooled across FAO areas to define stocks at the country and species level (stock$_{C,S}$).

Because the spatial distribution of biological unit stocks is often smaller than the spatial extent of FAO statistical areas, there was often more than one stock$_b$ linked to a single stock$_{C,F,S}$. Weighted means of $\%C_{CS}$ were calculated for each stock$_{C,F,S}$ or stock$_{C,S}$, weighted by the catch of biological stocks comprising the stock$_{C,F,S}$ or stock$_{C,S}$. First, the mean catch of the last 10 y of available data for each stock$_b$ was calculated ($\overline{C_{b_{C,F}}}$) and extracted from the RAM Legacy Stock Assessment Database (60). This was multiplied by the estimate of $\%C_{CS}$ for the biological stock, $\%C_{CS_b}$, to represent the recent catch tonnage under catch shares. Biological stocks without estimates of either $\%C_{CS}$ or $\overline{C_{b_{C,F}}}$ were omitted from this calculation. Second, the sums of total catch and catch tonnage under catch shares were calculated across biological stocks for each stock$_{C,F,S}$ and for each stock$_{C,S}$. Third, a ratio of the summed catch tonnage under catch shares to the summed total catch was calculated to represent a weighted mean $\%C_{CS}$, either for each stock$_{C,F,S}$:

$$\overline{\%C_{CS_{C,F,S}}} = \frac{\sum_b (\%C_{CS_b})\left(\overline{C_{b_{C,F}}}\right)}{\sum_b \left(\overline{C_{b_{C,F}}}\right)}, \quad [1]$$

or for each stock$_{C,S}$:

$$\overline{\%C_{CS_{C,S}}} = \frac{\sum_F \sum_b (\%C_{CS_b})\left(\overline{C_{b_{C,F}}}\right)}{\sum_F \sum_b \left(\overline{C_{b_{C,F}}}\right)}. \quad [2]$$

This resulted in 311 entities at the stock$_{C,F,S}$ level with estimates of $\overline{\%C_{CS_{C,F,S}}}$, 31% of which comprised two or more biological stocks. At the stock$_{C,S}$ level, this resulted in 295 entities with estimates of $\overline{\%C_{CS_{C,S}}}$, 36% of which comprised two or more biological stocks.

Datasets 1 through 3 aggregated to the stock$_{C,F,S}$ level and to the stock$_{C,S}$ level were merged with datasets 4 and 5 at the same level of aggregation, avoiding duplication of stocks. Datasets 1 through 3 provided weighted mean $\%C_{CS}$, but datasets 4 and 5 did not contain information about the proportional allocation of total catch into catch share fleets. Because datasets 4 and 5 were focused exclusively on catch share fisheries, we made the simplifying assumption that for stocks in these datasets, $\%C_{CS} = 100\%$. For stocks that occurred in (at least one of) datasets 1 through 3 as well as (at least one of) datasets 4 and 5, the value of $\%C_{CS}$ from datasets 1 through 3 was preferred because of its higher resolution of $\%C_{CS}$ estimates between 0 and 100%. After combining datasets, 455 stock$_{C,F,S}$ entities (and 423 stock$_{C,S}$ entities) with estimates of $\%C_{CS}$ were available. Of these, 166 (and 154) were derived from datasets 1 through 3 only, 147 (and 129) were derived from datasets 4 and 5 only, and 142 (and 140) were available from both, with the values from datasets 1 through 3 selected for use.

Weighted mean estimates of $\overline{\%C_{CS_{C,F,S}}}$ and $\overline{\%C_{CS_{C,S}}}$ from databases 1 through 5 were paired with FAO landings data and estimated landed values at the stock$_{C,F,S}$ level. If there was no corresponding value of $\overline{\%C_{CS}}$ available to pair with an entity in the FAO landings dataset, we assumed $\overline{\%C_{CS}} = 0\%$ for that entity. For each stock$_{C,F,S}$ in the FAO database, mean landed tonnage ($\overline{C_{C,F,S}}$) or mean landed value ($\overline{V_{C,F,S}}$) was multiplied by $\overline{\%C_{CS_{C,F,S}}}$ as well as by $\overline{\%C_{CS_{C,S}}}$, providing estimates of landed tonnage and landed value under catch shares for each stock$_{C,F,S}$ and at both aggregation levels. Landed tonnages or landed values were then summed across species and for one of the two levels of aggregation, also summed across FAO areas. A ratio of these sums provided an overall weighted-mean estimate of the proportion of total landings caught by catch share fleets and a similar estimate for landed value. This metric was calculated at the country:FAO area level:

$$\overline{\%C_{CS_{C,F}}} = \frac{\sum_S \left(\overline{\%C_{CS_{C,F,S}}}\right)\left(\overline{C_{C,F,S}}\right)}{\sum_S \overline{C_{C,F,S}}}, \quad [3]$$

as well as at the country level:

$$\overline{\%C_{CS_C}} = \frac{\sum_F \sum_S \left(\overline{\%C_{CS_{C,S}}}\right)\left(\overline{C_{C,F,S}}\right)}{\sum_F \sum_S \overline{C_{C,F,S}}}. \quad [4]$$

