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Abstract

In a decentralized open economy model with an endogenous growth sector and a renewable resource sector a steady state-balanced growth equilibrium will at best be attained by chance. An interior equilibrium where both sectors exist and the resource sector is in equilibrium while the other sector grows can be achieved by the help of government policy. The optimum equilibrium is unstable in the decentralized economy and active government policy is needed to enforce it. Apparently contradicting policies may be needed to first move the economy to the optimal equilibrium and then to keep it there. In the current model the resource good is exported in exchange for a foreign consumption good. Hence a tariff on imports will have the same qualitative effects as a harvest fee.

Keywords: Endogenous Growth, Renewable Resources, Resource taxation

JEL Classification: F43, H23, O41, Q22, Q28

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1. Introduction

When introduced in models on economic growth, natural resources are commonly treated as input in the production of final goods. Renewable resources are, for example, either treated as a constant flow, where it is assumed that the resource is being harvested at its maximum sustainable yield or some other constant rate that has been solved for or determined before the growth problem is solved (Solow (1999), Sachs and Warner (1995)), or the rate of harvest is treated as a choice variable that can be determined without use of other inputs (Tahvonen and Kuuluvainen (1991), Li and Löfgren (2000)).

A defining characteristic of many renewable resources is that they are unable to grow without bounds. There is some natural limit to their size in nature, often referred to as the carrying capacity of the environment. This feature, combined with the fact that the resource stock is a form of capital, precludes the attainment of a balanced growth path. Long run equilibrium solutions of growth models with renewable resources are therefore usually steady state solutions. To put it differently, the equilibrium growth rate is zero (see e.g. AK model in Aghion and Howitt (1998, ch. 5), Rodríguez and Sachs (1999), Herbertsson (1999, ch. 6)). There are, however, a few exceptions.

Examples of models where a renewable resource is used in production, and an equilibrium solution is charcterized by a balanced growth path are, for instance, given by Bovenberg and Smulders (1996) and Aghion and Howitt (1998, Schumpetrian model in ch. 5). The renewable resource in the Bovenberg and Smulders model as well as in the Aghion and Howitt model is environmental quality; and while the assumptions that drive sustainable growth may be appropriate in those circumstances, they are perhaps less so when applied to typical resources such as forests or fisheries (see Elíasson (2001) for further discussion).

In a recent paper Elíasson and Turnovsky (2004) solve an endogenous growth model with a renewable resource sector, and show sufficient conditions for the existence of a balanced growth path for the economy, along which the resource sector is in a steady state equilibrium. This happens despite the resource sector, which produces fish for export, and the non-traded sector, which drives long run growth in the model, both using labour from a common stock. The distribution of labour along the steady state – balanced growth path is determined endogenously in the model.

This paper studies a more disaggregated open access version of the Elíasson and Turnovsky model, which allows for inefficient over exploitation and introduces a potential welfare improving role for the government.

Section 2 sets out the structure of the model, describing the behaviour in different sectors of the economy. Section 3 describes the macroeconomic equilibrium, and the equilibrium concept in this model is further discussed in section 4. Policy instruments and their equilibrium effects are introduced in section 5, followed by policy implications in section 6. Section 7 introduces the Icelandic economy between 1950 and 1975 as a case study. Section 8 concludes.

2. Structure of the economy

The economy consists of households, two types of firms, and a government. The households maximize their utility, given a budget constraint. They have demand for consumption of the domestically produced (growth sector) good Y, and the imported good Z. The households' earnings come from supplying labour L, and renting capital K, to firms.

Firms in the growth sector maximize profits. There are many identical firms, which produce their output using capital and labour. The output Y is either consumed by the households C_Y, or used to increase the existing stock of capital. The total amount of capital in the economy increases productivity, but this is not taken into account by an individual firm because its own contribution to the total capital stock is negligible. In other words, there are positive production externalities associated with capital.

The harvest X from the resource sector is exchanged abroad for a consumption good, at a fixed world price p. The consumption good is then sold to the households in the home market. The relative price of the imported good and the non traded good (from the growth sector) is determined endogenously. Each fisherman ignores the externality he imposes on others, i.e. the fact that whatever he harvests of the resource will no longer be available to others. Hence there are negative externalities associated with the harvest effort.

The government can use three different instruments to achieve its goals. The instruments are income tax, tariff, and harvest fee. Possible goals are e.g. increasing efficiency, maximizing welfare, or ensuring sustainability. The government is not assumed to provide any services. It simply refunds the tax in a lump sum manner to the households.

2.1. Optimization by households

The households choose the level of consumption of the domestically produced good C_Y, consumption of the imported good C_Z, supply of labour to the growth sector L_Y, supply of labour to the resource sector L_X, and the rate of investment $\dot{K}$ to maximize the intertemporal utility function

$$\max \int_0^\infty \frac{1}{\gamma}\left(C_Y C_Z^\phi\right)^\gamma e^{-\rho t} dt , \qquad \gamma < 1, \quad \phi > 0, \quad \gamma(1+\phi) < 1 \tag{1}$$

subject to the budget constraint

$$C_Y + q(1+\tau_T)C_Z + \dot{K} = (1-\tau_I)(w_X L_X + w_Y L_Y + \psi K) + T \tag{2}$$

and the labor allocation constraint

$$1 = L_X + L_Y \tag{3}$$

where τ_T, τ_I are tariff and income tax, respectively, T is the lump-sum rebate, q is the relative price of imports in terms of the domestically produced good (net of the tariff), w and ψ are the wage and rental rates, respectively, ρ is the discount factor and ϕ is between 0 and 1 and represents the relative importance of the imported good in consumption.[1] The intertemporal elasticity of substitution ε is related to γ by $\varepsilon = 1/(1-\gamma)$.

