A Computable General Equilibrium Analysis of Fishery Management in a Small Honduran Community

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Abstract

Open access exploitation of a natural resource has been shown to completely dissipate rents. This is particularly problematic for small economies who rely heavily on natural resources for their livelihood. We study the case of a small Honduran community with an open access fishery. We construct a multi-sector general equilibrium model of the economy with mobile factors. We then simulate management policies on the fishery and analyze their economy-wide consequences. This paper, at its core, is an extension of the work of Dale T. Manning, J. Edward Taylor and James E. Wilen in '*General Equilibrium Tragedy of the Commons*'.

1 Introduction

Unregulated natural resource exploitation usually leads to inefficient use of factors and overexploitation. This phenomenon has been studied by many authors, but in a partial equilibrium setting. In this paper, we study the effects of an unregulated fishery in a Computable General Equilibrium (CGE) setting with mobile factors.

In particular, we look at the economy of a Honduran artisanal fishing village where the fishery operates under open access. We then test different management policies on this sector.

We model this CGE economy using baseline values from the Social Accounting Matrix (SAM) obtained by Manning et al. (2018). We then introduce resource dynamics to the model so that we can analyze the effects of management policies on both the economic situation and the fish population. These policies usually have the common goal of reducing the fishery's factor usage, and restoring the fish stock.

In fact, the theoretical results on this subject suggest that under open access, the fishery's factors will be overused (inefficiently used) and will lead to a low steady state fish population. Furthermore, this excessive use of fishing efforts leads to complete dissipation of rents. This is often referred to as the Tragedy of the Commons (TOC). The TOC has been discussed by many authors (Gordon 1954, Hardin 1968, Weitzman 1974) and can be summarized by the following example:

Given a natural resource, if it is common property (open access) then anyone is free to come exploit it. Therefore if the resource generates rents, it will attract more and more people. The newcomers, only concerned with their personal gains, will ignore the negative impact their extra unit of effort has on average productivity. This process will continue until all rents are driven to zero. The issue with this is that there is an excessive amount of effort invested in the exploitation of the resource, compared to if it had an owner. Therefore, the production factors (e.g. labor, capital) are inefficiently used.

Now, this overuse of efforts in the resource's exploitation has economy-wide repercussions when the production factors are mobile. This is particularly relevant in poor economies, where the excessive labor and capital used in the resource sector could be redistributed in other sectors in hope of improving the economy. Such an analysis is made by Manning et al. (2018) with a general equilibrium (GE) model of Honduran artisanal fishing villages. They perform empirical tests within a multi-sector, multi-factor economy. Congar and Hotte (2014) generalize the repercussions in a theoretical two-sector economy with two mobile factors.

Although Manning et al. (2018) and Congar and Hotte (2014) use a similar theoretical setting, they use different models to represent the open access (natural) resource sector. The primary goal of this paper is to replicate the tests of the former with their empirical data, but using the open access model of the latter.

In their paper, Manning et al. (2018) test a temporary capital restriction in the fishery in order to let the fish stock grow. They find that this decreases the short term wages and household income. However, in the long run, after the policy is lifted, economic activity, wages and household income all increase significantly. They therefore argue that this management policy improves the overall economic situation of this poor community.

During the analysis of our results, we found a flaw in the stability of the steady state fish stock used by Manning et al. (2018). We corrected this by choosing the stable steady state, which required a small modification of the fishing production function. We also broadened this study by running experiments on an alternative fish population growth function, which was based on observed biological models in fisheries.

Furthermore, we extend the work of Manning et al. and test two management policies on the fishery. These policies are: i) capital restriction and ii) tax per catch. In general, we found that both policies improve the state of the fish stock, but with mixed economic results. The capital restriction policy has the smallest reduction in total income for the first growth model, and is the only one to increase income for the alternative model. However, this restriction creates the largest wage inequalities. Finally, the tax per catch restriction has perhaps the most interesting results. With the income generated by the tax, the total income in the economy increases for both growth models. But this new income, depending on how it is spent, has the potential to greatly improve the long term situation of the economy.

This paper is organized as follows. In the second section, we describe the theoretical background of this paper. We present a short review of the article by Manning et al. (2018), which will be referred as the original article for the rest of this paper. We then discuss their open access model and compare it to the one of Congar and Hotte. We will also talk about the major changes of our approach compared the original. Section 3 gives a complete description of the economy. Section 4 states all of the equilibrium conditions of the economy. In Section 5 we simulate various policies on the resource sector. The final section is dedicated to the conclusion.

2 Theoretical Background

In this section, we begin with an overview of the article "General Equilibrium Tragedy of the Commons" by Dale T. Manning, J. Edward Taylor and James E. Wilen (2018) and discuss how they describe open access. We then describe a different way to to model the open access regime based on Congar and Hotte (2014) in order to analyze its potential GE effects. Finally, in section 2.4, we describe the main modifications and extensions made from the Manning et al. (2018) model.

2.1 Overview

Manning et al. (2018) model a multi-sector, multi-factor economy in a GE setting with one sector being a natural resource exploited under open access. They apply their model to an artisanal fishery in Honduras, where national laws prohibits restricted access to natural resources (such as fish). Furthermore, the authors state that there are some fishing regulations in the country, but they are poorly enforced. Thus the fishing activities represent a case of unrestricted open access. Their data demonstrates that overfishing is in fact both an ecological and economic issue.

In fact, fishing is an important source of food and work for many people in these villages, so a great amount of effort (inputs) is put into it. But since many of the fishermen in Honduras also work in other production sectors, the time they spend fishing is time taken away from another sector[1]. So if factors were more efficiently allocated in the fishery, there would be more factors available for the rest of the economy. Therefore resource management policies which reduce the fishery input use will have economy-wide consequences. The analysis of such policies and their impact on social welfare is the main goal of their paper.

They acquired data from artisanal fishing villages near the city of Tela in Northern Honduras. They interviewed 154 households in May 2012 about their economic activities in 2011. From their data, they developed their GE model with 7 sectors (agriculture, fishing, fish resale, retail, services, production, tourism), 7 factors (family labor, low-skilled labor, high-skilled labor, fishing capital, land, fish stock, physical capital), a representative consumer, the government, and external trade. They model the fishery as the open access sector. All the other sectors are modeled as profit maximizing industries, where they equate the inputs marginal product to their marginal cost. The description of this model is explained in Section 2.1.

From their data obtained, they construct a social accounting matrix (SAM), which illustrates all the monetary transfers within the economy at a certain period. They then use this SAM to calibrate their GE model and find the values of all the unknown parameters. They do so using Generalized Algebraic Modeling System (GAMS). After calibration, they find in particular that the fishery production function, assumed to be Cobb-Douglas, is

$$y_{fish} = 1.35\, L_F^{0.174}\, L_{LS}^{0.104}\, K_F^{0.322}\, x^{0.4}$$

where 1.35 is technology parameter, L_f is the family labor in the fishery, L_{LS} is the hired low-skilled labor, K_F is the fishing capital, and x is the fish population in a given period. Note that to obtain this equation, they had to assume a production-fish stock elasticity of 0.4. They also assume other parameters of the model, such as the intrinsic growth rate of the fish population. The reasoning and the sensitivity of these assumptions is discussed in great detail in their paper.

With their calibrated model, the authors run experiments using GAMS. First, they test a fishing capital restriction in the fishery. They interpret this as a forced reduction in boats in the fishery. For all their experiments, they enforce a 20% capital reduction for 5 periods to let the fish population grow. This forces fishing capital to enter the tourism industry, as it is the only other activity using boats in their model. They then remove the restriction to let the fishery's fishing capital return to its original level, and let the economy evolve for another 15 periods. A comparison is then made between the baseline values in the economy and after these 20 periods.Their general results are as follows.

During the 5 periods of restriction, all the fishery inputs, harvest, wages and income decrease while the fish stock increases. With the restriction lifted, the fish population keeps growing, and so does all fishery's variables (inputs, output, wages). At the end of the 20 periods, inputs, harvest, wages and income have all surpassed their baseline value. They state "This exercise illustrates that the higher resource stock combined with a restriction on capital creates a rent in the fishery collected only by boats that remain in the sector. This income gradient creates a strong incentive for capital to enter the fishery illegally, meaning that strong enforcement is required." (p.90). They also notice

[1]Note that this implicitly assumes full employment.

that after 20 periods, the harvest has now surpassed the fish stock growth, so the new level of income is not sustainable. In all, this policy increased output in every sector with the exception of agriculture and fish resale.

In summary, this policy is an improvement of the long term economic situation of the village, at the cost of the state of the short term economy. Since the setting is a poor economy, compensation might be needed for those more affected by the policy, so that they do not fall below the poverty line. Furthermore, this policy does not eliminate the open access factor inefficiencies.

In their conclusion, the authors state that their results predict a decrease in the resource sector as the resource depletes. This differs from usual open access results, in which an increase in exploitation efforts will drive the resource to a low steady state.

2.2 The open access model

To model the open access resource, Manning et al. (2018) assume an economy with 3 factors: labor (L), capital (K), and the fish stock (x). There are two outputs: y_1 (resource production, the fishery) and y_2 (another production) with exogenous prices p_1 and p_2 (i.e. fixed by external trade)[2]. The pertinent sector here is the fishery. Its production is

$$y_1 = f\left(L_1, K_1, x\right)$$

where f is homogeneous of degree 1, concave, and increasing in all inputs.

Now we know that in profit maximizing activities, the equilibrium production level is reached when the marginal productivity of inputs is equal to their respective marginal cost. That is, we have

$$p_1 \frac{\partial f}{\partial z_1} = w_z \tag{1}$$

for each input z at the equilibrium. But since the fishery has no owner, no payment is made to the fish. Therefore there is no such thing as w_x.

So the authors assume a proportion $\theta \in [0,1]$ of the fish stock's contribution to production is collected by labor, and $(1-\theta)$ is collected by the capital. Then how does this affect $w_L$and w_K? From Euler's theorem, we know that

$$p_1 f\left(L_1, K_1, x\right) = L_1 p_1 \frac{\partial f}{\partial L_1} + K_1 p_1 \frac{\partial f}{\partial K_1} + x p_1 \frac{\partial f}{\partial x}$$

They then define $Q := x p_1 \frac{\partial f}{\partial x}$ which is the "payment made to the fish". Each worker collects his share of θQ, so the marginal revenue of labor is: $p_1 \frac{\partial f}{\partial L_1} + \frac{\theta Q}{L_1}$. Similarly, the marginal return on capital is: $p_1 \frac{\partial f}{\partial K_1} + \frac{\theta Q}{K_1}$.

