Privatizing renewable resources: Who gains, who loses?

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Abstract

Privatizing renewable resources reduces rent dissipation. When harvesting rights are grandfathered, as it is usual practice, resource rents accrue to producers. We analyze the conditions under which consumer surplus and intramarginal rent of resource workers increase or decrease with the efficient privatization of harvesting rights. For the Northeast Artic cod fishery we find a substantial wealth transfer from consumers to producers: with efficient management resource rent would increase by 8 billion NOK, while consumer surplus would decrease by 3 billion NOK.

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It is a well-known fact that many of the world's renewable resources are managed inefficiently. With better management, annual profits from marine fisheries could increase by some 50 billion dollar (World Bank 2008). Given the highly varying success of resource management world-wide (Copeland and Taylor 2009), we study the distributive effects of implementing efficient resource management, starting from a situation of no or inefficient resource management.

Akin to the common practice of grandfathering use rights (for example, fishing quotas), we assume that use rights for renewable resources are given out free of charge, allocating resource rents to producers.[1] The aim of this paper is to derive conditions under which efficient privatization of renewable resources will increase or decrease (a) consumer surplus of households utilizing resource products (for example, seafood) and (b) intramarginal rent of workers employed in the resource harvesting sector.

The previous literature comes to mixed conclusions. Turvey (1964) and Copes (1972) show that consumer surplus may increase or decrease under efficient fisheries management, but without identifying clear conditions for one or the other case. Similarly, Hannesson (2010) argues that the increase in resource rents as estimated by World Bank (2008) is not necessarily a good measure for the benefit of privatization, as non-rentiers may benefit or lose from privatization. The early theoretical literature on how privatizing the commons affects worker income concludes that workers, or more generally a variable factor, will always be better off under open access than under efficient private ownership (Samuelson 1974, Weitzman 1974). Later, Meza and Gould (1987); Brito, Intriligator and Sheshinski (1997); and Baland and Bjorvatn (2010) provide examples where workers are better off in consequence of privatization. Olson (2011) summarizes the empirical evidence of ten fisheries that have been privatized and finds examples for

[1]Throughout the paper, we do not take into account possible compensation payments between different stakeholder groups. This is in line with the previous literature, and indeed compensation of consumers or workers may be very difficult in practice.

both increases and decreases in crew income and employment.

In this paper, we build our analysis on the canonical model of renewable resource economics (Clark 1991), where the dynamics of the renewable resource are governed by a concave stock-growth function, and harvesting technology is described by a generalized Gordon-Schaefer production function (Gordon 1954, Schaefer 1957, Clark 1991).

The approach overcomes shortcomings of previous studies in two respects. Contrasting open access with full efficiency, the previous literature neglects that most renewable resources are at least partially managed (Copeland and Taylor 2009), i.e. not all resource rents are dissipated. Accordingly, we consider initial situations that may lay between open access and full efficiency. Moreover, most of the existing literature considers static models of resource use. These models do not allow for disentangling the different classes of externalities typical for renewable resource use. As classified by Munro and Scott (1985), Class I common property externalities refer to rent dissipation through depletion of the resource, while Class II common property externalities refer to rent dissipation through the excessive use of production inputs leading to crowding. Class II externalities arise independently of any feedbacks on resource stocks and hence are not limited to renewable resources. By contrast, Class I externalities capture inherently dynamic problems specific to renewable common property resources. We exclude Class II crowding externalities by assuming a constant marginal product of harvesting effort and focus on Class I externalities in our dynamic analysis.

Following Turvey (1964), the social welfare derived from using a renewable resource is the sum of (i) resource rent, (ii) consumer surplus and (iii) intramarginal rents for other production inputs besides the resource. To understand distributive effects in renewable resource markets, we consider three stakeholder groups, (i) a group H that aims at maximizing present value of resource rent, (ii) a group C that aims at maximizing present value of consumer surplus and (iii) a group L that aims at maximizing present value of intramarginal rents for labor in the resource sector. We study the effects of giving each

of these groups the exclusive and permanent right of using the resource. Comparing the optimal harvesting plans of the three groups then reveals how the well-being of these groups is affected by efficient privatization. In order to disentangle market power and time preference effects from distributive effects, all agents are assumed to behave competitively and apply the same discount rate. We show that giving group H the use rights will be efficient, and that social welfare would be lower when giving resource rights to groups C or L. By comparing the optimal dynamic harvesting plans of the different stakeholder groups we identify conditions when (a) consumers or (b) resource workers benefit or lose in consequence of resource privatization.

We find that the 'stock effect' of harvesting (Clark and Munro 1975) is crucial and drives a wedge between stock dynamics that maximize resource rent, consumer surplus and worker income. The 'stock effect' captures how the productivity of harvesting depends on the size of the resource stock. Typically harvesting becomes more productive the larger the stock size is, for example because search costs for a dispersed resource decrease. Depending on the patchiness of resource abundance and harvesting technology, the stock effect may vary from a linear increase of productivity with stock size (e.g. Gordon 1954) to no dependence of productivity on stock size at all (Clark 1991, Hannesson 2007). We show that with a strong stock effect, consumers and workers tend to lose from privatization, while in the absence of a stock effect, dynamic management plans of all stakeholder groups are the same and hence consumers and workers would benefit from privatization compared to any inefficient situation.