2.2. Growth sector firms

There is a large number, N say, of small identical firms, producing the domestic output Y which is used for consumption C_Y and investment $\dot{K}$. Each firm has the production function

$$Y_i = AK_i^{\alpha}(KL_i)^{1-\alpha} \tag{4a}$$

where $i \in [1,N]$ identifies the firm. Each firm takes the total amount of capital K as given, because its own actions have only negligible effects on the aggregate stock of capital. However, productivity of labour increases with the aggregate stock of capital. Following Romer (1986) the use of the aggregate capital stock as a productivity index is justified by assuming that knowledge is proportional to capital. Total output in the growth sector is

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[1] The utility function (1) is equivalent to the logarithmic utility function if $\gamma = 0$, i.e. $\log(C_Y C_Z^{\phi}) = \lim_{\gamma\to 0}\left(\left[(C_Y C_Z^{\phi}) - 1\right]/\gamma\right)$.

$$Y = AKL_Y^{1-\alpha} \tag{4b}$$

Each growth sector firm maximizes, at each instant, its profit function

$$\Pi_i = AK_i^{\alpha}\left(KL_i\right)^{1-\alpha} - w_Y L_i - \psi K_i \tag{5}$$

2.3. Resource sector

There is free access to the resource, so labour will enter fishing as long as the benefits exceed the costs. In this sense the fishing industry can be thought of as consisting of a continuum of infinitesimal firms; each hiring labour in order to maximize its profit function given per unit catch value and labour cost. Effort is measured by labour which is the only input, and decreasing returns to effort are present. Total harvest is thus[2]

$$X = BL_X^{1-\beta} \tag{6}$$

The industry is earning profits

$$\Pi_X = \left(\frac{q}{p} - m\right)B\left(L_X\right)^{1-\beta} - w_X L_X \tag{7}$$

where *q/p* is the value of catch in terms of domestic output and *m* is the harvest fee.[3]

2.4. Government

The government achieves its goals by levying taxes on income and imports, in addition to charging fees for harvest. The tax revenues are redistributed as a lump-sum payment *T* at each instant. The government runs a continuously balanced budget, as given by its budget constraint

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[2]This function is a usable approximation for harvest from a stock that keeps its density constant, such that the rate of harvest does not depend on the stock size The Schaefer harvest function is discussed in Appendix B. See e.g. Hannesson (1993) for a discussion of these and alternative forms of the harvest function.

[3] *p* is the price of imports in terms of exports, and *q* is the price of imports in terms of the domestic good. These relative prices are taken as given by the individual firm.

$$T = \tau_I \left(w_X L_X + w_Y L_Y + \psi K \right) + \tau_T q C_Z + mX \tag{8}$$

The government's budget constraint can actually be derived by subtracting the household's budget constraint (2) from the economy wide resource constraint

$$\dot{K} = Y + \frac{q}{p} X - C_Y - q C_Z \tag{9}$$

which simply states that whatever is left of total output after consumption, is added to the stock of capital. p is the fixed world price of imports in terms of exports, i.e. p^{-1} is the terms of trade. Since only the resource good is traded this can further be simplified to

$$\dot{K} = Y - C_Y \tag{9a}$$

$$p C_Z = X \tag{9b}$$

i.e. output of the growth sector is used for consumption and investment, while output of the resource sector is exchanged for imports at the rate p. There is no mechanism for borrowing in this model so the economy runs a continuously balanced trade. Furthermore, there is only one traded good, the resource good, and therefore the value of imports must at each instant equal the value of the resource good.

In addition, the government is aware of the resource constraint

$$\dot{S} = rS\left(1 - \frac{S}{\bar{\bar{S}}}\right) - X \tag{10}$$

which it takes into account when choosing its policy.

3. Macroeconomic equilibrium

The economy will be characterized by a 'perfect foresight equilibrium', i.e. planned output and labour equal the real supplies, and all anticipated variables are correctly forecast (Turnovsky (2000)). Taking the first order conditions from the intertemporal utility maximization of the households together with the demand functions for capital and labour that are derived from maximization of profits in the growth sector together with the free access assumption in the resource sector, the governments budget constraint (8), and the resource constraint (10), we have a description of the optimality conditions for the economy. Assuming an interior solution for the labour shares we have the equilibrium wage rate $w \equiv w_X = w_Y$ and the first order conditions for the decentralized open access economy are (in addition to the government budget constraint (8) and the resources constraint (10))[4]

$$C_Y^{\gamma-1} C_Z^{\gamma\phi} = \lambda \tag{11a}$$

$$\phi C_Y^{\gamma} C_Z^{\gamma\phi-1} = q\lambda(1+\tau_T) \tag{11b}$$

$$\frac{1-\alpha}{1-\beta} A L_Y^{-\alpha} K = \left(\frac{q}{p} - m\right) B L_X^{-\beta} \tag{11c}$$

$$\frac{\dot{\lambda}}{\lambda} = -\alpha A L_Y^{1-\alpha}(1-\tau_I) + \rho. \tag{11d}$$

The first two equations (11a) and (11b) result from the households' maximization problem. They equate the marginal utility of consumption of the two goods (measured in terms of the non-traded good) to the shadow value of capital. Growth sector firms hire labour until its marginal product equals the wage rate in the growth sector (left hand side of equation (11c)).[5] Under the open access assumption, effort in the resource industry will increase until the marginal profit is zero, yielding the right hand side of (11c), which is equal to the wage rate in the resource sector. Households supply labour to the sector paying a higher wage rate. If the wage rates in both sectors are equal the labour allocation is determined by equation (11c). Equation (11d)

[4] The first order conditions (11) are derived in Appendix A.
[5] See the profit function (6).

equates the rate of return to investing in capital to the rate of return on consumption, measured in terms of the non-traded good.

