0.1 Regulating a fishery through seasonal closure

According to Gordon (1954), seasonal closure in the Canadian Atlantic Coast lobster fishery led to an increase in the number of lobster traps being used by each fisher. He estimates that "the same quantity of lobster could be caught with half the present number of traps." (134) This is to say that seasonal closure has actually resulted in increased total effort, while total harvest has remained constant.[1] The following model will help us make sense of this puzzling outcome.

0.1.1 The free access Nash equilibrium

A fishery is subject to a free access by n identical fishers. The fish stock is considered exceedingly low and the authorities decide to regulate fishing activities by reducing the length of the fishing season. With a shorter season length, it is reasonable to assume that a given effort level yields a lower harvest rate, all else equal. For instance, less lobster is caught if a given number of traps is used for six months instead of a full year. Or one thousand man-hours of fishing effort does not yield the same harvest if constrained to be applied over four months instead of one year. Accordingly, we must distinguish between *true* and *effective* effort. Let x_i be the true effort of fisher i and ℓ be the length of the fishing season expressed in fraction of one year, $\ell \in (0, 1)$. With a shorter fishing season, the effective effort of each fisher goes down; it is denoted by $e_i = \alpha(\ell)x_i$, where $\alpha'(\ell) > 0$ and $\alpha(1) = 1$. The unit cost of true effort is c and the total harvest function is $h(E)$, where E is the total effective effort, with $h'(E) > 0$ and $h''(E) < 0$. (We abstract from dynamic effects for now.) Let us derive the Nash equilibrium true effort level for any given season length ℓ.

The problem for one fisher is

$$\max_{x_i} \pi_i = \frac{h(E)}{E}\alpha(\ell)x_i - cx_i \text{ where } E = \alpha(\ell)\sum_{j=1}^{n} x_j = \sum_{j=1}^{n} e_j$$

Substituting for x_i, the problem can be represented as

$$\max_{e_i} \pi_i = \frac{h(E)}{E}e_i - \frac{c}{\alpha(\ell)}e_i. \tag{1}$$

Note how, once it is expressed in terms of choosing the effective effort, the problem becomes analogous to that of the standard free access to a resource. From the individual fisher's perspective, the sole difference is that a reduction in the fishing season length leads to a higher cost of fishing effort. Taking the first-order condition for each fisher and assuming a symmetrical Nash equilibrium, we get

$$\frac{h(E^N)}{E^N} + e^N \frac{\partial}{\partial E}\frac{h(E^N)}{E^N} - \frac{c}{\alpha(\ell)} = 0, \text{ where } E^N = ne^N. \tag{2}$$

This equation characterizes the Nash equilibrium. It can also be expressed in terms of true equilibrium efforts as follows

$$\frac{h(\alpha(\ell)X^N)}{\alpha(\ell)X^N} + x^N \frac{\partial}{\partial X}\frac{h(\alpha(\ell)X^N)}{\alpha(\ell)X^N} = \frac{c}{\alpha(\ell)}, \tag{3}$$

[1] See also Weninger and Waters (2003)**?** and Homans and Wilen (1997)**?**.

where $X^N = nx^N$. If $\alpha(\ell) = 1$, we recover the standard free-access Nash equilibrium condition (see section XX). One effect of reducing the season length ℓ is thus to increase the unit cost of x, as a unit tax on effort would do. But $\alpha(\ell)$ also appears on the LHS of the equilibrium condition. This was not the case with the tax (see equation XX). Hence, there are additional effects that make this policy instrument different from a tax. To see how, let us simplify the analysis and consider the case of an arbitrarily large number of fishers. With $n \to \infty$, the equilibrium is characterized by

$$\frac{h(n\alpha(\ell)x^N)}{n\alpha(\ell)x^N} \equiv \frac{h(ne^N)}{ne^N} = \frac{c}{\alpha(\ell)}. \tag{4}$$

We still have full rent dissipation. This is not surprising as the free access to the resource remains in place even though the season is shorter. With a large number of non-cooperating fishers, this means that they will still try to scramble for any remaining positive rent, leading to an equilibrium without rents. The introduction of stock effects yields additional insight.

0.1.2 Introducing stock dynamics in steady-state

Let $g(S)$ be a logistic function that denotes the natural rate of change of the resource and $h(E, S) \equiv ES$ be the total harvest rate as a function of the *effective* effort level. In terms of true total effort, we have $h(X, S) = \alpha XS$, such that in steady-state, $g(S) = \alpha XS$ or $X = g(S)/\alpha S$. This implies that a shorter season length, a larger true effort is called for in order to maintain the same steady-state harvest rate. This is represented in figure (sol-graphic-regul-season-length.pdf), where revenue curves $p^{ss}h(X)$ and $p^{ss}h(\alpha X)$ respectively denote the total steady-state revenue with respect to true effort for a full season and for a shortened season ($0 < \alpha < 1$).