The intuition behind the result that the stock effect leads to diverging management plans of stakeholders is as follows. Under efficient management, the stock effect is taken into account, which increases the optimal steady-state stock size compared to a situation without a stock effect. Consumers, who do not care about harvesting costs, perceive this as an over-investment that blocks temporarily increased consumption. Similarly, workers perceive high stock sizes as a rivaling input in resource production, although they depend

on a productive stock to accommodate employment in the resource sector. Following workers' interest, a high efficient stock size blocks temporarily increased employment (and hence intramarginal rents).

We apply our model to the Northeast Artic cod (NEAC) fishery, one of the largest cod fisheries world-wide. Under pure open access until 1978, stock biomass steadily declined until 1983. By gradually regulating harvest and decreasing illegal fishing, the stock was rebuilt until 2010 to 91% of the stock size that yields the maximum sustainable yield (MSY). Due to the stock effect of the harvesting technology, the efficient stock size would exceed the MSY-stock by 17%, however. By comparing a stop of the rebuilding at the current stock size with a continued rebuilding to the efficient stock size, we show that the distributive effects of incremental efficiency gains can be substantial.

The rest of the paper is organized as follows. Section 1 briefly introduces the canonical model of renewable resource economics on which we build our analysis. In Section 2, the model is used to derive resource harvesting plans that maximize resource rent, consumer surplus and intramarginal rent for labor in the resource sector. A comparison of these policies in Section 3 explains distributive effects in renewable resource markets. Section 4 calculates the distributive consequences of a continued rebuilding of the Northeast Artic cod fishery. Section 5 concludes.

1 Dynamic model of renewable resource use

We consider a representative infinitely lived household whose felicity function is quasi-linear, depending on a quantity y of a composite numeraire good and a quantity h of renewable resource harvest. Using ρ to denote the discount rate for the numeraire, the household's utility at time $t = 0$ is given by

$$\int_0^\infty (u(h) + y)\, e^{-\rho t} dt \tag{1}$$

The renewable resource sector depends on a resource stock x which grows according to

$$\dot{x} = g(x) - h, \tag{2}$$

where $\dot{x} \equiv dx/dt$ is the natural growth of the resource stock; $g(x)$ is a growth function, which is assumed to be strictly concave with $g(0) = 0$ and $g(K) = 0$ for some $K > 0$. This implies that a unique stock size x_{MSY} with $0 < x_{\text{MSY}} < K$ exists that generates the maximum sustainable yield (MSY).

In the following, we use x_ρ to denote the stock size at which $g'(x) = \rho$ holds. We assume that $x_\rho > 0$, i.e. we exclude the case of optimal extinction (Clark 1973). The initial positive stock size x_0 may result from a situation of open access or some form of (inefficient) resource management.

We consider a harvesting technology where harvest depends only on labor input l in resource harvesting and the stock size x. The harvesting technology is described by a generalized Gordon-Schaefer harvesting function (Gordon 1954, Schaefer 1957, Clark 1991)

$$h = q(x)\, l \tag{3}$$

with $q'(x) \geq 0$, which means that harvest weakly increases with stock size at any given effort level. The function $q(x)$ captures the 'stock effect'. A linear function $q(x) = q\,x$ would describe a very strong stock effect, while a constant $q(x) = q$ would indicate no stock effect at all.

The numeraire sector produces using labor as the sole input, according to a technology described by a production function $f(\cdot)$ with positive but decreasing returns to labor, $f'(\cdot) > 0$ and $f''(\cdot) < 0$. Total labor supply is normalized to unity. Hence, output y of the numeraire sector is

$$y = f(1 - l). \tag{4}$$

2 Optimal harvesting plans for different stakeholder groups

We consider three stakeholder groups, (i) a group H that aims at maximizing present value of resource rent, (ii) a group C that aims at maximizing present value of consumer surplus and (iii) a group L that aims at maximizing present value of intramarginal rent for labor in the resource sector. We study the effects of giving each of these groups the exclusive and permanent right of using the resource. In all three scenarios, the stakeholder group who owns the use rights incorporates the resource stock dynamics in its optimization problem. All other agents and stakeholder groups in the economy are assumed to behave as competitive price takers. This assumption prevents that market power effects influence the dynamic harvesting plans of the different stakeholder groups.

2.1 Use rights for stakeholder group H

Given the use rights over the renewable resource, stakeholder group H maximizes the net present value of resource rents, which are given by the difference between revenues from selling resource harvest at the market price p paid by the consumers less expenses for the labor employed at the wage rate w on the labor market. As explained by Gordon (1954), this resource rent is a social surplus due to real scarcity of the renewable resource, rather than representing artificial scarcity as in standard monopoly. Monopoly rent is excluded by stakeholder group H taking prices p and w as given when optimizing (5).