The growth rate of the consumption to capital ratio in the growth sector (defined as $c \equiv C_Y / K$) is

$$\frac{\dot{c}}{c} = \frac{1}{1-\gamma}\left(\alpha(1-\tau_I)AL_Y^{1-\alpha} - \rho + \gamma\phi(1-\beta)\frac{\dot{L}_X}{L_X}\right) - AL_Y^{1-\alpha} + c \tag{12}$$

Taking the time derivative of the first order condition (11c) and solving for the rate of change of the growth sector employment, yields

$$\frac{\dot{L}_Y}{L_Y}\left[\alpha + \frac{L_Y}{1-L_Y}\right] = -\frac{\dot{c}}{c} \tag{13}$$

where, for convenience, it is assumed that the resource use fee is set proportional to the relative price of the imported consumption good, such that

$$m = \upsilon\frac{q}{p} \tag{14}$$

(where υ is a constant between 0 and 1). This is a reasonable assumption. If the government sees a reason to increase costs in the resource sector by imposing a harvest fee, then this is an attractive method, because here the resource firms earn their income by selling the imported good in the home market at the price *q*, while the amount of imports is proportional to the harvest. The harvest fee is thus a fraction of the total value of the catch.

With perfect property rights the resource stock plays the role of a sluggish variable in addition to the capital stock, thus generating stable transitional dynamics in the model (see Elíasson and Turnovsky (2004)). Here, on the other hand, equations (12) and (13) are linearly dependent, so the dynamic system has collapsed to a single dynamic equation in *c*. The resource constraint (10) is completely ignored by the agents studied so far, i.e. household, growth and resource sectors.[6]

4. Steady state/balanced growth path

Steady state in the resource sector is characterized by three possibilities. That is 1) the resource sector disappears,[7] either because the resource is not harvested, and it therefore reaches its natural steady state level (the carrying capacity), or 2) it is completely depleted, or 3) the harvest will be at a constant rate, and equal to the own growth rate of the stock at the steady state level. In other words $\dot{L}_X = 0$ must hold in steady state.

On a balanced growth path, with a constant labour share in the resource sector, the capital stock is growing at a constant rate, as long as the consumption to capital ratio is constant, i.e.

$$\xi \equiv \frac{\dot{K}}{K} = AL_Y^{1-\alpha} - c\,. \qquad (9a')$$

Hence the capital stock and the rate of consumption are growing at the same rate. Therefore the growth rate of *c* is zero, i.e.

$$\dot{c} = 0 \qquad (15)$$

Together equations (12), (13) and (10) give the growth rates of the consumption to capital ratio in the growth sector, the share of labour in the growth sector, and the resource stock, as functions of these three variables, the government's policy instruments and the parameters. As stated above the decentralized economy ignores the resource constraint (10) and the dynamics (12) and (13) collapse to a single equation. Given that labour is used by both sectors, the labour shares, consumption to capital ratio, and growth rate of the non-traded sector will therefore stay at their

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[6] Elíasson and Turnovsky (2004) discuss the open acces case briefly (see section 4.3. in their paper).
[7] This requires the parameter $\phi = 0$ in the utility function (1), indicating that the imported good has zero weight in the case of a closed economy.

equilibrium values, and the system has no transitional dynamics. The equilibrium value of employment in the resource sector will in turn determine the harvest rate. Whether the resource sector will attain an equilibrium rate of harvest depends on the equilibrium labour share and the initial size of the resource stock *S*. If the rate of harvest is too high the resource will be depleted.

Given the nature of the harvest function (6), the stable equilibrium under free access (if one exists) is here to the right of the maximum sustainable yield level (S_{MSY}). For that to be the case total cost must be rising faster than net revenues as a function of effort at the point where they are equal, and this has to correspond to an effort level that is less than needed to harvest at the maximum sustainable rate (known as maximum sustainable yield or MSY). This condition can in principle be compared to the value of the labor share determined by the balanced growth path to find if such a steady state exists.

If conditions for an interior solution for the labor shares are satisfied, then the economy jumps straight to the equilibrium characterized by the steady state harvest rate and the balanced growth determined by the constant ratio *c*. If the steady state/balanced growth path exists, it may not be sustainable. If the harvest rate is high enough, the resource will be depleted completely. Even if the harvest rate is low enough for sustainability of the resource stock at a particular level, it may be that the stock was too small to begin with to cope. So even if the dynamics are redundant we can not simply claim that the economy will jump straight to the steady state. It may not jump to an equilibrium at all, and even if it jumps to one, that equilibrium may not be stable—it may lead to extinction of the resource stock.

The resource sector employment in the decentralized economy under the open access assumption is, other things equal, greater than if the resource dynamics are taken into account by the harvesting firms, such as would happen if perfect property rights are assumed. Further, resource sector employment may be too high, such that it drives the resource stock to extinction. If it is low enough to be sustainable, then it is associated with a stock level that is higher than it would be in the case of perfect property rights (see Elíasson and Turnovsky (2004) for a detailed discussion about the case of perfect property rights).

5. Policy tools and steady state effects

The government has three instruments, the income tax τ_{I}, the import tariff τ_{T}, and the harvest fee ratio ν[8], that it can use to affect the economic equilibrium. The steady state effects of an increase in the policy instruments are summarized in table 1.

Table 1. Steady state effects of an increase in policy instruments. There are separate columns for small steady state stock levels (smaller than the maximum sustainable yield level) and large steady state stock levels. The last column shows the effect on the growth rate of consumption and capital on the balanced growth path.