Similar calculations were performed using $\overline{V_{C,F,S}}$ instead of $\overline{C_{C,F,S}}$, resulting in metrics $\overline{\%V_{CS_{C,F}}}$ and $\overline{\%V_{CS_C}}$. Summarized values in Table 1 were based on Eq. **4**. These calculated proportions $\overline{\%C_{CS_{C,F}}}$ and $\overline{\%C_{CS_C}}$ (or $\overline{\%V_{CS_{C,F}}}$ and $\overline{\%V_{CS_C}}$) are assumed to be indices of catch share exclusivity for each country:FAO area entity or for each country, respectively. They may underestimate true proportions if fisheries under catch share management were not accounted for in datasets 1 through 5. Second, because of the assignment of biological stocks to a single primary country and single primary FAO area, $\%C_{CS}$ for countries and areas other than the primary ones do not include the other-than-primary contributions from those stocks. Finally, while the assumption of $\%C_{CS} = 100\%$ for stocks in datasets 4 and 5 is generally reasonable because stocks in this dataset are under catch share fleets, this may overestimate $\%C_{CS}$ for some stocks. Although there is uncertainty in overall magnitudes of $\overline{\%C_{CS_{C,F}}}$ and $\overline{\%C_{CS_C}}$ for the above reasons (and even greater uncertainty in magnitudes of $\overline{\%V_{CS_{C,F}}}$ and $\overline{\%V_{CS_C}}$, because of the additional uncertainties associated with ex-vessel price predictions), the indices are expected to be reliable as a means for comparison across countries.

Review of RRMs. Some of the main differences among the extractive industries examined in this study are pertinent to ease of monitoring and the nature of property rights. As an illustration, inventory estimation is relatively straightforward for forestry compared with oil, gas, mineral, and fishery resources. Additionally, property rights in forestry, oil, gas, and mining are tied to pieces of land. With the exception of cases like Territorial Use Rights Fisheries, this is not the case for fisheries, in which the property rights are not spatially explicit. In general, the investigated extractive industries require permits or privileges that are awarded by the government to access the resource. While some sort of property security is necessary for private firms to pursue the extraction of natural resources, such security can be provided through a variety of institutional forms. For example, a government can offer oil drilling and extraction sale, lease lumber rights on public land, or issue tradable fishing permits for a limited number of firms. The heterogeneity of these legal structures contrasts with a critical purpose underlying each of them: to provide security of resource rents to firms.

Using the global fisheries database compiled by UCSB (59), we identified 56 transferable and nontransferable catch share programs in 18 countries. We examined these types of catch share programs, because theory and evidence indicate that they diminish the race to fish (8). For each program, we obtained detailed information on allocation, permanence, transferability, and RRMs through conducting extensive review of literature, covering a range of documents such as peer-reviewed publications, gray literature (i.e., government reports), legal documents (e.g., laws, regulations, tax codes), and government data repositories. Similarly, we reviewed the occurrence of resource rent schemes in the other extractive industries—namely forestry, oil, gas, and mining—in the same 18 countries. The sources used to determine whether resource rent schemes exist in these industries consisted mostly of 1) actual legislation/regulation and 2) summaries of industry or national regulatory framework. The former type of source consisted of government documents, websites, and guides, while the latter consisted of private sector industry overviews, whether from legal firms (e.g., Thomson Reuters Practical Law), industry organizations, or multinational organizations (e.g., Organisation for Economic Co-operation and Development and FAO).

The resulting resource rent dataset consisted of 90 country-industries, each of which may or may not have a RRM. These observations take on a binary value: the RRM exist ("1") or do not exist ("0"). Due to data limitations, there are also observations in which 1) there was little or no data on the country-industry taxation policy or 2) there was some data on the country-industry, but either the sources were, for example, contradictory, unclear, limited, or questionable, such that it is unlikely an RRM exists but the imperfect evidence leaves much room for error. Such observations were assigned "0?."

Classifying the collected information involved two main steps: 1) distinguishing an RRM from a CR scheme and w) determining whether there is enough information about the occurrence of RRM in an industry. The purpose of 1) is to exclude payment schemes that are aiming to recover management costs paid by the government. If there is a clear and sufficient basis for deciding that some tax policy concerning resources exists, then the question becomes which category the particular policy belongs in, but in more complicated cases, the two questions may go hand in hand.