When maximizing the present value of resource rents, stakeholder group H takes into account the scarcity of the resource, captured by the stock dynamics (2) and the harvesting technology, notably the stock effect of harvest, as described by equation (3). Hence, stakeholder group H chooses the harvesting plan h and associated stock development x as well as labor input l in resource harvesting such as to maximize the present

value of resource rents. Formally, stakeholder group H's optimization problem reads

$$\max_{\{h,l,x\}} \int_0^\infty (p\,h - w\,l)\; e^{-\rho\,t}\,dt \quad \text{subject to (2) and (3).} \tag{5}$$

With current-value shadow price μ_H for constraint (2) and inserting (3), the current-value Hamiltonian is $H = p\,q(x)\,l - w\,l + \mu_H\;(g(x) - q(x)\,l)$. The first-order conditions for stakeholder group H's optimal harvesting plan are

$$p = \frac{w}{q(x)} + \mu_H \tag{6a}$$

$$p\,q'(x)\,l + \mu_H\;(g'(x) - q'(x)\,l) = \rho\,\mu_H - \dot{\mu}_H \tag{6b}$$

with given initial stock x_0, transversality condition $e^{-\rho T}\,\mu_H(T)\,x(T) \xrightarrow{T\to\infty} 0$, and together with (2).

Condition (6a) states that marginal revenue p equals the sum of marginal harvesting costs $\frac{w}{q(x)}$ plus the marginal value of the stock μ_H. The latter term reflects the marginal reduction of stock value by reducing it through harvesting. With the household maximizing felicity subject to budget constraint, it follows $p = u'(h)$. Firms in the numeraire sector maximize profits, hence $w = f'(1-l)$. Thus, condition (6a) in market equilibrium reads

$$u'(h) = \frac{f'(1-l)}{q(x)} + \mu_H, \tag{7}$$

where the marginal value of the stock is determined by (6b).

We shall consider this equation in steady state, i.e. when $\dot{\mu}_H = 0$ and $\dot{x} = 0$. The latter condition requires that natural production $g(x)$ must equal harvest in steady state. Thus, $l = g(x)/q(x)$ in steady state. The optimal steady state x_H according to stakeholder group H's harvesting plan is given by the following condition

$$g'(x_H) = \rho - \frac{f'(1 - g(x_H)/q(x_H))\,q'(x_H)\,\frac{g(x_H)}{q(x_H)}}{u'(g(x_H))\,q(x_H) - f'(1 - g(x_H)/q(x_H))}. \tag{8}$$

The stock size has a positive impact on harvesting productivity and hence a negative effect on unit harvesting costs. The second term on the right-hand side of condition (8)

is non-negative. Thus, we have the well-known result of Clark and Munro (1975) that $x_H \geq x_\rho$. The optimal steady-state stock for stakeholder group H is unambiguously larger than the open-access steady-state stock x_{OA} (see appendix), and it may be larger or smaller than the stock that generates the maximum sustainable yield, x_{MSY}.

By comparing the conditions for the dynamic market equilibrium when resource rights are given to stakeholder group H with the conditions for the social optimum (derived in Appendix 5), we find that this scenario leads to the dynamic social optimum:

Lemma 1. *The optimal harvesting plan of stakeholder group H is identical to the socially optimal harvesting plan.*

2.2 Use rights for stakeholder group C

Consumers take numeraire production whose consumption yields no consumer surplus as given. Their consumer surplus stems from the consumption of the renewable resource through time. When given the use rights over the renewable resource, stakeholder group C optimizes present value of consumer surplus over the harvest stream and hence stock dynamics. They take as given the producer price p of resource harvest.

$$\max_{\{h,x\}} \int_0^\infty (u(h) - p\,h)\; e^{-\rho\,t}\,dt, \quad \text{subject to (2).} \tag{9}$$

With current-value shadow price μ_C for constraint (2), the current-value Hamiltonian is $H = u(h) - p\,h + \mu_C\;(g(x) - h)$. The first-order conditions for stakeholder group C's optimal harvesting plan are

$$u'(h) = p + \mu_C, \tag{10a}$$

$$\mu_C\, g'(x) = \rho\,\mu_C - \dot{\mu}_C, \tag{10b}$$

with given initial stock x_0, transversality condition $e^{-\rho\,T}\,\mu_C(T)\,x(T) \xrightarrow{T\to\infty} 0$, and together with (2).