The equilibrium conditions for the fishery are then:

$$p_1 \frac{\partial f}{\partial L_1} + \frac{\theta Q}{L_1} = w_L \tag{2}$$

$$p_1 \frac{\partial f}{\partial K_1} + \frac{\theta Q}{K_1} = w_K \tag{3}$$

[2]Prices are in Millions of Lempira, the Honduran currency.

The equilibrium wages are hence higher than in equation (1). As a result, this completely dissipates the resource rents. In fact, the authors prove that with the conditions (2) and (3), the rent $R = p_1 f(L_1, K_1, x) - L_1 w_L - K_1 w_K$ is equal to zero.

2.3 The Congar-Hotte approach to open access

In their paper, Congar and Hotte define the open access regime differently. Their approach is the more classical one in the literature (Gordon 1954, Weitzman 1974). This model explains the rent dissipation with the average product of inputs being driven down to equate their marginal cost. Gordon (1954) gives a great example to illustrate it.

Picture a fishing ground that is completely unrestricted. The optimal level of harvest is attained when marginal productivity of fishing effort is equal to its marginal cost (we will assume constant costs, so that the marginal cost is the same as the average cost). This generates the maximum level of rent. But since the fish is common property, the rent it yields cannot be appropriated by anyone. No fisherman is the owner of a certain area of the fishing ground, so any other fisherman can come and collect a rent for himself. So as long as there is rent generated, there will be new fishermen coming to collect a part of it. But the newcomer, adding only one unit of fishing effort to the total harvest, earns the average product of fishing effort. Now, each extra unit of effort decreases his marginal return, and so also the average return. But every fisherman, seeking only personal gains, will not care about the negative impact his fishing effort has on the average return, and will enter the fishery. This will then continue until the average return of fishing activity is equal to the average cost. The rent will now have completely dissipated.

To model this, Congar and Hotte (2014) assume an economy with two sectors, a manufacturing sector (restricted access) and a resource sector (open access). The resource sector production is defined as

$$y_1 = f(z)$$

where $z = F(x)$ is the effective input effort, and x is the sector of inputs. The open access equilibrium conditions, stating that the average productivity is equal to marginal (average) costs, is therefore defined by

$$p_1 \, \Phi(z) \, F_i(x) = w_i \tag{4}$$

for each input x_i. The function $\Phi(z) \equiv \frac{f(z)}{z}$ denotes the average product of effective effort, and $F_i(x) = \frac{\partial F(x)}{\partial x_i}$.

The authors then also prove that with equilibrium conditions defined by equation (4), correspond to complete rent dissipation.

2.4 Our Approach and Main Differences

As stated previously, in this paper we will do a similar work as Manning et al. (2018). We model a Honduran artisanal fishing village in a GE framework, where the fishery is the sector operating under an open access regime. We then simulate various policies in hopes of improving the poor local economy. To carry out these tests, we use GAMS and the data obtained by the original authors. This means that we are using the same economy, with the same production sectors and factors. We will also use the same parameters that they used, such as the production-fish stock elasticity of 0.4 and the fish stock intrinsic growth rate of 0.5. Although our work is heavily based on the original paper, there are nonetheless several differences between them. Here are the main changes or assumptions we made:

1. The first modification, and the idea which launched this research paper, is the different model of the open access resource. We will be using the Congar and Hotte (2014) open access model instead of the original authors model. That is, the fishery equilibrium conditions will be defined by equation (4) instead of equations (2) and (3). The exact description of these conditions is given in the fourth section, where we also define all the other equilibrium conditions.

2. In order to follow their open access theory, the original authors added an account for the fish population in their SAM. Since we don't need such a value for the Congar and Hotte model, we retracted this account from the SAM, and redistributed its expenditures and receipts in the appropriate accounts. We also made a few more assumptions about the values in the SAM, since we did not have all the information necessary.We removed the payment made from the household to itself for simplicity reasons, and since it has no impact on the qualitative results. We assumed the payment made from the External Trade to the Households to be a constant remittance. We assumed the payment made from the Government to the Households to be fixed, and the former's other expenditures to be in fixed proportions. All these changes can be seen in our modified SAM in the appendix[3].

3. For the growth of the fish population, we will use the same function but with a different steady state equilibrium. We will also perform our experiments using another growth function. Further details on these functions are given in section 3.1.

4. In the original paper, the steady state fish stock equilibrium used in unstable. Since the ones we will use are stable, the capital restriction test has been modified. In order to have lasting effects, the restriction will have to be permanent (instead of only for 5 periods). Detailed explanations of our test variant are given in section 5. We will also experiment with other management policies in that same section.

5. We also made other various minor changes and assumptions, which are stated throughout this paper.

[3]In the SAM, the columns represent the expenditures, and the rows represents the receipts or incomes.

3 The Economy

In this section, we give a detailed explanation of the economy, which describes an artisanal fishing village in Honduras. First, we assume the economy to be operating at a steady state. Therefore, all the values seen in the SAM are at an equilibrium.

The economy is composed of 7 sectors, 6 factors of production, a representative household, the government, and external trade.

The 7 sectors are: fishing, agriculture, fish resale, retail, services, production and tourism. We assume that all the sectors have tradable product, so that their selling prices are fixed by the economy. The fishery sector is assumed to be operating under open access. The other 6 sectors are assumed to be profit maximizing.

The factors of production are: family labor (L_F), low-skilled labor (L_{LS}), high-skilled labor (L_{HS}), fishing capital (K_F), physical capital (K_P) and land (T). We assume that family labor, fishing capital, physical capital and land are non-tradable. Low-skilled labor and high-skilled labor are assumed to tradable, so their wages are fixed.

The consumers are represented by a representative household.

The government receives its income from a tax on income, and completely redistributes its funds.

External trade is seen as any trade made with entities outside of the local community. This also captures all the imports and exports.

3.1 Fishery

The fishery sector is the main focus of this paper. Since it operates under open access, its inputs are inefficiently used, which contributes to the failure of the economy.

To characterize this sector, we give a description of its production function and a description of the fish stock dynamics. For the latter, we will describe two different population growth models, which are developed in section 3.1.2 and 3.1.3.

3.1.1 Harvest

The fishery is assumed to have the Cobb-Douglas production function

$$y_{fish} = A_{fish} L_F^{\alpha} L_{LS}^{\beta} K_F^{\delta} x^{\omega} \tag{5}$$

where A_{fish} is the technology parameter of the fishery, L_f, L_{LS}, K_F are the inputs used, and x is the fish stock in a given period. An issue with this function is that no payment is made to the fish stock, therefore it does not appear in the SAM. It is then impossible to distinguish the value of A_{fish} from x^{ω} in our model calibration. In order to solve this problem, we must fix the value of ω, which is the production-fish stock elasticity. Just as the originial authors, we assume $\omega = 0.4$. Equation (5) then becomes

$$y_{fish} = A_{fish} L_F^{\alpha} L_{LS}^{\beta} K_F^{\delta} x^{0.4} \tag{6}$$

where $\alpha + \beta + \delta = 0.6$.

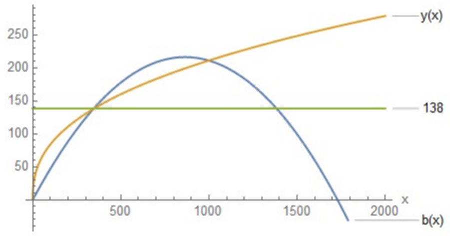

Figure 1: graph of logictic growth b(x), and harvest y(x)

3.1.2 Growth

We assume the growth of the fish stock is represented by

$$x_{t+1} = x_t + b(x_t) - y_t \tag{7}$$

where $b(x_t)$ represents the biological growth of the fish population, and is assumed to be strictly concave.

In Manning et al. (2018), the authors assume a logistic growth, with an intrinsic growth rate of 0.5.[4] This is represented by

$$b(x_t) = 0.5\, x_t\, (1 - \frac{x_t}{K}) \tag{8}$$

where K is the environmental carrying capacity[5]. Now, with a harvest of 138.32 units and assuming that the stock is at 20% of its carrying capacity, we find that the steady state stock is 345.79 units. This also implies that $K = 1728.95$. This seems fine and it is consistent with the idea that overfishing has driven the fish stock to low levels. But there is one problem with this steady state, it is not stable. We can see so in Figure 1. The harvest function y_{fish} is greater than the growth function b to the left of the steady state. Therefore if the population is a tiny bit smaller (to the left) than the steady state, harvest is larger than population growth, and it will drive the fish stock to zero. Similarly, if we are to the right of the steady state, a larger growth than harvest will drive the fish stock to the next steady state. Consequently, we cannot assume that the fish stock is as the steady state of 20% as any variation in stock will drive the stock to another steady state. It is therefore almost impossible that the economy got to that equilibrium.

In light of these facts, we will instead consider the other steady state, which is the second intersection of y_{fish} and b. Notice that this steady state is stable, since $y_{fish} < b$ to its left, and $y_{fish} > b$ to its right. Such a state of the fish stock is much more plausible, as any stock between 20% and 100% of the carrying capacity will converge to it over time.

The second time the growth is equal to 138.32 is when $x = 1383.15$, which is 80% of the carrying capacity. While 80% is not ecologically speaking an over fishing problem, we will nevertheless do an analysis with this steady state in order to use the same growth function as the original authors. Note that we also introduce a different growth function further in this section, will do the same analysis with it, and will compare the results obtained with both functions.