In the absence of season closure and with a low constant marginal cost c_L, the rent dissipation equilibrium at point A yields a total effort level of X_1^N.[2] This corresponds to a biologically inefficient exploitation level as output would increase with a lower effort, due the small size of the fish stock. For this reason, a regulating authority imposes seasonal closure, which moves the steady-state equilibrium to point B and results in a higher equilibrium true effort level accompanied with a higher harvest rate. This surprising outcome is due to the stock effect. To see this, imagine that the true effort level were to remain at level X_1^N, while the season is shorter. As the effective effort drops to αX_1^N, fish stocks are rebuilt, thus producing a total revenue well above the total cost in steady-state. In open access, the additional rents are dissipated away with increased real effort up to point B and true effort level X_α^N.

Note that with if the initial marginal cost of effort is high, season closure will produce the desired result of reducing total effort by moving the equilibrium from point A' to B' (see total cost curve $c_H X$ on the graphic). But this is not a very interesting case since the initial stock size is unlikely to be critically low, so that intervention to rebuild stocks would not be

[2] Period-by-period rent dissipation will still hold in a dynamic setting (see Brooks et al. (1999)**?**).

required in the first place. Making use of implicit differentiation, equations (4) yields

$$\frac{\partial X}{\partial \alpha} \gtreqless \Leftrightarrow h^{ss'}(E) \gtreqless 0. \tag{5}$$

$$\frac{\partial E}{\partial \alpha} > 0. \tag{6}$$

When the stock size is smaller than the *MSY* size, introducing season length actually increases the true effort level. Effective effort, however, will always go down.

A general lesson is that if a regulator imposes controls at a given margin while the free access to the resource remains in place, users will adjust at other margins and inefficient use will remain. There may, however, be side-effects on the resource which turn out to be either positive or negative.

0.1.3 Exercises and extensions

Quadratic steady-state harvest function

Answer the following two questions assuming that $n \to \infty$.

a) *Assume $h(e) = ae - be^2$. What is the effect of season length on the total true effort level? On the total effective effort level? On the steady-state resource stock level? On fisher welfare? Discuss.*

Making the proper substitutions, we obtain

$$e^N = \frac{a}{b} - \frac{c}{\alpha(\ell)b}, \tag{7}$$

$$x^N = \frac{a}{\alpha b} - \frac{c}{\alpha^2 b}. \tag{8}$$

This yields

$$\frac{\partial x^N}{\alpha} = \frac{1}{b\alpha^2}\left(\frac{2c}{\alpha} - a\right) \gtreqless 0 \Leftrightarrow \alpha \lesseqgtr \frac{2c}{\alpha}. \tag{9}$$

It can be verified that this last condition corresponds to the following

$$h'(e^N) \gtreqless 0. \tag{10}$$

Hence, reducing the fishing season length will produce the desired result of reducing the total fishing effort in steady state only when the stock size is larger than the *MSY* level, i.e. when the stock size is relatively large already. Conversely, when the stock size is smaller than the *MSY* size, i.e. when $h'(e) < 0$, reducing the season length actually increases the true effort level. This means that precisely when the regulator is most likely to intervene will reducing season length lead to the undesirable outcome of increased true effort.

As for the effective effort level, we can see from (7) that reducing the season length will always produce the desired lower effective effort level in equilibrium. As a result, the resource stock level always increases in the steady-state equilibrium, which may have been the initial objective. But fisher welfare is not improved as the *open access* situation remains in place and total rents are dissipated.

b) *Is it possible to find a fishing season length that would yield an equilibrium at the maximum sustainable yield? Explain.*

The MSY is obtained when the effective effort is such that $h'(e) = 0$. This implies that $e^{MSY} = a/2b$. Letting $e^N = e^{MSY}$ and using expression (7) above, we get $\alpha(\ell) = 2c/a$. Hence, as long as $2c/a \in (0, 1)$, it is possible to set the season length such that the maximum sustainable yield is attained in equilibrium.

Fixed catch limit

Gordon (1954) also discusses the case example of fixed-catch limits on the Pacific halibut fishery in Canada established in the early thirties. It led fishermen to invest in "more, larger, and faster boats in a competitive race for fish." (133) In one area, the fishing season to catch the limit dropped from six months in 1933 to twenty-six days in 1952. Propose a model to analyze the effects of regulation based on fixed-catch limits.