As consumers themselves internalize the stock feedback into their optimization problem, harvest is supplied by myopic competitive firms in the resource sector. Because of constant returns to scale, resource harvesters have zero profits, hence the producer price of resource harvest is $p = w/q(x)$. Firms in the numeraire sector maximize profits, hence $w = f'(1-l)$. Thus, the market equilibrium conditions when stakeholder group C has the use rights over the resource is

$$u'(h) = \frac{f'(1-l)}{q(x)} + \mu_C. \tag{11}$$

It is noteworthy that the structure of (11) equals the efficient one of (6a). That is, in each point in time consumers equate their marginal utility of consuming the resource with the sum of the marginal harvesting costs plus the marginal costs of reducing the stock. The difference to the efficient harvesting plan originates from consumers disregarding the effect of stock abundance on harvesting productivity. Absent in (10b), this effect is captured in (6b).

It is however perfectly rational for price-taking consumers to disregard this effect. Consumer surplus is determined by quantity h and absolute price p on the inverse demand curve. Consequently, the absolute price level and not its components (marginal harvesting costs plus the marginal costs of reducing the stock, cf. (11)), determine consumer welfare.

In case the consumers own the use rights, only the unit harvesting costs are real payments while the marginal user costs of reducing the stock are taken into account as pure opportunity costs of current consumption. The argument that only absolute price matters for consumers may be clearer for cases in which consumers do not own the use rights. In the case of privatization, consumers pay for both unit harvesting costs and marginal stock value, the latter becoming resource rents for producers. Changes in this rent-cost structure do not impact consumers whose welfare depends on the absolute price level. It is this dependence on absolute price and not price composition that explains

why the effect of privatization on consumers is ambiguous.

The condition for the steady state maximizing present value of consumer surplus, x_C, follows as

$$g'(x_C) = \rho, \tag{12}$$

implying $x_C = x_\rho$.

Intuition might suggest that consumers prefer the stock size x_{MSY} in steady state, because this stock yields the maximum harvest level. As this is the maximum sustainable supply of fish on the market, this would maximize steady-state consumer surplus. The above result shows, however, that this is not the optimal steady state. This is because increased short-run consumption during the disinvestment phase from x_{MSY} to x_ρ plus a subsequent long-run consumption of $g(x_\rho)$ yields a higher consumer surplus in net present value terms than a continued consumption of $g(x_{\text{MSY}})$. By disregarding the rent-cost structure and taking the price as given, consumers mimic a social planner in the absence of harvesting costs who chooses x_ρ, a case analyzed by Plourde (1970). The optimal steady-state stock for stakeholder group C is thus unambiguously smaller than the stock that generates the maximum sustainable yield, x_{MSY}. As $x_C = x_\rho$, deliberate extinction by stakeholder group C is non-optimal as long as $g'(0) > \rho$. This is one of the conditions that renders extinction non-optimal for the social planner as well (Clark 1991). As consumers do not care about harvesting costs, the steady-state stock x_C preferred by stakeholder group C may be larger or smaller than the open-access steady-state stock x_{OA} (see appendix).

Comparison of the conditions for the optimal harvesting plan of stakeholder group C with the conditions for the dynamic social optimum (see Appendix) yields the following result.

Lemma 2. *If $q'(x) > 0$, the optimal harvesting plan of stakeholder group C is inefficient. If $q'(x)$, it is efficient.*

2.3 Use rights for stakeholder group L

Workers employed in the resource sector receive income $w\,l$. The higher the employment in resource harvesting, the higher the marginal product of labor in the numeraire sector and hence equilibrium wage. Workers in the resource sector thus earn rent of intramarginal labor for which the wage rate exceeds the opportunity costs of working in the resource sector instead of seeking employment in the numeraire sector. The net present value of this intramarginal rent on employment in the resource sector follows as

$$\max_{l,x} \int_0^\infty \left(w\,l - \int_0^l f'(1-\tau) d\,\tau \right) e^{-\rho\,t}\,dt. \tag{13}$$

Given the use rights over the renewable resource, resource workers maximize (13) subject to to resource dynamics (2) and harvesting technology (3). They take as given the wage rate w that is paid by resource harvesting firms.

With the current-value shadow price μ_L for constraint (2), using (3) and solving the inner integral in (13), the current-value Hamiltonian follows as $H = w\,l + f(1-l) - f(1) + \mu_L\,(g(x) - q(x)\,l)$. The first-order conditions for stakeholder group L's optimal harvesting plan are

$$w = f'(1-l) + \mu_L\,q(x) \tag{14a}$$

$$\dot{\mu}_L = (\rho - g'(x) + q'(x)\,l)\,\mu_L \tag{14b}$$

with given initial stock size x_0, transversality condition $e^{-\rho T}\,\mu_L(T)\,x(T) \xrightarrow{T\to\infty} 0$, and together with the equation of motion (2).