[4]The authors state that all the qualitative results hold for intrinsic growth rates between 0.2 and 0.8

[5]The carrying capacity is "the size of the fish stock in natural equilibrium (i.e. withouth fishing)." Hannesson (1978, p.17)

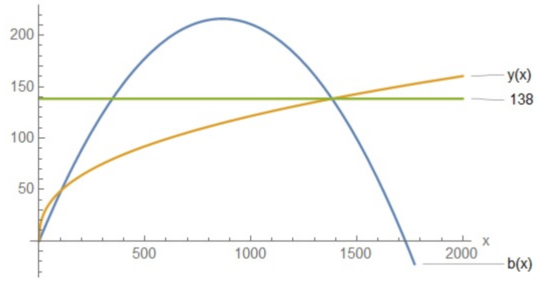

Figure 2: graph of logistic growth b(x), and modified harvest function y(x)

In order for the point (1383.15, 138.32) to be a steady state, the harvest function must be equal to 138.32 when $x = 1383.15$ (and with all the same inputs). In order to do so, we must modify the harvest function a bit. We compensate this increased value of $x^{0.4}$ by decreasing the value of the technology. We found that $A_{fish} = 0.7771$ gives the desired results, compared the the original value of 1.35. The shape of this new harvest function, and the new stable steady state can be seen in Figure 2.

In short, with the logistic growth function (equation (8)), and with $K = 1728.95$, $A_{fish} = 0.7771$ and $y_{fish} = 138.32$, we have a stable steady state at $x = 1383.15$ (80% of carrying capacity).

3.1.3 Alternative Fish Growth Function

As mentioned in the previous section, we will now introduce and alternative fish growth function. The idea is that because of the shape of the harvest function, it is always the second equilibrium which will be the stable steady state[6]. Because of this, we looked for a growth function which would have its second steady state at a more appropriate proportion of the carrying capacity. While we can find an arbitrary function to make this equilibrium as small as we want, we wanted to take a function that is somewhat representative of an observed fish species.

Pella and Tomlinson (1969) gave a more general model for fish growth which is described by:

$$b(x_t) = Hx_t^m - Jx_t \tag{9}$$

where H,J, and m are constants, $m \geq 0$. In their article, they describe how different values of m will skew the growth curve. For values of $0 < m < 2$, the curve is skewed to the left, and for $m > 2$, the curve is skewed to the right. We are interested in left-skewed functions, as it will give us a smaller stable steady state.

Fletcher (1978) then restructured equation (9) with the following differential equation:

$$b(x_t) = \gamma m(\frac{x_t}{K}) - \gamma m(\frac{x_t}{K})^n \tag{10}$$

[6]This is assuming it intersects the growth function twice. If it has no intersection, then $y_{fish} > b$, $\forall x$, and the only steady state is extinction. If it has only one intersection, the fishery is operating at its maximum sustainable yield, which is extremely unlikely. An ϵ increase in harvest from such a steady state would put harvest larger than growth, consequently leading to extinction.

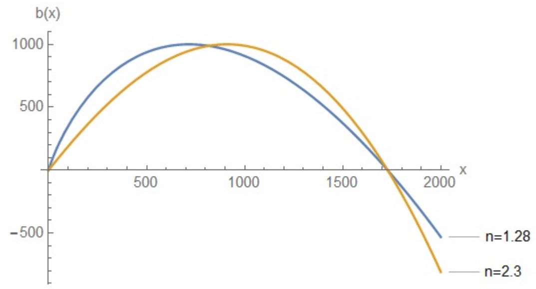

Figure 3: graph of Fletcher growth with different values of n

where $\gamma = \frac{n^{n/n-1}}{n-1}$, K is the carrying capacity (maximum stock size), n is the skew parameter (which controls the function's curvature), and m is the "level where maximum productivity occurs" (often called the *maximum sustainable yield* in recent literature).

For our alternative approach, we will be using Fletcher's growth function (10). We assume the values of the parameters $m = 140$ and $K = 1728.95$ (which will ensure that both growth functions are on the same scale)[7]. For a value of n, we look for an empirical estimate.

In their article, Bledsoe and Rivard (1978) do exactly that. They look at estimates for n obtained by Pella and Tomlinson (1969), Fox (1971) and Ricker (1975), and compare them to their estimate obtained using the Levenberg-Marquardt algorithm (LMA). For the yellowfin tuna in the eastern Pacific Ocean, the values of n range from 1.4 to 2.3, and for the Pacific halibut, the values range from 1.28 to 2.0. The effects of these different values of n on the shape of the curve can be see in Figure 3.

Since we want a left skew, we will use $n = 1.28$, which was obtained by Bledsoe and Rivard using the LMA. Now, these values of n are for values of K and m different from the ones I am using, but we took the liberty of using it as so to have a stable steady state much smaller than at 80% of the maximum population.

In fact, using $K = 1728.95$, $m = 140$, $n = 1.28$, we get the following growth function

$$b(x_t) = 11.0394(140)\left[1 - (\frac{x_t}{1728.95})^{0.28}\right]. \tag{11}$$

With a harvest of 138.32, it has a stable steady state at $x = 815.589$. This population represents 47.17% of the carrying capacity, which is ecologically speaking more representative of an over fishing problem. Note that in order for the harvest function to pass by that point, the technology parameter had to be adjusted to $A_{fish} = 0.960$.

3.2 Production technology

All the production sectors are assumed to have Cobb-Douglas technologies. Their respective production functions are:

1. Agriculture: $y_1 = A_1 L_F^{a_1} L_{LS}^{b_1} T^{e_1}$

[7]Different values of m alter the height of the function's peak. A bigger m implies a higher peak, and so the second intersection between harvest and growth will be at a larger value of x (a higher percentage of K). The value of K represents the scale of the x-axis, it is the second root of the function.

2. Fishery: $y_2 = A_2 L_F^{a_2} L_{LS}^{b_2} K_F^{d_2} x^{0.4}$
3. Fish resale: $y_3 = A_3 L_F^{a_3} K_P^{g_3}$
4. Retail: $y_4 = A_4 L_F^{a_4} L_{LS}^{b_4} K_P^{g_4}$
5. Services: $y_5 = A_5 L_F^{a_5} L_{LS}^{b_5} K_P^{g_5}$
6. Production: $y_6 = A_6 L_F^{a_6} L_{LS}^{b_6} K_P^{g_6}$
7. Tourism: $y_7 = A_7 L_{HS}^{c_7} K_F^{d_7} K_P^{g_7}$

We also assume that all the functions are homogeneous of degree 1, so the sum of the exponents in each function is equal to 1.

In Manning et al. (2018), they assume that only agriculture, fishing, fish resale and tourism are tradable, and that the other 3 sectors are non-tradable. We instead assume that all 7 sectors are tradable, since retail, services and production (the 3 sectors originally assumed to be non-tradable) all have either imports or exports when we look at the SAM. We therefore thought it was more appropriate to consider them as tradable. This means that all 7 selling prices are exogenous.

Notice that fishing capital is only used in the fishery and in tourism, and since this factor can move between these two sectors, changes in the fishery have a greater impact on tourism than on the other sectors.

3.3 Factors of Production

The 6 factors of production used in this economy are as stated earlier, family labor, low-skilled labor, high-skilled labor, fishing capital, physical capital, and land.

From the SAM, we see that there are payments made to low-skilled and high-skilled workers from the external trade account. This indicates that some of them work outside of their community[8]. We also assume that workers from the outside can come work inside the community. These two factors are therefore assumed to be tradable. Hence they have infinitely elastic supplies and their wages are exogenous.

Family labor, fishing capital, physical capital, and land are assumed to be non-tradable. Therefore their wages are endogenous. Furthermore, following the assumptions of the original authors, physical capital and land have fixed quantities in their respective production activity.

3.4 Consumers

The consumers demands are assumed to be derived from a Cobb-Douglas utility function for a representative consumer. They have demands for the production sectors and for imported goods. Their utility function is:

$$U = CD_1^{\alpha_1} CD_2^{\alpha_2} CD_3^{\alpha_3} CD_4^{\alpha_4} CD_5^{\alpha_5} CD_6^{\alpha_6} CD_8^{\alpha_8} \tag{12}$$

[8]Not all of them work outside of the community. Some of the low-skilled and high-skilled workers work domestically.

where $\sum_{i=1}^{8} \alpha_i = 1$, and CD_8 represents their demand for imported goods. Notice sector 7 is missing from the utility function since it is tourism and the local community does not "consume" tourism.

For their income, they collect all the money paid to the production factors. They also receive money from the government and from outside the community.

As for investments, Manning et al. (2018) stated: "It should be noted that investment is not modeled explicitly here, due to lack of data. It is assumed that households are able to maintain constant capital stocks across time and that the surveyed economy was at steady state. While potentially time inconsistent, this assumption does not qualitatively affect the market failures that are the focus of this model. It does, however, miss any interactions between other-sector growth and fisheries management." (p.86)

3.5 Government

The government in this economy receives all its funds from a tax on income. We assume this tax to be a constant proportion of the households' income. With this money, we assume it pays a fixed amount of government transfers (GTR) to the households, which can be seen as subsidies. The government also hires high-skilled workers (e.g. civil servants, police, teachers) and imports goods (that cannot be produced locally). We assume these two expenditures to be in fixed proportions.

As seen in the SAM, the income received by the government compared the the households' income is fairly low. We can infer that taxes are not collected from everyone in a poor economy, as many people will not bother paying them.

3.6 External Trade

External trade in this economy encapsulates all the money transfers made with agents outside of the community.

Imports are made by the production sectors, the government, and the representative household. For the government and household, we can think of these imports as consumable goods. For the imports made by the production sectors, we view them as intermediate inputs (as opposed to production factors)[9]. We assume each sector's intermediate input demands to have a Leontieff relationship.

Expenditures by the external trade account (or the community's exports) are made to the production sectors, the household, and to the tradable production factors. The payments made to the production sectors are the exports of these activities. The transfer made to the household represents a remittance (REM), which is paid by family abroad or humanitarian organizations. Finally, the payments made to low-skilled and high-skilled workers represent the salaries paid to the people of the community who work outside of the community.

[9]While these intermediate inputs are not seen in the production functions (see Section 3.2), they are accounted for in the valude-added price of each sector. These prices are discussed in Section 4.2.

4 Equilibrium Conditions

We model this economy with a GE model. We then calibrate the model using GAMS. For the calibration, we used the initial values seen in the SAM in the appendix. Recall that in the original paper, there is an account for the fish population in the SAM. Since we remove this account, we redistributed its income and expenditure between family labor, low-skilled labor, and fishing capital, in their appropriate proportions.

For the GAMS calibration, it is standard to set the prices and wages equal to 1, and the units of inputs and outputs will adjust themselves so that the price of one unit is 1.