Instrument	$\tilde{L}_X$	$\tilde{c}$	$\tilde{S}_{\mathrm{S}}$	$\tilde{S}_{\mathrm{L}}$	ξ
τ_{I}	+	+/–	+	–	–
τ_{T}	–	+	–	+	+
ν	–	+	–	+	+

Increasing the income tax causes the effort level in the resource sector to rise. This has a negative effect on the consumption to capital ratio, because of decreased employment in the (capital producing) growth sector. This negative effect on the

[8] Recall that the harvest fee m is proportional to the relative price of the value of the catch to the domestic good, i.e. $m = \nu(q/p)$.

consumption to capital ratio in steady state is (at least partially) offset by the effect of substitution out of investment and into consumption (because decreased employment in the growth sector results in a lower return to capital).

The effect on the steady state resource stock depends on whether it is above or below S_{MSY}. If it is small then an increase in the income tax will result in a larger equilibrium resource stock, but if it is large, then the steady state stock will move in opposite direction to the income tax rate. An increase in the income tax will unambiguously lower the equilibrium growth rate. In an open access equilibrium the $\tilde{S}_L$ column is the relevant one while $\tilde{S}_S$ applies in a perfect property rights model (i.e. where the resource dynamics are taken into account by the optimizing agents).

Qualitatively the tariff and the harvest fee have identical effects on the equilibrium variables. This is because the harvest, and only the harvest, is traded for the imported consumption good. Therefore an increase in the price of the imported good (tariff) has the same qualitative effects as a decrease in the net revenues in the fishing sector (harvest fee). Increasing the value of either of these instruments lowers the return to fishing in terms of utility gained by consuming the imported good. It therefore reduces employment in the resource sector, increases it in the growth sector and thus adds to the growth rate. Again, the effects on the equilibrium stock of the resource depend on whether the equilibrium value is above or below the MSY level. If it is below, then a higher tariff or harvest fee results in a lower equilibrium stock level. If the equilibrium stock is above S_{MSY} then it will rise following an increase in the tariff or harvest fee.

6. Implications for policies

Comparing the decentralized open access solution to the first best equilibrium, reveals the feasible policy options there are for copying the first best. The steady state/balanced growth equilibrium in the centrally planned economy is derived from the following first order conditions:

$$C_Y^{\gamma-1}\left[p^{-1}BL_X^{1-\beta}\right]^{\gamma\phi} = \lambda \tag{16a}$$

$$\frac{1-\alpha}{1-\beta}AL_Y^{-\alpha} = \phi c L_X^{-1} - \mu B L_X^{-\beta} \tag{16b}$$

$$\frac{\dot{\lambda}}{\lambda} = -AL_Y^{1-\alpha} + \rho \tag{16c}$$

$$\frac{\dot{\mu}}{\mu} = AL_Y^{1-\alpha} - r\left(1-2\frac{S}{\overline{S}}\right) \tag{16d}$$

where μ is the shadow value of the resource (valued in terms of the non-traded good *Y*). In addition the transversality conditions

$$\lim_{t\to\infty}\lambda K e^{-\rho t} = 0 \tag{16e}$$

$$\lim_{t\to\infty}\lambda\mu S e^{-\rho t} = 0 \tag{16f}$$

must hold. Macroeconomic equilibrium in the decentralized economy was derived from the first order conditions (11). In equation (16a) the balanced trade condition (9b) and the harvest function (6) have been substituted in for consumption of the imported good. Otherwise equation (16a) is identical to (11a). There are, however, a few differences in the first order conditions.

The return to labour in the resource sector has two terms in the central planners solution. First it affects utility, since a larger harvest means more consumption of the imported good and less of the domestic good. Second, the central planner recognizes the shadow value of the resource stock, because the resource dynamics are taken into account.

The central planner also internalizes the externality caused by the aggregate capital stock in the production function in the non-traded sector (hence the α is missing from equation (16c) (as compared to (11d))). The central planner recognizes the role of the aggregate capital stock as a proxy for knowledge and therefore allocates more labor to the growth sector than in the decentralized case.

6.1. Growth enhancing policies

The growth rate of the economy can be increased by raising the import tariff, increasing the harvest fee, or lowering the income tax. From (11b) we see that increasing the tariff, or raising the harvest fee, will lower the observed return to labour in the resource sector. This leads to a substitution of labour from the resource sector to the growth sector, thus increasing the rate of growth. From (11d) a decrease in the income tax rate will increase the return to capital, leading to a shift from consumption to investment, increasing the growth rate. All these policies will lower the rate of harvest. Whether the resource stock will increase or decrease as a result depends on whether it was being harvested at a sustainable rate or not; and if it was harvested too forcefully, then how small was the stock at the time that the policy was changed. From table 1 we see that given that an equilibrium exists at both the old and the new rate of harvest, then the relative size of the stock at the equilibrium depends on whether they are to the left or the right of the MSY stock size. This does not say anything about whether the change in policy would actually cause the stock size to move to the new equilibrium or not. There are four possibilities for the stock size at the time when a policy change caused the resource sector employment to fall. First, it could be at an equilibrium above S_{MSY}. In this case, as the rate of harvest falls, the stock will grow until it reaches a new stable equilibrium to the right of the previous one. Second, it could be at an (unstable) equilibrium below S_{MSY}. Here, the stock will also start growing, until it reaches the new stable equilibrium. Third, it could have been harvested at an unsustainable rate, and the stock size had fallen below the unstable equilibrium associated with the new rate of harvest. The new lower rate of harvest will still be too high at the current stock size, and the stock will be harvested to extinction. Finally, the stock could have been harvested at an unsustainable rate, but the stock size was above the unstable equilibrium associated with the new rate of harvest. Once again, the new harvest rate is smaller than the own growth of the resource under the new policy, and the stock will grow until it reaches the new stable equilibrium, above the S_{MSY}.