After being determined by the optimization of stakeholder group L, harvest is supplied by competitive firms in the resource sector. Because of constant returns to scale, resource harvesters have zero profits and thus pay their employees owning the use rights a wage $w = p\,q(x)$. Inserting $w = p\,q(x)$ in (14a), the payment of the resource harvesting firms to stakeholder group L consists of the market wage rate $f'(1-l)/q(x)$ plus a scarcity rent of the stock, μ_L. In market equilibrium, households maximize felicity

subject to budget constraint, such that we furthermore have the condition $p = u'(h)$ for the market price of resource harvest. Using these conditions, the market equilibrium condition is

$$u'(h) = \frac{f'(1-l)}{q(x)} + \mu_L, . \tag{15}$$

Equation (15) has the same structure as (7) and (11). Resource workers also equate marginal utility of consumption with marginal harvesting costs plus the marginal loss in stock value. When determining the marginal value of the stock, resource workers take into account that stock size increases its marginal harvesting productivity $q'(x)\,l$ in (10b).

We consider the steady state again. Using the steady-state condition for the stock size, $l = g(x)/q(x)$, the condition for the steady state x_L that maximizes present value of intramarginal rent for labor in resource harvesting follows as

$$g'(x_L) = \rho + \frac{q'(x_L)}{q(x_L)}\, g(x_L). \tag{16}$$

This implies $x_L \leq x_\rho$.

Intuition might suggest that workers prefer the steady state which maximizes steady-state employment and, hence steady-state intramarginal rents for workers in the resource sector. As employment equals $l = g(x)/q(x)$ in steady state, this would be the stock size $\tilde{x}$ for which the condition $g'(\tilde{x})/g(\tilde{x}) = q'(\tilde{x})/q(\tilde{x})$ holds. Due to $g(\tilde{x}) > 0$, $q(\tilde{x}) > 0$, $q'(\tilde{x}) \geq 0$, it follows that $g'(\tilde{x}) \geq 0$ and hence $\tilde{x} \leq x_{\text{MSY}}$. Although workers depend on a positive stock size for employment, the stock x also functions as a rival input for the production of h. A positive stock effect $q'(x) > 0$, that is a catch per unit effort that increases with stock size, intensifies this rivalry and triggers workers to choose $\tilde{x} < x_{MSY}$. But again, the additional effect of discounting renders the steady state $\tilde{x}$ non-optimal as workers prefer the temporarily higher intramarginal rents during the disinvestment from $\tilde{x}$ to some lower x_L over continuously receiving rents from maximum employment at $\tilde{x}$.

Condition (16) defines the steady state stock size according to stakeholder group L's optimal harvesting plan if it has a positive solution. Otherwise, $x_L = 0$. Stock depletion may well be an optimal policy for stakeholder group L. As an example, consider $q(x) = q\,x^{\chi}$ and the logistic growth function with carrying capacity normalized to unity, $g(x) = r\,x\,(1-x)$. It follows $x_L = \frac{(1-\chi)r-\rho}{(2-\chi)r}$ which is positive for $\chi < \frac{r-\rho}{r}$.

In the Gordon-Schaefer model (Gordon 1954, Schaefer 1957) that is used in the empirical example of the Northeast Artic cod, we have $\chi = 1$ and hence $x_L = 0$. For the case of $\chi = 0$, we have $x_L = x_\rho$, such that extinction is non-optimal for stakeholder group L as long as $g'(0) > \rho$, which is the same condition that renders extinction non-optimal for stakeholder groups H and C as well.

The finding that $\chi = 1$ induces resource workers to fully deplete the stock while $\chi = 0$ saves it from extinction as long as it is not socially optimal, has an interesting link to the finding that for $\chi = 0$, steady state employment rises from x_0 to x_H while the opposite holds for the Schaefer model with $\chi = 1$.

The optimal steady-state stock for stakeholder group L is thus unambiguously smaller than the stock that generates the maximum sustainable yield, x_{MSY}, and similar to the case of stakeholder group C, it may be larger or smaller than the open-access steady-state stock x_{OA} (see appendix). The intuition here is that stakeholder group L does not care about the benefits of harvesting.

Comparison of the conditions for the optimal harvesting plan of stakeholder group L with the conditions for the dynamic social optimum (see Appendix) yields the following result

Lemma 3. *If $q'(x) > 0$, the optimal harvesting plan of stakeholder group L is inefficient. If $q'(x)$, the optimal harvesting plan of stakeholder group L is efficient.*

3 Distribution and stock effect

In sum, the objective functions of the three stakeholder groups give the social surplus of utilizing the resource with labor input l over the alternative of not using the resource at all and instead employing the full labor endowment of 1 in the numeraire sector,

$$\int_0^\infty ((p\,h - w\,l) + (u(h) - p\,h) + (w\,l + f(1-l) - f(1)))\; e^{-\rho\,t}\,dt$$
$$= \int_0^\infty (u(h) + f(1-l) - f(1))\; e^{-\rho\,t}\,dt \quad (17)$$

We have shown that the market equilibrium conditions for all three scenarios are formally identical (equations 7, 11, and 15). Also, the resource dynamics are formally identical and given by (2). The differences in the three regimes arise because of the different optimal harvesting dynamics, which are given by the conditions governing the dynamics of the marginal stock value of the resource, (6b) for stakeholder group H, (10b) for stakeholder group C and (14b) for stakeholder group L. Comparing the three optimal harvesting plans and associated market equilibria and resource dynamics reveals that the differences depend on the 'stock effect' of harvesting. A positive stock effect is a necessary and sufficient condition for differences in resource dynamics preferred by society, consumers and workers, as stated in the following proposition.