4.1 Factors of production

Low-skilled labor and high-skilled labor are tradable, therefore their wages are exogenous. By convention they are fixed at 1:

$$w_{L_{LS}} = w_{L_{HS}} = 1 \tag{13}$$

All the other factors are non-tradable, therefore their wages are determined within the local economy. More precisely, they are obtained from the production factor demands.

For all the inputs, we assume a fixed amount available in the economy. Note that we also assume these totals to be fixed over time. We will also assume no capital depreciation, just as the original authors did. We obtain the market clearing conditions for these production factors from the SAM. They are:

$$L_{F1} + L_{F2} + L_{F3} + L_{F4} + L_{F5} + L_{F6} = 77.41 \tag{14}$$

$$L_{LS1} + L_{LS2} + L_{LS4} + L_{LS5} + L_{LS5} + L_{LS6} + L_{LS8} = 40.21 \tag{15}$$

$$L_{HS7} + L_{HSG} + L_{HS8} = 37.89 \tag{16}$$

$$K_{F2} + K_{F7} = 67.11 \tag{17}$$

$$K_{P3} + K_{P4} + K_{P5} + K_{P6} + K_{P7} = 22.35 \tag{18}$$

$$T = 2.45 \tag{19}$$

where L_{Fi} represents the family labor employed in the production sector i, and so on. L_{HSG} is the high-skilled labor hired by the government. L_{LS8} and L_{HS8} are the low-skilled and high-skilled labor working for the external trade account. Note that L_{LS8} and L_{HS8} could potentially be negative if there is more workers from the outside working inside the community than locals working outside of it.

Recall that we assumed land and physical capital to be fixed in each activity. That is, the values of T and $K_{P3}, ..., K_{P7}$ are all fixed. An important remark is that there is therefore five different rental rates for physical capital, one for each activity. There will therefore be different values for $w_{K_{P3}}, ..., w_{K_{P7}}$.

4.2 Pricing

All the sectors are tradable, and so all their selling prices are exogenous. As per GE convention, we set all the prices equal to 1, and the output units will adjust themselves so that the price per unit if of 1. Hence

$$p_1 = p_2 = ... = p_7 = 1 \tag{20}$$

Now, the production sectors do not only use the factors of production as inputs, but also intermediate inputs. These intermediate inputs consist of the output of other activities and imported goods. The intermediate inputs have a Leontieff relationship for the production. That is, they will affect the cost of production in fixed proportions. Each production sector then considers these costs in its received price, which we call the *value-added price*. The value-added price of a sector is the selling price, to which we subtract the costs of intermediate inputs (in the proportion that they are used).

This can be expressed as:

$$pva_i = p_i - \sum_{j=1}^{7} s_{i,j} p_j - s_{8,i} \tag{21}$$

where $s_{i,j}$ is the share of sector j's expenditures that is spent on the intermediate input i.

For example, the agriculture sector uses agriculture, services, and external trade as intermediate inputs. So then

$$\begin{aligned} pva_1 &= p_1 - s_{1,1}p_1 - s_{5,1}p_5 - s_{8,1} \\ &= 1 - (\frac{3.38}{28.32})(1) - (\frac{0.16}{28.32})(1) - (\frac{8.23}{28.32}) \\ &= 0.5844 \end{aligned}$$

It is then these prices that the sector considers when it determines its factor demands.

4.3 Fishery

As stated before, the main goal of this paper is to compare the open access model of Congar and Hotte to the one of Manning et al. To develop the Congar-Hotte model, we first consider the fishery's demand for fishing capital.

The fishery is operating under an open access regime. This means at the equilibrium, the marginal cost of capital must equate its average return:

$$pva_2 \, \Phi(z, x) \, \frac{\partial F}{\partial L_F} = w_{L_F}$$

where $\Phi(z, x) = \frac{f(z,x)}{z}$, $f(z, x) = AL_F^{\alpha} L_{LS}^{\beta} K_F^{\delta}$ and $z = F(L_F, L_{LS}, K_F) = L_F^{\frac{\alpha}{\alpha+\beta+\delta}} L_{LS}^{\frac{\beta}{\alpha+\beta+\delta}} K_F^{\frac{\delta}{\alpha+\beta+\delta}}$.

Plugging these in, we obtain:

$$pva_2\left[\frac{Az^{\alpha+\beta+\delta}x^{0.4}}{z}\right]\left[\frac{\alpha}{\alpha+\beta+\delta}L_F^{\frac{\alpha}{\alpha+\beta+\delta}-1}L_{LS}^{\frac{\beta}{\alpha+\beta+\delta}}K_F^{\frac{\delta}{\alpha+\beta+\delta}}\right] \quad = \quad w_{L_F}\,,$$

which implies

$$pva_2\left[Az^{\alpha+\beta+\delta}x^{0.4}\right]z^{-1}(\frac{\alpha}{\alpha+\beta+\delta})z \quad = \quad w_{L_F}L_F\,,$$

and so

$$\frac{\alpha}{\alpha+\beta+\delta}\,pva_2\,y \quad = \quad w_{L_F}L_F\,.$$

Doing a similar reasoning for L_{LS} and K_F, and using the fact that $\alpha+\beta+\delta=0.6$, we obtain the fishery's factor demand equations:

$$\frac{\alpha}{0.6}\,pva_2\,y = w_{L_F}L_{F2}\,, \tag{22}$$

$$\frac{\beta}{0.6}\,pva_2\,y = w_{L_{LS}}L_{LS2}\,, \tag{23}$$

$$\frac{\delta}{0.6}\,pva_2\,y = w_{K_F}K_{F2}\,. \tag{24}$$

4.4 Other Production Sectors

The other 6 productions sectors are behaving optimally. It is assumed that they are all in perfectly competitive markets, so that they produce until the marginal cost of the inputs equates their respective cost. Since these sectors have Cobb-Douglas production functions, we know exactly what their factor demands look like. For example, for the agriculture sector (recall $y_1 = A_1L_F^{a_1}L_{LS}^{b_1}T^{e_1}$), its factor demand equations are:

$$a_1\,pva_1\,y_1 = w_{L_F}L_{F1}$$

$$b_1\,pva_1\,y_1 = w_{L_{LS}}L_{LS1}$$

$$e_1\,pva_1\,y_1 = w_TT_1$$

and similarly for the other sectors.

More generally, the share of the revenue spent on an input is this input's exponent in the production function, i.e. if $y = AL^\alpha K^\beta$, then its factor demand are

$$\alpha\,y\,pva = w_LL\,. \tag{25}$$

.

4.5 Households

The household's income is the sum of all of its factor incomes, the government transfers, and the remittance:

$$Y = w_{L_F} L_F + w_{L_{LS}} L_{LS} + w_{L_{HS}} L_{HS} + w_{K_F} K_F + \sum_{i=4}^{7} w_{K_{P,i}} K_{P,i} + w_T T + GTR + REM \,. \tag{26}$$

Their disposable income, defined as their income after taxes, is

$$YD = (1 - t)Y \,. \tag{27}$$

We assume a fixed tax rate of $t = 2.90\%$, since this is the tax rate observed in the SAM.

The representative consumer has a Cobb-Douglas utility function, as described by equation (12). His consumption demands are therefore easily shown to be:

$$CD_i = \frac{\alpha_i YD}{p_i} \,, \tag{28}$$

for $i = 1, ..., 6, 8$.

The consumers must also respect their budget constraint, which we assume to be binding. The balance of their accounts is thus:

$$YD = \sum_{i=1}^{6} p_i CD_i + CD_8 \tag{29}$$

4.6 Government

The government collects all of its income from the tax it imposes on the household's income. Therefore its income is equal to tY. The government then uses this money and redistributes it to other agents. In order to balance our economy, we assumed that the amount they transfer to the households is fixed at 0.22 Million Lempira and the rest is distributed in fixed proportions to high-skilled labor and external trade. We used the baseline proportions of the SAM, which are 1.40% paid to labor, and 98.6% paid to external trade (after removing the GTR). The government's balance equation can therefore be represented by:

$$tY = GTR + L_{HS,G} + GD_8 \tag{30}$$

where Y, t, and GTR are as they appear in the household budget constraint, GD_8 is the government's demand of imported goods, and $L_{HS,G}$ is its demand of high-skilled labor.

4.7 External Trade

The external trade equilibrium condition is the balance between the community's imports and exports. This balance is represented by:

$$\sum_{i=1}^{7} INTER_i + GD_8 + CD_8 = \sum_{i=1}^{7} EX_i + REM + L_{LS8} + L_{HS8} \tag{31}$$

where $INTER_i = s_{8,i}\, y_i$ is the imported intermediate input demand by sector i, and EX_i is the amount of output i bought by external sources (exports). When all the other equilibrium conditions hold, and since the economy is assumed to be in a steady state, equation 31 is implicitly balanced by the rest of the economy.

4.8 Fish Stock Dynamics

Now that the economy is completely defined, we are ready to introduce fish stock dynamics. At the end of a period t, when all the above equilibrium conditions hold, we have a quantity of harvest (y_2) and of fish (x_t). The fish population is then updated via the function

$$x_{t+1} = x_t + b(x_t) - y_2 \,.$$

We then use the new fish population x_{t+1} to find a new equilibrium (using all the same conditions) for period $t + 1$. We reiterate this process for as many periods as we need.

4.9 Overview

In summary, equations (13) to (31) completely represent the economy's equilibrium conditions at the steady state. To model fish stock dynamics, we add equation (8) or (11), depending on which growth model we use.

In particular, the fishing production function is $y_{fish} = A_{fish}\, L_F^{0.174}\, L_{LS}^{0.104}\, K_F^{0.322}\, x^{0.4}$.

If we use the logistic growth, as described by equation (8), the fishery has a technological parameter of $A_{fish} = 0.7771$, and an initial fish population of $x = 1383.15$ (80% of carrying capacity).

If we use the Fletcher growth, as described by equation (11), the fishery has a technological parameter of $A_{fish} = 0.960$, and an initial fish population of $x = 815.589$ (47.17% of carrying capacity).