In case 3, the resource will eventually disappear. In cases 1, 2 and 4, the resource will reach a stable equilibrium under the new policy, where the stock size is above the maximum sustainable yield level. The new equilibrium will therefore be inconsistent with the resource sector transversality condition (16f). In fact the policy will increase the amount of the stock that sits there doing nothing but increasing in value (since the same harvest can be sustained at a lower stock level). [9]

Maximizing the rate of growth implies that the income tax rate will be abolished, and the tariff or harvest fee will be prohibitive (such that $L_{\mathrm{X}} = 0$).[10] Discarding the resource sector is not consistent with the first best equilibrium solution found in the centrally planned economy. The reason is that although the harvest comes at the cost of lower growth, it does add to utility by increasing the variety in consumption.

6.2. Ensuring sustainability

The assumptions of cases 3 and 4 above imply that the resource sector was not

[9] Elíasson and Turnovsky (2004) point out that if the harvest function is of the form $X = BL_X^{1-\beta}S$ then it is no longer apparent that the equilibrium value under perfect property rights (as would apply here in the centrally planned economy) is less than the MSY level.

[10] Note that in equilibrium the relative price of the imported good is rising at the growth rate of the domestic sector. Measured in units of the domestic good the economy is thus growing at the rate of output of the domestic sector.

sustainable before the policy change. It follows from the discussion above that in order to ensure sustainability of the resource sector in equilibrium, it is necessary to raise the harvest fee or tariff sufficiently (or lower the income tax rate) for the harvest rate to drop below the own growth of the resource stock at the current level. As the resource stock grows, it is then possible to relax the instruments, allowing for an increased harvest rate, as long as the rate of harvest is kept no greater than the own growth of the resource stock.

6.3. Replicating the first best

Comparing the optimality conditions for the decentralized economy to the conditions for the first best optimum reveals that giving the policy variables the following values changes the former to the latter:

$$\tau_I = -\frac{1-\alpha}{\alpha} \tag{17a}$$

$$\tau_T = 0 \tag{17b}$$

$$m = \mu \tag{17c}$$

Equation (17a) implies a negative income tax, or a subsidy, and that a large one for plausible values of α.[11] This subsidy has to be funded by tariffs, harvest fee, or a direct transfer from the households (a negative T).

Implementing these policies is, however, not sufficient to ensure that the economy will move to the first best equilibrium because the resource stock may be larger than the MSY level (and certainly so if a sustainable open access equilibrium had evolved), and hence its shadow value may not be following equation (16d). So even if the harvest rate has been lowered from its inefficiently high rate under free

[11] E.g. if $\alpha = 1/3$, then $\tau_T = -2$.

access, the intertemporal inefficiency of the stock size has increased. We can therefore conclude that starting from a stable equilibrium under free access in the resource sector, the economy can only be moved to the first best optimum by first increasing the rate of harvest, in order to drive the stock size to its optimum level, and then decreasing it again, such that it exactly equals the own growth of the resource at the optimum (unstable) equilibrium.

If the government was passive at the original free access equilibrium, then its only option in order to increase the employment level in the resource sector is to levy an income tax. Lowering a nonexistent import tariff or a zero harvest fee are clearly not options. Then, once the preferred stock size is reached, the income tax could be abolished, raising the growth rate. The government then has a choice of a tariff or harvest fee to keep the resource sector employment at the preferred level.

The first best optimum is locally stable in the centrally planned economy, because the central planner takes the resource dynamics into account. It is unstable in the open access economy, because the private firms ignore the resource dynamics. It can only be stabilized through active government policy.

7. Case study: The Icelandic economy between 1950 and 1975

The model studied in this paper represents a simplified economy, where only a resource good, or harvest of a resource, can be traded for imports. This is a fair approximation to some economies; the Icelandic economy, particularly a few decades ago, being one example.

Iceland is situated in the north Atlantic and is surrounded by bountiful fishing grounds. Until 1975 the main concern regarding fisheries was limiting the access of foreign fleets to Icelandic territories. Jurisdiction over the Icelandic fisheries was expanded in a few steps in the twentieth century. In 1952 Iceland’s territorial waters were expanded from 3 to 4 nautical miles (a process that began in 1950). In 1958 the fishing zone was further expanded to 12 miles, and to 50 miles in 1972. The final step was taken in 1975 when Icelandic jurisdiction was expanded to 200 miles, or midline from neighbouring countries if that was closer. From then onwards the emphasis has been on controlling the fisheries in order to ensure sustainability as well as high revenues. During the period from 1950 to 1975 the fisheries were more or less characterized by open access, while that description is less appropriate from then on. The following discussion will therefore focus on the period from 1950 to 1975.

The model in this paper makes some strong assumptions about the fisheries sector. Two important ones are that: 1) all of the harvest from the fisheries is exported, and 2) the harvest from the fisheries is the only exported good. Domestic consumption of harvest from the fisheries in Iceland during the period from 1950 to 1975 is shown in figure 1.

Figure 1. Domestic consumption of fish as a percentage of Icelandic harvest (source: Jónsson and Magnússon (1997)).

The domestic consumption is shown as a share of total catch caught by

Icelanders. During the first half of the period other nations caught about as much fish in Icelandic waters as Icelanders. Consumption of fish as a fraction of total catch is therefore lower if catch by other nations is added (see fig. 2). It seems therefore to be more or less consistent with the data to assume that all of the harvest from the fisheries is exported.