At the start of the classification process, the first distinction is made on the basis of the mechanism (Fig. 3). An RRM is considered an explicit payment by an extractive industry to the government for the access and extraction of publicly owned natural resources. Generally, RRMs comprise two broad forms. First, resource rent charges that are linked to the production, value, or profitability of firms (not solely applied to cover regulatory costs) are one form (27, 50) (Fig. 3). Common examples are royalties set as a share of production output, and rent-based charges intended to capture resource rent after deducting current and capital costs from revenues (4, 27). The second form, auctions, generally serve two roles: 1) create a revenue ex ante for the government through selling access rights (i.e., not tied to production) and 2) allocate natural resources to the most-efficient firms (61). A relatively uncommon mechanism to recover resource rent is privatization, in which through selling natural resources, governments recover resource rent as the sale value in "one strike" (27). The purpose of a CR, on the other hand, is to recover costs incurred by the government that largely benefit the private sector (27). In fisheries, CR mechanisms include costs such as annual license fees, limited entry fees, or landings taxes collected for specific management costs. When differentiating between an RRM and CR, one major ambiguity lies in the link between the charges paid by companies and the benefits they gain from government activities; the link may be weak or not visible. While some charges are extremely clear—for example, Portugal's mining industry pays a CR based on an estimate of the cost to the government agency of writing up the mining contract—others are less so. The general rule we followed is that payment must be linked to government activity somehow, even if it is rather weak. Fees that are charged per inspection instead of being linked to production, or any regular operation that involves government participation, are not considered an RRM (i.e., it is a CR).

The second classification concerns the sufficiency of the evidence and the distinction between "0?" and "0." The main difficulty arises from the epistemic issue that lack of evidence for is not evidence against. In other words, it is easy to find a document stating that a charge exists, but there are no documents stating which charges do not exist—the fact that proof of a charge was not found does not provide proof that the charge does not exist. Even within the uncertainty that this epistemic fact creates, there is variation in the evidence found and the way we categorized it. If clear evidence of an RRM policy (as classified by the decision tree in Fig. 3) was found for a country-industry, then a "1" was assigned. If a source that seemed to exhaustively describe the regulatory framework of the country-industry was found, and it made no mention of a policy resembling an RRM, then a "0" was assigned as there was a reasonable basis for claiming that no RRM exists within that country-industry. However, there were also cases in which sources describing a country-industry were conflicting, clearly nonexhaustive, limited, or otherwise insufficient. In such cases, a "0?" was used to indicate that some information on the country-industry was found but was not as conclusive as those assigned a (cautiously) confident "0."

For each of the 18 countries evaluated and each extractive industry type, we summarized "1" as "RRM common or ubiquitous"; "0" as "RRM limited or absent"; and "0?" as "Information deficient" (Fig. 2). Given the wide range of possible RRM policies within each country-industry, the categories "RRM common or ubiquitous" and "RRM limited or absent" indicate the extent to which RRMs 1) occur at the national level or by the administrative entities (largely relevant to Canada and the United States) and 2) are prevalent within an industry. For 1), we assigned "1" if we found a RRM at the federal level and/or if RRMs occur in the majority of states or provinces (*SI Appendix*, Table S3). To illustrate 2), we assigned "1" for the oil industry in Portugal, because RRM is prevalent in the oil industry in general (RRM imposed on offshore and onshore operations), despite that offshore production in fields that are deeper than 200 m is completely exempted from RRM (*SI Appendix*, Table S3). These discrepancies in RRM implementations are sometimes observed in the oil and gas industries in which RRM regimes usually distinguish between, for example, offshore and onshore operations. While these categories can be viewed as coarse in some countries-industries, they communicate the wide variations in RRM implementation within countries-industries.

Several caveats exist in the resource rent assignments. First, proof of the existence of a charge gives far more certainty to a "1" than the lack of proof gives to a "0." This tendency implies that in general, the proportion of "1s" relative to "0s" is biased upwards. In other words, we are more likely to have overlooked a "0" than a "1," since "1s" are easier to find. Second, certain industries, like oil and gas, have particularly good data. Combined with the first caveat, we may suspect that country-industries with more accessible and detailed documents relevant to RRM are more likely to have "1s" than "0s," suggesting that the proportion of rent charges for these country-industries might be biased upwards. Finally, a single charge tied to output resembles

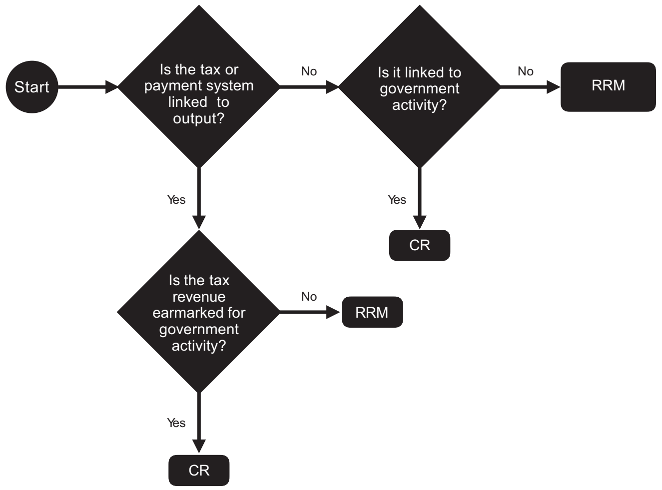

Fig. 3. Decision tree for determining whether the mechanism corresponds to RRMs or CR. RRMs that are not tied to production generally reflect auctions.

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an RRM rather than a CR, but we have little to no information about how the funds from RRM are used. If we find evidence of an RRM but no evidence of a separate CR or of the funds from an RRM going to CR purposes, we consider it as an RRM despite the possibility that some or most of the RRM revenues might be paid for CR.

Data Availability. All study data are included in the article and/or *SI Appendix*.

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