5 Policy Analysis

In this section, we will analyze two fishery management policies and their impact on the economy. Both of these policies were tested on the calibrated GE model in GAMS[10]. The goal of the policies is to reduce the fishing activity so that the production factors will be more efficiently allocated in the economy, and also in hopes of restoring the fish population. The first policy is the same as in the original article, but with a small difference. It is a binding cap of the fishing capital in the fishery. In their article, the authors cut this factor by 20% for 5 periods to make the fish stock grow, after which they remove the cap so that the fishing capital can return to its original level. In this paper, since we are starting from a stable steady state, once a temporary restriction is lifted we will always return to the steady state. Therefore we will be imposing a permanent 20% cut in fishing capital. The second policy that we will analyze is a tax per catch, which is a tax paid for each unit of fish sold. In the original version of this paper we also looked at a third policy, the total allowable catch. Modeling this policy proved to be more complex than expected, and mistakes were found in our model. This policy test was therefore removed from this paper, but a discussion of the policy and its difficulties is given in section 5.3. Finally we will briefly discuss other possible policies with the addition of their strengths and weaknesses.

We will be performing these tests using both growth models as described earlier by equations (8) and (11). Since we can compare our results of the capital restriction test with the results of the original authors, we will use them as a target harvest rate for our tests. This is, instead of targeting the optimal harvest rate (the one a firm would target if they were the sole owner of the fishery), we will target the harvest rate obtained with the capital restriction test. This is much more plausible than enforcing the optimal harvest, especially since the regulations are poorly enforced in this region (Manning et al. 2018).

5.1 Test 1: capital restriction

In their article, Manning et al. (2018) describe how in Honduras there are restrictions on the fishing gear, but the country's laws state that access to naturals resources (e.g. fish) cannot be restricted. Therefore, to try to limit fishing activity, they look at the effects of a boat restriction. To do so, they cut the fishery's fishing capital use by 20%. As stated above, we will replicate this test, but with the restriction being permanent. This will fix the level of fishing capital and hence its return will be endogenous. This policy hopes to decrease total harvest, increase the fish stock, and increase the household's income. An important remark about this test is that it analyzes the income of the households that live in this small economy, but does not consider the ones who live outside the economy but come to work in it.

We model this experiment by assuming all the equilibrium conditions still hold, but we replace the fishery's fishing capital demand by fixing it at 80% of its original amount. So we replace $pva_2\, \Phi(z, x)\, \frac{\partial F}{\partial K_F} = w_{K_F}$ by $\bar{K} = 0.8K_F$. In the baseline case at equilibrium, we have $K_F = 65.89$ and so with the 20% restriction we then have $\bar{K_F} = 52.71$. The

[10]The GAMS code for the first test can be found in the appendix. The files for the other tests can be supplied upon request. Our work was mainly inspired by exercises from Filipski and Taylor (2014) and lecture notes from Dr. Yazid Dissou (2019).

Table 1: Impact of 20% fishing capital reduction in the fishery (Logistic growth)

	(1)	(2)	(3)	(4)	(5)
	Baseline	First period of restriction	After 5 periods	After 20 periods	total percentage change
Fishery factor employment					
Family labor	35.75	32.54	32.91	32.99	- 7.72%
Low-skilled labor	21.28	19.29	19.52	19.56	- 8.08%
Fishing capital	65.89	52.71	52.71	52.71	- 20%
Fish stock	1383.15	1383.15	1413.27	1419.15	+ 2.6%
Harvest	138.32	125.36	126.85	127.14	- 8.08%
Wages					
Family labor	1	0.996	0.996	0.996	- 0.4%
Fishing capital (tourism)	1	0.17	0.17	0.17	- 83%
Fishing capital (fishery)	1	1.13	1.15	1.15	+ 15%
Income	425.03	423.11	423.83	423.97	- 0.25%

only other sector using fishing capital is the tourism sector. Therefore, all the fishing capital (which we assume to be boats) forced out of the fishery will be used for tourism purposes. The effects of this capital cap can be seen in Table 1, where we indicate the baseline economy in column 1. Column 2 presents the economy with the cap in place. Column 3 shows the state of the economy after 5 periods, where it is converging towards a new equilibrium. Column 4 presents the economy after 20 periods, which our tests carried out in GAMS show that the economy is now at the new equilibrium. Then column 5 indicates the percentage change of each variable from the baseline case to the new equilibrium after the 20 periods.

We first investigate the impacts of this policy on the economy, using the logistic growth function (8) for the fish stock. Recall with this model, the fish population at the equilibrium is at 1383.15 units, which represents 80% of the carrying capacity of 1728.95.

Column 2 shows that after the capital reduction is enforced, this immediately drops the total harvest and the use of the other two factors. This reduction in production caused by the forced reduction of capital can explain the reduction of labor. If labor usage was to remain to its original level, its average return would be too low compared to the wage (average cost) and so the fishery would be operating with negative rents. Family labor wage is therefore almost not affected, while low-skilled labor isn't affected at all since it is exogenous. We see that the fishing capital wage for the tourism sector has had a significant drop of 83%. This is explained by the significant drop of marginal returns of fishing capital in the tourism caused by all the extra boats (fishing capital) forced into this industry. The tourism sector was only using 1.22 units of boats in the base case, and is now using 14.4 units, which is a 1080% increase. Furthermore, not only was tourism not using a lot of boats, it is also not a fishing capital intensive industry. In fact, only 16% of its expenditures on inputs are spent on this factor. The combination of these two results explains the drastic decrease in marginal returns. Then, since the wage is determined in order to match the marginal return, it is in turn drastically decreased.

The wage for fishing capital in the fishery increases to 1.13. Similarly to the tourism sector, this is a result of the increase in marginal return of fishing capital in the fishery. The fishery has decreasing marginal returns in its factors. Therefore a reduction in boats will increase their marginal return.

In this column, we also see that household income has decreased, which is explained in part by the reduction in harvest.

Now that the policy is in place, we can see the evolution of the economy in columns 3 and 4. We notice a steady increase in both labors and in harvest. This is consistent with what we expect to see in practice. Since the number of boats is limited but the fish stock has increased, fishermen will put more workers on each boat. This increases the boat's productivity, and so will increase their equilibrium wage. This is verified by our test, as we see the wage paid to fishing capital (in the fishery) increases over time.

With the lower harvest after the restriction, we see that throughout the periods the fish population constantly increases towards a new steady state. After 20 periods is roughly stable at 1419.15, which represents 82% of the carrying capacity. While this is not a big increase, it is one nonetheless. This steady increase in fish stock leads to an increasing harvest, since the latter is a function of the former. We see in Table 1 that harvest did in fact go from 125.36 in the first period of the cap, to a new equilibrium of 127.14 after 20 periods.

In all, this policy leads to lower harvest (-8.08%), higher fish stock (+2.6%), slightly lower total income (-0.25%) and has mixed consequences on the factor wages. Overall, this policy is an ecological improvement, but at the cost of some social welfare (household income).

Furthermore, it creates large inequalities in the community. Owners of fishing capital used for tourism will be heavily harmed by this policy, while owners of boats used for fishing will be better off. So this policy can be extremely detrimental to some households.

We then tested the same policy, but with the Fletcher growth function (equation (11)) instead of the logistic growth function. Recall that in this model, the fish population at the equilibrium is at 815.79, which represents 47.18% of the carrying capacity of 1728.95. The results of this test are shown in Table 2. An interesting difference with this test is that the values of the model took 50 periods to converge[11], compared to the 20 periods for the logistic growth.

For this test, the overall qualitative results are the same, with one important exception. In the end, income has increased! Similarly to the first model, it initially drops, as all the inputs and harvest levels decrease. It then steadily increases as the boats marginal productivity increases. This is also reflected in the increasing fishing capital (fishery) wage, which reaches a higher level of 1.21, compared to 1.15. But then, unlike the first model, the income converges to a higher value. In fact, after 50 periods, the income has increased to 427.07. These results can be explained by the larger (proportional) increase of the fish population. Since the fish stock has grown more than in the first test, fishing becomes more profitable and so the factors can be used in larger quantities, and more effectively.

[11] We say that the model converges when all of its variables differ by less than 0.01 in two consecutive periods.

Table 2: Impact of 20% fishing capital reduction in the fishery (Fletcher growth)

	(1)	(2)	(3)	(4)	(5)	(5)
	Baseline	First period of restriction	After 5 periods	After 20 periods	After 50 periods	total percentage change
Fishery factor employment						
Family labor	35.75	32.55	33.44	34.35	34.56	- 3.33%
Low-skilled labor	21.28	19.29	19.84	20.47	20.54	- 3.48%
Fishing capital	65.89	52.71	52.71	52.71	52.71	- 20%
Fish stock	815.79	815.79	858.85	908.96	914.68	+ 12.12%
Harvest	138.32	125.38	128.97	133.04	133.50	- 3.48%
Wages						
Family labor	1	0.996	0.997	0.998	0.998	- 0.2%
Fishing capital (tourism)	1	0.17	0.17	0.17	0.17	- 83%
Fishing capital (fishery)	1	1.13	1.17	1.20	1.21	+ 21%
Income	425.03	423.12	424.86	426.85	427.07	+ 0.48%

Similarly to the first test, harvest and labor levels have decreased in total. But as we can see in Table 2, these decreases were less important in this test.

An interesting difference between the two tests is the proportional increase in fish population. In this experiment, it goes up by 12.12% compared to a 2.6% in the first one. In fact, the fish stock increases to a new equilibrium at 914.68 units, which represents 52.90% of the carrying capacity.

In all, with the Fletcher growth model, the capital restriction leads to an increase in fish stock, a lower harvest, and a higher total income. This is both an ecological and a social welfare improvement. Therefore, this policy is much more beneficial to the community if the fish growth is represented by the Fletcher equation. Furthermore, with this model, the fish stock increase is much more important.

5.2 Test 2: Tax per catch

The second management policy we test is a tax per catch. This is a tax paid by the fishermen on each unit of fish he harvests. Although one might think that it would be more appropriate to enforce a tax on inputs, it is much harder to accomplish. “A tax on fishing effort would require separate optimal taxes on all factors or production constituting fishing effort, so as not to distort the choice of a cost-minimizing technology.” (Hannesson, 1978, p.91).

The author then states that this does not imply that a tax per catch is a simple solution. In fact “... in the cases where a fishery exploits more than one stock of fish it would be necessary to vary the tax according to which stock was being exploited.” (Hannesson, 1978, p.91). Although the fishermen in our Honduran artisanal fishery harvest more than one type of fish, our model assumes only one type, so we do not encounter this problem.