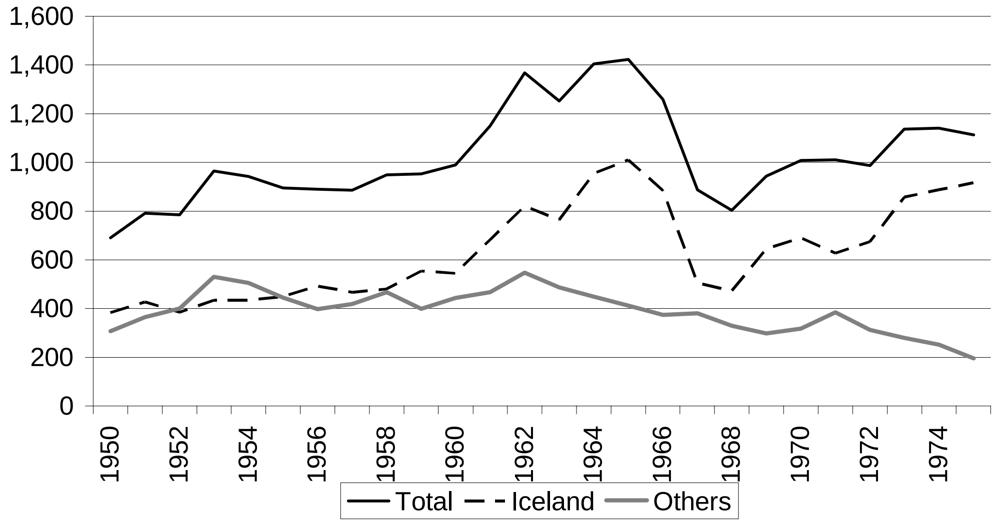

Figure 2. Total catch in Icelandic fisheries in thousands of tons (source: Jónsson and Magnússon (1997)).

Figure 3 shows the share of fisheries in total exports and in goods exports. Exports of fisheries products is about or above 50% of total exports in the period and well above 70% of exported goods. In fact it is only in 1968, when the stock of herring had virtually been harvested to extinction, that the share of fisheries in exported goods falls significantly below 90%.[12] Although it is a great simplification to assume that harvest from the fisheries is the only export, it is still not an invalid assumption in this case, since it is clearly the single most important export throughout

[12] After 1968 the share of fisheries in exports stays lower than before because of the growing share of aluminum in exports.

the period.

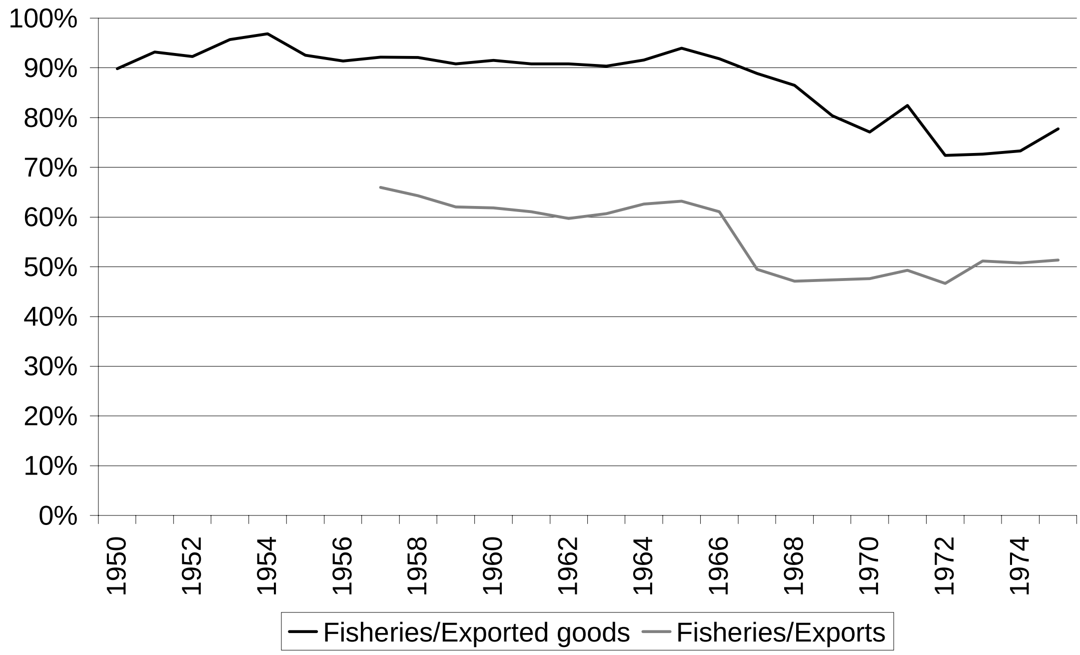

Figure 3. Exports of fish and fisheries products as a portion of 1) total exports, and 2) exported goods (source: Jónsson and Magnússon (1997)).

As already mentioned the main concern during this period was to gain full control over the fisheries, which clearly is a necessity for any policy action. The Icelandic fisheries were effectively an open access resource and as such subject to over fishing. Two suggestions follow from the model. The first is that in order to enforce sustainability the fishing effort has to be reduced, and that this can be attained by some form of a harvest fee or, equivalently, a tariff on imports. The second suggestion is that, in equilibrium, given a fixed world price of fish p^{-1}, and fixed size of the resource sector, the real exchange rate q^{-1} must be falling at the rate of growth of the economy.

The policy structure, regarding particularly tariffs and exchange rates, that evolved in Iceland during the open access period is complicated. In particular between 1951 and 1959 a system of multiple exchange rates was in effect, and by 1958 about

55% fee was added to most exchanges. This fee was used to subsidize exports; in particular the fishing industry. In addition considerable tariffs were levied on most imports. Some estimates amount to between 33% to 110% tariffs on protected industries. Jónsson (1975) suggests that in the context of a general tariff on imports the appropriate estimate lies around 25% in 1970. He concludes that protection of domestic industries through tariffs was in fact a form of a resource tax, since the bulk of exports originated in the fisheries sector.