Proposition 1. *1.a) For $q'(x) > 0$, optimal harvesting plans for stakeholder groups H, C, and L are different. The steady state stock x_L preferred by stakeholder group L is smaller than the steady state stock x_C preferred by C, which in turn is smaller than the socially optimal steady state stock which is the one preferred by stakeholder group H, x_H:*

$$x_L < x_C = x_\rho < x_H = x^* \quad (18)$$

1.b) For $q'(x) = 0$, optimal harvesting plans for stakeholder groups H, C, and L are identical, and so are the preferred steady-state stock sizes, $x_L = x_C = x_\rho = x_H = x^*$.

The existence of a stock effect compared to its absence leads to an increase of the efficient stock size as the sensitivity of harvesting costs to stock abundance induces the rent-maximizing agent to infringe the marginal productivity rule $g'(x) = \rho$.

The increase in harvesting productivity that comes with building up the resource stock to the efficient steady-state size $x^* > x_\rho$ does not benefit consumers as the absolute price level along their inverse demand curve and not price composition determines consumer surplus. If the resource price for consumers would equal average harvesting costs in case of zero efficiency (open access), marginal harvesting costs plus the shadow price of the resource in case of full efficiency or some intermediate rent-cost structure under partial resource management is of no direct relevance to them.

Given a time preference, all steady states with $x > x_\rho$ represent an over-investment in the stock from consumers' perspective. This over-investment becomes especially costly for consumers in case of a strong stock effect that leads to stock sizes where sustainable yield is even smaller (because of decreased natural growth at very large stock sizes) than in the optimal steady state for consumers. This are stock sizes x for which $g'(x) < -\rho$. In this case, an efficient policy not only blocks temporarily increased consumption during disinvestment towards x_ρ, but also leads to lower consumption in steady state, $g(x^*) < g(x_\rho)$.

Workers are directly affected by a stock effect as the cost reductions that motivate a stock $x^* > x_\rho$ are lost worker income and hence foregone intramarginal rent for workers. As workers do not care about output, harvesting dynamics of workers differ from the efficient ones. This difference vanishes with $q'(x) = 0$, while for a positive stock effect, workers react to their marginal productivity becoming sensitive to stock abundance by decreasing the rival production input below x_ρ, a policy directly oppositional to the efficient harvesting policy with a steady state stock size above x_ρ.

Given the optimal harvesting plans for consumers and workers, one can state the following sufficient conditions for distributive effects caused by efficient privatization:

Proposition 2. *For $q'(x) > 0$,*

2.a) consumers lose welfare when privatizing the renewable resource compared to a steady state at x_0 if

$$x_C \leq x_0 \leq x^*.$$

2.b) workers lose welfare when privatizing the renewable resource compared to a steady state at x_0 if

$$x_L \leq x_0 \leq x^*.$$

The conditions on the initial stock size given in Proposition 2 are sufficient, but not necessary. Consumers and workers may also lose from privatizing the renewable resource for initial stock sizes x_0 smaller than x_C and x_L, respectively. For very small initial stock sizes, however, consumers or workers may benefit from privatization. The intuition behind this possibility is that the harvest stream during rebuilding reaches the initial level fast when the initial stock is very low and hence its growth rate is very high. The incidental stakeholder benefits of a short-run rebuilding from $x_0 \ll x_\rho$ towards x_ρ can then outweigh the long-run rebuilding towards $x^* > x_\rho$, which is regarded as a costly overshooting by workers and consumers. We give an example in the following section where we consider the case of the Northeast Arctic cod fishery.

4 The Northeast Artic cod fishery

We illustrate the potential for distributive effects by the example of the Northeast Artic cod (NEAC) fishery. The NEAC fishery is based on a *Gadus morhua* cod stock in the Barents Sea and Svalbard waters north of Norway and Northeast Russia.

With an estimated carrying capacity of about 5.73 million t (Kugarajh, Sandal and Berge 2006), the NEAC is the potentially largest stock of true cod in the world (Nakken 1994). Although stock dynamics show significant inter-annual variations due to environmental factors (recruitment positively linked to water temperature) and stock in-