A tax per catch will lower the average return curve, and so will reduce the equilibrium harvest. We assume in our model that this tax is collected by the government, and then

Table 3: Impact of 0.1968 tax per catch on the fishery (Logistic growth)

	(1) Baseline	(2) First period of restriction	(3) After 5 periods	(4) After 20 periods	(5) total percentage change
Fishery factor employment					
Family labor	35.75	25.52	25.82	25.88	- 27.61%
Low-skilled labor	21.28	15.01	15.20	15.23	- 28.43%
Fishing capital	65.89	65.15	65.18	65.18	- 1.08%
Fish stock	1383.15	1383.15	1413.32	1419.16	+ 2.60%
Harvest	138.32	125.32	126.84	127.14	- 8.08%
Wages					
Family labor	1	0.988	0.988	0.988	- 1.2%
Fishing capital	1	0.713	0.722	0.723	- 27.7%
Income	425.03	405.86	406.41	406.52	- 4.35%
Tax per catch income		24.66	24.96	25.02	n.a.

redistributed in the economy. To model this tax, we assume all the prior equilibrium conditions hold, but now a tax is removed from the income received from selling one unit of fish. This translates into a reduction of the valud-added price. So for our test we replace the value of pva_2 by $pva_2 - (tax\ per\ catch)$. We set the tax per catch to a level which results in an equilibrium harvest equal to the harvest obtained in the first test.

In short, for the logistic growth model, we implement a 0.1968 Million Lempira tax per unit of catch to reduce harvest to 127.14[12]. For the Fletcher growth model we set a tax per unit of catch of 0.1985 Million Lempira to reduce harvest to 133.5. The results of this experiment for the logistic model are shown in Table 3, and in Table 4 for the Fletcher model.

We again obtain the same harvest and fish stock, by construction. We also see a decrease in all inputs, just as in the previous test. But we notice in both Table 3 and 4, that the decrease in labor is much more significant than for the other policy.

If we compare the input decrease in this test compared to those of Test 1, we see that in this case it was done more efficiently. By this we mean that in this test we decreased harvest without forcing specifically capital to decrease. This lets the economy's inputs adjusts themselves naturally within the economy, to their most efficient levels possible.

So if the inputs are allocated more efficiently in this test than in Test 1, one might ask themselves why the decrease in income is much larger in this test. For the logistic model, after 20 periods income decreased to 405.25, while it only decreased to 423.97 for the capital restriction. This is because the value of the income does not tell the whole story. We cannot forget about the tax per catch. In table 5 we see that the tax per catch amounted to 25.02 Million Lempira. In our model, we assumed that the government redistributes this money in the economy with the same proportions as before. But if we imagine a scenario where it uses all this money for subsidies for the households, this money essentially acts as household income. If we add the tax income to the household

[12]Recall that the unit of catch is adjusted so that the price remains 1. Furthermore, since the price is equal to 1, a 0.1968 tax per catch is equivalent to a 19.68% ad valorem tax

Table 4: Impact of 0.1985 tax per catch on the fishery (Fletcher growth)

	(1) Baseline	(2) First period of restriction	(3) After 5 periods	(4) After 20 periods	(5) After 50 periods	(6) total percentage change
Fishery factor employment						
Family labor	35.75	25.44	26.17	26,99	27.08	- 24.25%
Low-skilled labor	21.28	14.96	15.41	15.90	15.95	- 25.05%
Fishing capital	65.89	65.14	65.21	65.29	65.30	- 0.90 %
Fish stock	815.79	815.79	859.28	909.15	914.64	+ 12.12%
Harvest	138.32	125.21	128.91	133.05	133.50	- 3.48%
Wages						
Family labor	1	0.988	0.989	0.989	0.990	- 1%
Fishing capital	1	0.711	0.731	0.754	0.756	- 24.4 %
Income	425.03	405.71	407.04	408.54	408.70	- 3.84%
tax per catch income		24.85	25.59	26.41	26.50	n.a.

income, we get 430.27, which is both larger than 423.97 but also larger than the baseline income of 425.03.

Therefore this policy has the potential of increasing social welfare, depending on what is done with the revenue generated from the tax per catch. Although if completely spent on subsidies, the tax will increase welfare, it is hard to imagine that it would be spent this way in practice. However, if it is spent on research and development (either for the fishing industry or for other purposes), a short term decrease in income might be worthwhile for the long run economic prowess of the economy.

5.3 Test 3: Total allowable catch

As mentioned earlier, we initially tested a third management policy, the total allowable catch (TAC). This policy enforces an upper bound on harvest. Once this bound is reached, all fishing activities are prohibited for the rest of the period. Although this policy is appealing at first glance, in practice it usually leads to some problems. As argued by various authors (Conrad 2010, Hart and Reynolds 2002), a TAC leads to a *race for the fish*. Since the total harvest is limited, every fisherman races to earn his part of it before the bound is reached. To do so, they usually use excessive amount of inputs or fish for long hours during the opening period of the fishing season. The expected results of such behavior is well described by Jon M. Conrad (2010, p. 90):

> One might predict that the fishing season would become compressed over time and that a large amount of fish would be landed during progressively shorter seasons. This, in turn, would lead to falling dockside prices because fish has to be frozen. The fisher would lose the price premium normally associated with the marketing of fresh (not previously frozen) fish. It also might be the case that in their race for the fish, fishers would take ill-advised risks (overloading a boat in heavy seas) that could result in capsizing and loss of human life.

Since we do not have data about this scenario, it is impossible to distinguish which inputs are inefficiently used under the TAC policy. We therefore had to make certain assumptions, but with no reference point. This led to erroneous results, and so we decided to remove our analysis of the TAC management policy.

5.4 Other policies

The three management policies presented above are not the only ones possible, and are not necessarily the best. One policy, which is often considered an improvement to the total allowable catch (Clark 2006, Conrad 2010, Hart and Reynolds 2002), is the individual transferable quotas (ITQs). This policy gives fishing quotas to all the fishermen, that add up to the TAC. Each owner of a quota can either use or sell it, or even buy the quotas of other fishermen. The fishers with high efficiency will have an incentive to buy the quotas from those who are less efficient. "Under ideal circumstances the fishery will tend to be exploited in an economically optimal manner." (Clark, 2006, p.22).

Other management policies (Clark 2006, Conrad 2010, Hart and Reynolds 2002) that could potentially be used are:

- *Tax on effort.* As briefly discussed in section 5.2, a tax on effort could be an alternative to the tax per catch. Fishermen could pay a tax per boat, per fishing equipment, etc.

- *Effort control.* Instead of a limit on the total allowable catch, a limit on effort could be enforced. This could be certain gear restrictions such as the size of fishing nets or the size of boats. It could also be a limit on the number of boats or fishers allowed on the fishing grounds.

- *Size limits.* Size limit refers to a minimum size of fish allowed to be sold. This policy hopes to protect the young fish, so that they can reach sexual maturity and contribute to the growth of the fish population.

- *Closed seasons.* This is a determined period(s) of the year where fishing is allowed. During the rest of the year it is prohibited, so that the fish population can restore itself. Interestingly, as stated by Manning et al., there is no regulated season length in Honduras.

6 Conclusion

The initial goal of this paper was to model the Honduran fishing village with the Congar and Hotte open access model, incorporate it in a GE framework, and carry out a comparative analysis of our work to the one of Manning, Taylor and Wilen. However, since we had to modify the steady state fish stock (or the growth function entirely), a direct comparison with our model is not an appropriate representation of their differences. We nevertheless conducted experiments with various fishery management policies and obtained new results.

The tests done in this study showed that the policies are successful in increasing the fish population, and decreasing fishing activity. We also saw that with the Flectcher growth model, the increase in steady state fish stock, following a fishing restriction, was much more pronounced than with the logistic growth model.

We saw that the capital restriction policy was detrimental to the total income with the logistic growth, but beneficial with the Fletcher growth. This test also resulted in major wage inequalities, since it forced an excessive amount of boats into the tourism industry.

In contrast, the tax per catch policy was revealed to be potentially the best policy. It had the same ecological benefits, but had better overall economic results. With the extra income generated by the tax, the total income actually increased. If this tax income is redistributed to the households, their welfare could be higher than in the baseline. It could also be spent on technological advancement, in hopes of increasing the whole economy's productivity. A drawback of the last point is that the poor households may not be able to withstand this decrease in income. But maybe a balance could be found between household subsidies and R&D to have better long term economic situation, without destroying the short term economy. Furthermore, this policy also creates inequality in wages.

It is important to note that all our experiments are theoretical, and they assumed perfectly rigorous enforcement of the policies. In practice, it is essentially impossible to have perfect enforcement, as there will always be people who will not respect the policies. Also, the values used for the SAM are imperfect, as the original authors reported having data shortages in their study.

Overall, the benefits of the policies tested in this paper seem to overshadow their drawbacks. The changes in equilibrium fish stock and harvest were much more substantial than the changes in (total) income. However, they create inequalities in wages, which in some cases might not be sustainable by the poor households. Therefore these tests suggest that a fishery management policy is a good way to improve the overexploitation of the open access resource (fish), but at the cost of some individual welfare. Interesting future investigations could be to test less drastic policies, who then become more significant overtime. Furthermore, a cost analysis of the enforcement of these policies would be interesting, as some of them are much harder to implement and/or enforce than others.

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Appendix

Table 7: Social accounting matrix (SAM) of the Honduran artisanal fishing village.