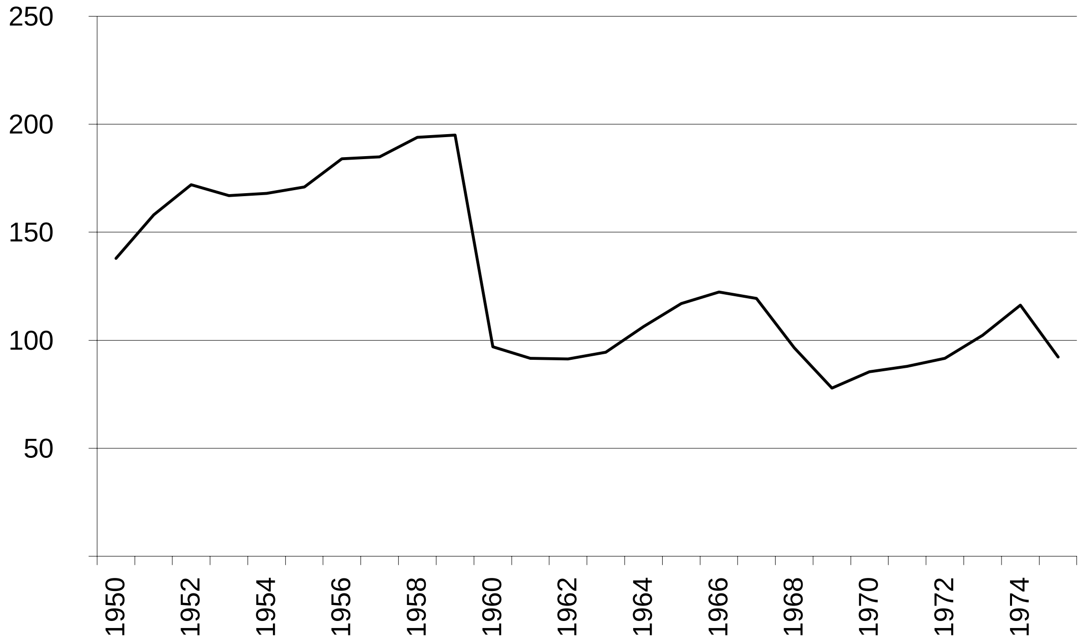

Figure 4. Icelandic real exchange rate (source: Jónsson and Magnússon (1997)).

Some form of a fixed exchange rate was in effect most of the period from 1950 to 1975. Despite steadily improving terms of trade throughout the period, where in particular the foreign price of fish was for the most part rising, in addition to increasing harvest (with the important exception of 1967 and 1968) the real exchange rate kept rising under the fixed exchange rate regime. This resulted in repeated devaluations of the Icelandic currency, in order to ensure profitability of the fishing industry (fig. 4, see Nordal and Tómasson (1985), and Jónsson (1975)).[13]

It has been suggested that this system may have developed as a means for controlling the effort in the fisheries sector, while at the same time redistributing the gains to the society (although it was not constructed with that intention) (see e.g. Jónsson (1975)).

8. Conclusions

The model studied here has two sectors. One is a Romer (1986) type growth sector, while the other is a typical open access renewable resource sector. This is therefore a growth model, and it is lacking a sluggish variable (in addition to the capital stock) in order to yield stable transitional dynamics. The model is thus always in equilibrium, and it simply jumps to a new equilibrium following a shock to the parameters. It is then left to chance whether the resource stock is approaching a stable equilibrium or whether it is being depleted. The resource dynamics are ignored by the agents in the model. Furthermore, if the resource sector attains a stable equilibrium it is bound to be an inefficient one, because the same rate of harvest can be sustained at a smaller resource stock. This may, however, follow from the form of the harvest function.

If the open access economy is in an equilibrium with a stable resource stock, then an income tax could be used to move labour from the growth sector to the resource sector. This would temporarily further lower the growth rate, while simultaneously increasing the availability of imports. Upon reaching the desired stock size, the income tax could be relaxed, causing labour to move back from the resource to the growth sector. Under open access there is too much employment in the resource

[13] The high exchange rate prior to 1960 in fig. 4 is somewhat exaggerated. In 1960 the nominal exchange rate was devalued by 57%, but only by about one third if the 55% fee on exchanges that was charged prior to this devaluation is accounted for.

sector, so even more labour must be sent from the resource to the growth sector. This is achieved by either a harvest fee or a tariff on imports.

The observation that qualitatively the effects of a tariff and a harvest fee are identical is a result of the setup of this model, following directly from the assumption that the harvest from the resource sector is the only exported good. Allowing other goods to be traded would change this.

Despite its simplicity this model appears to relate in some aspects to the Icelandic economy in the 1950s and ‘60s. There, under open access to a fishery that was the source of the nation’s main export, a system of import tariffs and multiple exchange rates developed. It can be argued that this resulted, perhaps unintentionally though, in reduced effort in the fishery as well as redistributing the gains from the fisheries sector to the society. This system was then discarded, after the nation gained full control over the fishing grounds.