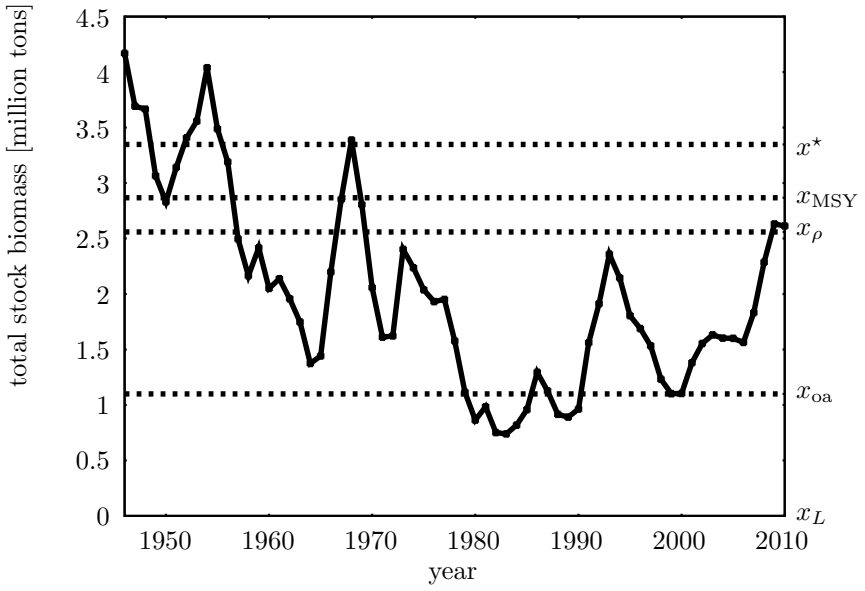

Figure 1: The Northeast Artic cod stock 1946-2010.

teractions (cannibalism and abundance of main prey species capelin), declines in stock biomass were mainly caused by fishing (Nakken 1994).

Total stock biomass showed a negative trend from its record high of 4.2 million t in 1946 to a minimum of 0.7 million t in 1983, cf. Figure 1. During that period, annual landings exceeded a million tons in five years (ICES 2011). After quotas were introduced for the trawler fleets in 1978 and for the coastal fleets in 1989, a series of low annual fishing mortalities allowed the stock to recover such that it currently has full biological reproductive capacity (ICES 2011). The Norwegian NEAC fishery and a Russian demersal trawl fishery targeting NEAC have been certified as 'sustainable' by the Marine Stewardship Council in 2010.

To study the distributive consequences of a continued stock rebuilding, we use the bio-economic model of Kugarajh, Sandal and Berge (2006). From their estimated inverse demand function, we have

$$u'(h) = 10.53 - 5.97\ h, \tag{19}$$

where $u'(h)$ is measured in billions of Norwegian Krones (NOK) in 1998 prices, and h

is measured in million t. The biomass growth function adopted from Kugarajh, Sandal and Berge (2006) is

$$g(x) = 0.46\, x \left(1 - \frac{x}{5.73}\right), \tag{20}$$

where stock sizes are measured in million tons. We assume that the Norwegian wage rate is independent of labor employment in the fishery and focus on the distributional effects between producers and consumers. For this sake, we only need information on $w/q(x)$. We use the estimate of Arnason et al. (2004) (also used by Kugarajh, Sandal and Berge 2006),

$$\frac{w}{q(x)} = \frac{8.86}{x}, \tag{21}$$

in billions of NOK, with x measured in million tons. Thus, as $q(x) = q\,x$, workers would prefer depletion of the stock, i.e. $x_L = 0$.

The MSY-stock is $x_{\text{MSY}} = 2.87$ million tons. Using an annual discount rate of $\rho = 0.05$, we find that the optimal steady state for consumers is $x_\rho = 2.56$ million tons and the optimal steady state for producers is $x^* = 3.35$ million tons. These values are also shown in Figure 1. Total biomass $x_{2010} = 2.61$ million tons (ICES 2011) is currently at 91% of x_{MSY}. Due to the stock effect of the harvesting technology, the optimal stock size however equals 117% of x_{MSY}. Landings in 2008–2010 amounted to 73%, 79% and 92% of the biological surplus production. This suggests that the stock is still rebuilding, but at a decreasing rate.

In the following analysis, we contrast a stop of the rebuilding, i.e. a steady state the current stock size x_{2010}, with the efficient transition towards the stock size x^*. The current stock size is very close to the optimal steady state for consumers, x_ρ, at a discount rate of $\rho = 0.05$. The optimal harvesting plan for consumers thus is a stop of the rebuilding and the consumption of the complete biological surplus at x_{2010}.

Under efficient management at a discount rate of 5% per year the NEAC fishery could generate a maximum present value of resource rents of about 50 billion NOK (Table 2). Keeping the stock at its current size would result in 8 billion NOK of foregone resource

Table 1: Distributive effects of a continued rebuilding of the Northeast Artic cod stock. Net present values in billion NOK; 1998 prices.

	rebuilding $x_{2010} \rightarrow x^*$	steady state at x_{2010}	difference
consumer surplus	22.9	26.0	-3.1
resource rent	50.3	41.9	8.4
total	73.2	67.9	5.4

rent. Implementing efficient management would entail a loss of consumer surplus of more than 3 billion NOK, which is about 40% of the resulting increase in resource rent.

As an example where consumers would have benefited from privatizing a renewable resource consider the Northeast Artic Cod fishery in the 1980s. For consumers, a (long) rebuilding from steady state stocks below 1.9 million tons would increase net present value of consumer surplus. In 2010, the stock however is at 2.61 million tons which is above $x_\rho = 2.56$ million tons, and consumers would prefer not to further rebuild the stock.