	Agriculture	Fishing	Fish resale	Retail	Services	Production	Tourism	Gov	Households	Family labor	Low-skilled labor	High-skilled labor	Fishing capital	Land	Physical capital	External trade	Total
Agriculture	3.38			6.57		1.65			1.91							14.81	28.32
Fishing			1.53			2.06			2.62							132.1	138.31
Fish resale									6.92							6.36	13.28
Retail		15.4		1.01		0.34			67.6								84.35
Services	0.16					0.01			3.61							4.59	8.37
Production						0.02			10.38							46.78	57.18
Tourism																7.68	7.68
Gov									12.34								12.34
Households								0.22		77.42	40.21	37.89	67.12	2.45	22.36	177.39	425.06
Family labor	11.68	35.75	0.26	12.51	2.48	14.73											77.41
Low-skilled labor	2.42	21.28		1.15	0.01	5.39										9.97	40.22
High-skilled labor							3.49	0.17								34.23	37.89
Fishing capital		65.89					1.22										67.11
Land	2.45																2.45
Physical capital			3.85	13.8	1.35	0.38	2.97										22.35
External trade	8.23		7.63	49.31	4.53	32.59		11.95	319.66								433.9
Total	28.32	138.32	13.27	84.35	8.37	57.17	7.68	12.34	425.04	77.42	40.21	37.89	67.12	2.45	22.36	433.91	1456.22

```
$TITLE Logistic capital restriction test
*by: Frédéric Pouliot
*
*
*test: 20% restriction in fishing capital in FISHING
*using LOGISTIC growth, but at stable equilibirum

SET  i /         AGRI            agriculture
                 FISH            fishing (OPEN ACCESS)
                 FISHSALE        fish resale
                 RET             retail
                 SERV            services
                 PRD             production
                 TOUR            tourism
                 GOV             government
                 HOUSEH          households
                 FAMLAB          family labor
                 LSLAB           low-skilled labor
                 HSLAB           high-skilled labor
                 FISHCAP         fishing capital
                 LAND            land
                 FISHPOP         fish population
                 PHYSCAP         physical capital
                 EXTRADE         external trade
        /
ALIAS (i,j)

PARAMETERS
sam(i,j)

T1       agriculture
a1
b1
e1

T2       fish
a2
b2
d2

T3       fish sale
a3
g3

T4       retail
a4
b4
g4

T5       services
a5
b5
g5

T6       production
a6
b6
g6

T7       tourism
c7
d7
g7
```

```
Kf       factor totals
Lf
Lls
Lhs
LAND
Kp3
Kp4
Kp5
Kp6
Kp7

wLS      exogenous wages & prices
wHS
p1
p2
p3
p4
p5
p6
p7

alpha1   consumer utility shares
alpha2
alpha3
alpha4
alpha5
alpha6
alpha8

RET      Remittance
GTR      Government transfers to households

t        tax rate

io(i,j)          input-output (leontieff) coefficients
coltot(i)        sam column total

x                fish population

REPORT_TABLE_SECTOR(*,*) for report output

;


*calling SAM*
$CALL GDXXRW  sam_nofishpop.xlsx  trace=17  par=sam rng=Sheet1!b3  rdim=1 cdim=1
$GDXIN sam_nofishpop.gdx
$LOAD sam
$GDXIN
;

DISPLAY sam;



*##### PARAMETER INITIALIZATION #####*

a1 = 11.68/(28.32-3.38-0.16-8.23);
b1 = 2.42/(28.32-3.38-0.16-8.23);
e1 = 2.45/(28.32-3.38-0.16-8.23);
T1 = 28.32/((11.68**a1)*(2.42**b1)*(2.45**e1));
```

```
a2 = 21.45/(138.32-15.4);
b2 = 12.77/(138.32-15.4);
d2 = 39.53/(138.32-15.4);
T2 = 138.32/((35.75**a2)*(21.28**b2)*(65.89**d2)*(1383.15**0.4));

a3 = 0.26/(13.28-1.53-7.63);
g3 = 3.85/(13.28-1.53-7.63);
T3 = 13.28/((0.26**a3)*(3.85**g3));

a4 = 12.51/(84.35-6.57-1.01-49.31);
b4 = 1.15/(84.34-6.57-1.01-49.31);
g4 = 13.8/(84.34-6.57-1.01-49.31);
T4 = 84.34/((12.51**a4)*(1.15**b4)*(13.8**g4));

a5 = 2.48/(8.37-4.53);
b5 = 0.01/(8.37-4.53);
g5 = 1.35/(8.37-4.53);
T5 = 8.37/((2.48**a5)*(0.01**b5)*(1.35**g5));

a6 = 14.73/(57.17-1.65-2.06-0.34-0.01-0.02-32.59);
b6 = 5.39/(57.17-1.65-2.06-0.34-0.01-0.02-32.59);
g6 = 0.38/(57.17-1.65-2.06-0.34-0.01-0.02-32.59);
T6 = 57.17/((14.73**a6)*(5.39**b6)*(0.38**g6));

c7 = 3.49/7.68;
d7 = 1.22/7.68;
g7 = 2.97/7.68;
T7 = 7.68/((3.49**c7)*(1.22**d7)*(2.97**g7));

display t1,t2,t3,t4,t5,t6,t7;

Kf = 67.11;
Lf = 77.41;
LAND = 2.45;
Lls = 40.21;
Lhs = 37.89;
Kp3 = 3.85;
Kp4 = 13.8;
Kp5 = 1.35;
Kp6 = 0.38;
Kp7 = 2.97;

wLS = 1.0; wHS = 1.0;

p1 = 1.0; p2 = 1.0; p3 = 1.0; p4 = 1.0;
p5 = 1.0; p6 = 1.0; p7 = 1.0;

alpha1 = 1.91/(425.04-12.34);
alpha2 = 2.62/(425.04-12.34);
alpha3 = 6.92/(425.04-12.34);
alpha4 = 67.6/(425.04-12.34);
alpha5 = 3.61/(425.04-12.34);
alpha6 = 10.38/(425.04-12.34);
alpha8 = 319.66/(425.04-12.34);

RET = 177.39;
GTR = 0.22;

t = 12.34/425.04;

coltot(j)                  =sum(i, SAM(i,j)) ;
io(i,j)$coltot(j)          =SAM(i,j)/coltot(j) ;
```

```
x = 1383.15
;


VARIABLES

Lf1      AGRI factor demands
Lls1
land1

Lf2      FISH factor demands
Lls2
Kf2

Lf3      FISHSALE factor demands

Lf4      RET factor demands
Lls4

Lf5      SERV factor demands
Lls5

Lf6      PRD factor demands
Lls6

Lhs7     TOUR factor demands
Kf7

wF       wage FAMILY LABOR
wKf      wage FISHING CAPITAL
wT       wage LAND
wKp3     wage PHYSICAL CAPITAL (FISHSALE)
wKp4     wage PHYSICAL CAPITAL (RET)
wKp5     wage PHYSICAL CAPITAL (SERV)
wKp6     wage PHYSICAL CAPITAL (PRD)
wKp7     wage PHYSICAL CAPITAL (TOUR)

PVA1     price value-added
PVA2
PVA3
PVA4
PVA5
PVA6
PVA7

Lls8     low-skilled labor demand (by EXTRADE)
Lhs8     high-skilled labor demand (by EXTRADE)

Q1       output totals
Q2
Q3
Q4
Q5
Q6
Q7

Y        total income
YD       disposable income

CD1      consumption demands
CD2
```

```
CD3
CD4
CD5
CD6
CD8


GD8      Gov demand of imported goods
LhsG     high-skilled labor demand (by GOV)

EX1      exports of sectors
EX2
EX3
EX5
EX6
EX7

bogus    bogus variable to solve model
;



*##### VARIABLE INITIALIZATION #####*

bogus.L = 10;

Lf1.L = 11.68; Lls1.L = 2.42;   land1.L = 2.45;
Lf2.L = 35.75; Lls2.L = 21.28; Kf2.L = 65.89;
Lf3.L = 0.26;
Lf4.L = 12.51; Lls4.L = 1.15;
Lf5.L = 2.48;  Lls5.L = 0.01;
Lf6.L = 14.73; Lls6.L = 5.39;
Lhs7.L = 3.49; Kf7.L = 1.22;

display lf1.l, lf2.l;

wF.L = 1.0;
wKf.L = 1.0;
wT.L = 1.0;
wKp3.L = 1.0;
wKp4.L = 1.0;
wKp5.L = 1.0;
wKp6.L = 1.0;
wKp7.L = 1.0;

PVA1.L = p1 - io("AGRI","AGRI")*p1 - io("SERV","AGRI")*p5
         - io("EXTRADE","AGRI") ;
PVA2.L = p2 - io("RET","FISH")*p4 ;
PVA3.L = p3 - io("FISH","FISHSALE")*p2 - io("EXTRADE","FISHSALE") ;
PVA4.L = p4 - io("AGRI","RET")*p1 - io("RET","RET")*p4 - io("EXTRADE","RET") ;
PVA5.L = p5 -io("EXTRADE","SERV");
PVA6.L = p6 - io("AGRI","PRD")*p1 - io("FISH","PRD")*p2 - io("RET","PRD")*p4
            - io("SERV","PRD")*p5 - io("PRD","PRD")*p6 - io("EXTRADE","PRD");
PVA7.L = p7 ;

Y.L = wF.L*Lf + wLS*Lls + wHS*Lhs + wKF.L*Kf + wT.L*LAND + wKp3.L*Kp3
      + wKp4.L*Kp4 + wKp5.L*Kp5 + wKp6.L*Kp6 + wKp7.L*Kp7 + RET + GTR ;

YD.L = (1-t)*Y.L ;

CD1.L = alpha1*YD.L/p1 ;
CD2.L = alpha2*YD.L/p2 ;
CD3.L = alpha3*YD.L/p3 ;
```

```
CD4.L = alpha4*YD.L/p4 ;
CD5.L = alpha5*YD.L/p5 ;