Appendix A. Derivation of the first order conditions

The households choose consumption of the domestic good C_Y, imported good C_Z, labour allocation to each sector L_X, L_Y and rate of investment to maximize the Hamiltonian

$$\frac{1}{\gamma}\left(C_Y C_Z^{\phi}\right)^{\gamma} + \lambda\left[(1-\tau_I)(w_X L_X + w_Y L_Y + \psi K) + T - C_Y - q(1+\tau_T)C_Z\right] + \eta\left[1 - L_X - L_Y\right]$$

(A1)

which results in the first order conditions

$$C_Y^{\gamma-1} C_Z^{\gamma\phi} = \lambda \quad \text{(A2a)}$$

$$\phi C_Y^{\gamma} C_Z^{\gamma\phi-1} = q\lambda(1+\tau_T) \quad \text{(A2b)}$$

$$\lambda(1-\tau_I)w_X = \eta \quad \text{(A2c)}$$

$$\lambda(1-\tau_I)w_Y = \eta \quad \text{(A2d)}$$

$$\frac{\dot{\lambda}}{\lambda} = \rho - (1+\tau_I)\psi \quad \text{(A2e)}$$

The growth sector firms hire labour and capital to maximize profits

$$\Pi_i = AK_i^{\alpha}(KL_i)^{1-\alpha} - w_Y L_i - \psi K_i \quad \text{(A3)}$$

yielding the first order conditions

$$(1-\alpha)AK_i^{\alpha} K^{1-\alpha} L_i^{-\alpha} = w_Y \quad \text{(A4a)}$$

$$\alpha AK_i^{\alpha-1}(KL_i)^{1-\alpha} = \psi \quad \text{(A4b)}$$

Multiplying through (A4) by N^0 gives

$$(1-\alpha)A(NK_i)^{\alpha} K^{1-\alpha}(NL_i)^{-\alpha} = w_Y$$

$$\alpha A\left(NK_i\right)^{\alpha-1}\left(KNL_i\right)^{1-\alpha} = \psi$$

which can be written as

$$\left(1-\alpha\right)AKL_Y{}^{-\alpha} = w_Y \qquad \text{(A4a')}$$

$$\alpha AL_Y^{1-\alpha} = \psi \ . \qquad \text{(A4b')}$$

Effort in the fishing industry is increased until the marginal profit from labour is zero, i.e.

$$\left(1-\beta\right)\left(\frac{q}{p}-m\right)BL_X^{-\beta} = w_X \qquad \text{(A5)}$$

We are now ready to combine (A2), (A4') and (A5) to form the first order conditions (11) given in the text. Equations (11a) and (11b) are simply the equations (A2a) and (A2b). Equations (11c) is found by equating (A2c) with (A2d), substituting in for the wage rates from (A4a') and (A5). Finally, equation (11d) comes from plugging (A4b') into (A2e).

Appendix B. The Schaefer harvesting function

The Schaefer harvesting function

$$X = BL_X S \tag{B1}$$

differs from the function (6) in the text in two ways. First, it assumes that there are constant returns to effort (labour) in harvesting (i.e. $\beta = 0$). Second, it assumes that the harvest depends on the stock size S. Additional labour is attracted to fishing as long as the benefit from doing so is greater than the cost, i.e. as long as

$$\left(\frac{q}{p} - m\right) BSL_X > w_X L_X \tag{B2}$$

where increased effort has the effect of reducing the resource stock S. The fishing firms take the size of the stock S as given, and ignore the stock dynamics. It follows that, if the wage rate is neither too high nor too low, L_X will increase until profits

$$\Pi_X = \left(\frac{q}{p} - m\right) BSL_X - w_X L_X = 0 . \tag{B2'}$$

If the marginal cost of effort is sufficiently low, then the net revenue from additional labour will always be greater than the additional cost, and the resource sector will expand beyond the maximum sustainable yield level. The harvest will be larger than the own growth of the resource (at any stock level) and the resource stock will be driven to extinction. If the marginal cost is too high then no level of harvest will be profitable, and the harvest sector will not exist (while the resource stock is in equilibrium at the carrying capacity $\bar{S}$). In the case of a labor cost that is neither too low nor too high the effort would balance under free access where total cost equals total net revenues (see e.g. Hannesson (1993)). The first order condition determining labour use in the fishing sector (A5) is thus replaced by the zero profit condition

$$\left(\frac{q}{p}-m\right)BS = w_X\ . \tag{B3}$$

Restating the first order conditions (11) from the text, adding the new resource sector condition, yields

$$C_Y^{\gamma-1}C_Z^{\gamma\phi} = \lambda \tag{B4a}$$

$$\phi C_Y^{\gamma}C_Z^{\gamma\phi-1} = q\lambda(1+\tau_T) \tag{B4b}$$

$$(1-\alpha)AL_Y^{-\alpha}K = (1-\nu)\frac{q}{p}BS \tag{B4c}$$

$$\frac{\dot{\lambda}}{\lambda} = -\alpha AL_Y^{1-\alpha}(1-\tau_I)+\rho. \tag{B4d}$$

The central planners (perfect property rights) solution (16) now becomes

$$C_Y^{\gamma-1}\left[p^{-1}BL_X\right]^{\gamma\phi} = \lambda \tag{B5a}$$

$$(1-\alpha)AKL_Y^{-\alpha} = \phi C_Y L_X^{-1} - \mu BS \tag{B5b}$$

$$\frac{\dot{\lambda}}{\lambda} = -AL_Y^{1-\alpha} + \rho \tag{B5c}$$

$$\frac{\dot{\mu}}{\mu} = AL_Y^{1-\alpha} - r\left(1-2\frac{S}{\overline{S}}\right) + BL_X - \frac{\phi C_Y}{\mu S} \tag{B5d}$$

Again, the first best solution can be replicated by appropriately choosing values for the policy parameters τ_I, τ_T and ν. The major change from equations (16) in the text is in the dynamics of the variable μ. See Elíasson and Turnovsky (2004) for a discussion of the dynamics and steady state solution in this case.

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