5 Conclusion

In absence of a stock effect, the optimal harvesting plans for all stakeholder groups – producers, consumers, and workers – are aligned. They all would prefer a steady-state resource stock where the marginal stock growth equals the discount rate. If and only if the discount rate is zero, this is the stock size that generates the maximum sustainable yield (MSY). A long-term management based on maximum sustainable yield as it was signed at the World Summit on Sustainable Development in Johannesburg in 2002 and overtaken as a guideline for a new European Common Fisheries Policy (CFP) is thus coherent with all stakeholder interests in the absence of a stock effect and in the absence

of discounting.

A positive stock effect does not change the resource dynamics that would maximize consumer surplus, as consumer surplus depends on market price and quantity and not on the composition of resource rent and harvesting costs. Maximization of resource rent requires increasing harvesting productivity by increasing the stock size. For resource workers, such a stock increase is increased competition with a rival production input. Hence, workers would favor a stock decrease below the level at which marginal stock growth equals the discount rate. This divergence of optimal harvesting plans due to the stock effect is the root of distributional effects in renewable resource markets.

The distributive effects raise the question of compensation. Auctioning off harvesting rights or implementing royalty schemes would enable non-distortive lump-sum transfers, but a mechanism that allocates these transfers pointedly at consumers of renewable resources within society while leaving out non-consumers seems difficult to conceive.

In contrast to consumers, resource industry workers are easily identified and compensation seems feasible. Their usually strong political influence may furthermore explain why tightly regulated fisheries such as those in the European CFP have low stock sizes consistent with the dynamic worker optimum.

The result that the stock effect is essential for whether or not consumers and workers would benefit from privatizing renewable resources has an interesting link to the recent debate over the limits to the privatization of fishery resources (Clark, Munro and Sumaila 2010*a*;*b*, Grafton, Kompas and Hilborn 2007; 2010). The debate is centered on the question whether a private fishery owner would choose a positive steady state stock size. Grafton, Kompas and Hilborn (2010) argue that a private fishery is likely to manage a fishery such that its steady-state stock exceeds the MSY-stock. They consider this to be a win-win outcome, as economic objectives (resource rents are maximized) and ecological objectives (high stock sizes beyond the MSY-stock) are met concurrently. The underlying reason for such an outcome would be a strong stock effect. As our analysis

has shown, consumers and workers are likely to lose from privatization in presence of a strong stock effect. Hence, the win-win outcome for owners of resource rights and environmentalists might be paid for in part by consumers of the natural resource and workers in resource harvesting.

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Appendix: Open access and dynamic social optimum

Open access In the absence of any use rights for the resource, the market equilibrium condition becomes

$$u'(h) = \frac{f'(1-l)}{q(x)} \tag{22}$$

Using (2) with $\dot{x} = 0$ and (3), the open-access steady state is thus characterized by the condition

$$u'(g(x_{\mathrm{OA}})) = \frac{f'\left(1 - g(x_{\mathrm{OA}})/q(x_{\mathrm{OA}})\right)}{q(x_{\mathrm{OA}})} \tag{23}$$

Dynamic social optimum The objective of the social planner follows as

$$\max_{h,y,l,x} \int_0^\infty (u(h) + y)\, e^{-\rho\, t}\, dt \tag{24}$$

subject to (2) with shadow price μ, (3) with shadow price π and (4). The current-value Hamiltonian reads $H = u(h) + f(1-l) + \mu\ (g(x) - h) + \pi\ (q(x)\, l - h)$ with first-order conditions

$$u'(h) = \pi + \mu \tag{25a}$$

$$\pi\, q(x) = f'(1-l) \tag{25b}$$

$$\pi\, q'(x)\, l + \mu\, g'(x) = \rho\, \mu - \dot{\mu} \tag{25c}$$

with $x(t=0) = x_0$ and the associated transversality condition $e^{-\rho T}\, \mu(T)\, x(T) \xrightarrow{T\to\infty} 0$. The first-order conditions can be summarized as

$$u'(h) = \frac{f'(1-l)}{q(x)} + \mu \tag{26a}$$

$$\dot{\mu} = (\rho - g'(x)) - \frac{q'(x)}{q(x)}\, f'(1-l)\, l \tag{26b}$$

In steady state $l = \frac{g(x)}{q(x)}$ such that

$$g'(x^*) = \rho - \frac{f'\left(1 - g(x^*)/q(x^*)\right) \frac{q'(x^*)}{q(x^*)}\, g(x^*)}{u'(g(x^*))\, q(x^*) - f'\left(1 - g(x^*)/q(x^*)\right)} \tag{27}$$

Due to (25a), (25b), the denominator in (27) is negative and yields the well-known result (Clark and Munro 1975):

$$x^* \geq x_\rho. \tag{28}$$