CD6.L = alpha6*YD.L/p6 ;
CD8.L = alpha8*YD.L ;

display Y.l, YD.L, CD4.l;

GD8.L = 11.95 ;
LhsG.L = 0.17 ;

EX1.L = 14.81 ;
EX2.L = 132.10 ;
EX3.L = 6.36 ;
EX5.L = 4.59 ;
EX6.L = 46.78 ;
EX7.L = 7.68 ;

Lls8.L = 9.97 ;
Lhs8.L = 34.23 ;

Q1.L = T1*(Lf1.L**a1)*(Lls1.L**b1)*(land1.L**e1) ;
Q2.L = T2*(Lf2.L**a2)*(Lls2.L**b2)*(Kf2.L**d2)*(x**0.4) ;
Q3.L = T3*(Lf3.L**a3)*(Kp3**g3) ;
Q4.L = T4*(Lf4.L**a4)*(Lls4.L**b4)*(Kp4**g4) ;
Q5.L = T5*(Lf5.L**a5)*(Lls5.L**b5)*(Kp5**g5) ;
Q6.L = T6*(Lf6.L**a6)*(Lls6.L**b6)*(Kp6**g6) ;
Q7.L = T7*(Lhs7.L**c7)*(Kf7.L**d7)*(Kp7**g7) ;

Display Q1.L, Q2.L, Q3.L, Q4.L, Q5.L, Q6.L, Q7.L ;



EQUATIONS
*#################### EQUATION DECLARATION #########################
QQ1      production 1
QQ2      production 2
QQ3      production 3
QQ4      production 4
QQ5      production 5
QQ6      production 6
QQ7      production 7

factorLF         Factor market clearing conditions
factorLLS
factorLHS
factorKF
factorLAND

FD1LF            Factor demands
FD1LLS
FD1LAND
FD2LF
FD2LLS
FD2KF            Fishery fishing capital demand
FD2KFr           Fishery fishing capital demand (with restriction)

FD3LF
FD3KP
FD4LF
FD4LLS
FD4KP
FD5LF
```

```
FD5LLS
FD5KP
FD6LF
FD6LLS
FD6KP
FD7LHS
FD7KF
FD7KP

PPVA1    Price value-added
PPVA2
PPVA3
PPVA4
PPVA5
PPVA6
PPVA7

EQUIL1   Supply and demand equilibriums (per sector)
EQUIL2
EQUIL3
EQUIL4
EQUIL5
EQUIL6
EQUIL7

RHHincome        HH income (after restriction)
HHincome         HH income
HHdisp           HH disposable income

*HHbalance

CCD1             Consumption demands
CCD2
CCD3
*CCD4
CCD5
CCD6
CCD8

GOVbalance       Gov income
*govb1
govb2            Gov expenditure proportions

BBOGUS           bogus equation
;

*######################## EQUATION ASSIGNMENT  ######################
QQ1..    Q1 =E= T1*(Lf1**a1)*(Lls1**b1)*(land1**e1) ;
QQ2..    Q2 =E= T2*(Lf2**a2)*(Lls2**b2)*(Kf2**d2)*(x**0.4) ;
QQ3..    Q3 =E= T3*(Lf3**a3)*(Kp3**g3) ;
QQ4..    Q4 =E= T4*(Lf4**a4)*(Lls4**b4)*(Kp4**g4) ;
QQ5..    Q5 =E= T5*(Lf5**a5)*(Lls5**b5)*(Kp5**g5) ;
QQ6..    Q6 =E= T6*(Lf6**a6)*(Lls6**b6)*(Kp6**g6) ;
QQ7..    Q7 =E= T7*(Lhs7**c7)*(Kf7**d7)*(Kp7**g7) ;

factorLF..       Lf1 + Lf2 + Lf3 + Lf4 + Lf5 + Lf6  =E= Lf ;
factorLLS..      Lls =E= Lls1 + Lls2 + Lls4 + Lls5 + Lls6 + Lls8 ;
factorLHS..      Lhs =E= Lhs7 + Lhsg + Lhs8 ;
factorKF..       Kf =E= Kf2 + Kf7 ;
factorLAND..     LAND =E= land1 ;

FD1LF..          a1*PVA1*Q1 =E= Lf1*wF ;
FD1LLS..         b1*PVA1*Q1 =E= Lls1*wLS ;
```

```
FD1LAND..         e1*PVA1*Q1 =E= land1*wT ;

FD2LF..           (a2/0.6)*PVA2*Q2 =E= Lf2*wF ;
FD2LLS..          (b2/0.6)*PVA2*Q2 =E= Lls2*wLS ;
FD2KF..           (d2/0.6)*PVA2*Q2 =E= Kf2*wKf ;
FD2KFr..           Kf2 =E= 52.712 ;

FD3LF..           a3*PVA3*Q3 =E= Lf3*wF ;
FD3KP..           g3*PVA3*Q3 =E= Kp3*wKp3 ;
FD4LF..           a4*PVA4*Q4 =E= Lf4*wF ;
FD4LLS..          b4*PVA4*Q4 =E= Lls4*wLS ;
FD4KP..           g4*PVA4*Q4 =E= Kp4*wKp4 ;
FD5LF..           a5*PVA5*Q5 =E= Lf5*wF ;
FD5LLS..          b5*PVA5*Q5 =E= Lls5*wLS ;
FD5KP..           g5*PVA5*Q5 =E= Kp5*wKp5 ;
FD6LF..           a6*PVA6*Q6 =E= Lf6*wF ;
FD6LLS..          b6*PVA6*Q6 =E= Lls6*wLS ;
FD6KP..           g6*PVA6*Q6 =E= Kp6*wKp6 ;
FD7LHS..          c7*PVA7*Q7 =E= Lhs7*wHS ;
FD7KF..           d7*PVA7*Q7 =E= Kf7*wKf ;
FD7KP..           g7*PVA7*Q7 =E= Kp7*wKp7 ;

PPVA1..           PVA1 =E= p1 - io("AGRI","AGRI")*p1 - io("SERV","AGRI")*p5
                             - io("EXTRADE","AGRI") ;
PPVA2..           PVA2 =E= p2 - io("RET","FISH")*p4 ;
PPVA3..           PVA3 =E= p3 - io("FISH","FISHSALE")*p2
                             - io("EXTRADE","FISHSALE") ;
PPVA4..           PVA4 =E= p4 - io("AGRI","RET")*p1 - io("RET","RET")*p4
                             - io("EXTRADE","RET");
PPVA5..           PVA5 =E= p5 - io("EXTRADE","SERV");
PPVA6..           PVA6 =E= p6 - io("AGRI","PRD")*p1 - io("FISH","PRD")*p2
                             - io("RET","PRD")*p4 - io("SERV","PRD")*p5
                             - io("PRD","PRD")*p6 - io("EXTRADE","PRD");
PPVA7..           PVA7 =E= p7 ;

EQUIL1..          Q1 =E= CD1 + io("AGRI","AGRI")*Q1 + io("AGRI","RET")*Q4
                         + io("AGRI","PRD")*Q6 +EX1 ;
EQUIL2..          Q2 =E= CD2 + io("FISH","FISHSALE")*Q3 + io("FISH","PRD")*Q6
                         + EX2 ;
EQUIL3..          Q3 =E= CD3 + EX3 ;
EQUIL4..          Q4 =E= CD4 + io("RET","FISH")*Q2 + io("RET","RET")*Q4
                         + io("RET","PRD")*Q6;
EQUIL5..          Q5 =E= CD5 + io("SERV","AGRI")*Q1 + io("SERV","PRD")*Q6 +EX5 ;
EQUIL6..          Q6 =E= CD6 + io("PRD","PRD")*Q6 + EX6 ;
EQUIL7..          Q7 =E= EX7 ;

RHHincome..       Y =E= wF*Lf + wLS*(Lls) + wHS*(Lhs)+ wKf*Kf7
                        + (Q2*PVA2-(Lf2*wf+Lls2)) + wT*LAND + wKp3*Kp3
                        + wKp4*Kp4 + wKp5*Kp5 + wKp6*Kp6 + wKp7*Kp7 + RET + GTR ;
HHincome..        Y =E= wF*Lf + wLS*(Lls) + wHS*(Lhs)+ wKF*Kf + wT*LAND
                        + wKp3*Kp3 + wKp4*Kp4 + wKp5*Kp5 + wKp6*Kp6 + wKp7*Kp7
                        + RET + GTR ;
HHdisp..          YD =E= (1-t)*Y ;

CCD1..            CD1 =E= alpha1*YD/p1 ;
CCD2..            CD2 =E= alpha2*YD/p2 ;
CCD3..            CD3 =E= alpha3*YD/p3 ;
*CCD4..            CD4 =E= alpha4*YD/p4 ;
CCD5..            CD5 =E= alpha5*YD/p5 ;
CCD6..            CD6 =E= alpha6*YD/p6 ;
CCD8..            CD8 =E= alpha8*YD ;

GOVbalance..      Y*t =E= GTR + LhsG + GD8;
```

```
*govb1..          GD8 =E= (11.95/(12.34-GTR))*((t*Y)-GTR) ;
govb2..          LhsG =E= (0.17/(12.34-GTR))*((t*Y)-GTR) ;

BBOGUS..         bogus =E= 10;


*##### RESTRICTIONS #####*
Lf1.LO = 0.0001;   Lf1.UP = INF;
Lls1.LO = 0.0001;  Lls1.UP =INF;
land1.LO = 0.0001; land1.UP = INF;
Lf2.LO = 0.0001;   Lf2.UP = INF;
Lls2.LO = 0.0001;  Lls2.UP = INF;
Kf2.LO = 0.0001;   Kf2.UP = INF;
Lf3.LO = 0.0001;   Lf3.UP = INF;
Lf4.LO = 0.0001;   Lf4.UP = INF;
Lls4.LO = 0.0001;  Lls4.UP = INF;
Lf5.LO = 0.0001;   Lf5.UP = INF;
Lls5.LO = 0.0001;  Lls5.UP = INF;
Lf6.LO = 0.0001;   Lf6.UP = INF;
Lls6.LO = 0.0001;  Lls6.UP = INF;
Lhs7.LO = 0.0001;  Lhs7.UP = INF;
Kf7.LO = 0.0001;   Kf7.UP = INF;

LhsG.LO = 0.0001; LhsG.UP = INF;

wF.LO = 0.001;   wF.UP = INF;
wKf.LO = 0.001;  wKf.UP = INF;
wKp3.LO = 0.001; wKp3.UP = INF;
wKp4.LO = 0.001; wKp4.UP = INF;
wKp5.LO = 0.001; wKp5.UP = INF;
wKp6.LO = 0.001; wKp6.UP = INF;
wKp7.LO = 0.001; wKp7.UP = INF;
wT.LO = 0.001;   wT.UP = INF;

GD8.LO = 0.001;



*##### SOLVE #####*
OPTIONS ITERLIM=1000,LIMROW=1,LIMCOL=1 ;

MODEL oa /ALL - FD2KF - HHincome/ ;
MODEL oaNOr /ALL - FD2KFr - RHHincome/ ;

OPTION NLP = CONOPT;
SOLVE oaNOr MAXIMIZING bogus USING NLP;

OPTION DECIMALS=4 ;


display Q1.L, Q2.L, Q3.L, Q4.L, Q5.L, Q6.L, Q7.L ;
display Lf1.L, Lls1.L, land1.L, Lf2.L, Lls2.L, Kf2.L, Lf3.L, Lf4.L, Lls4.L
display Lf5.L, Lls5.L, Lf6.L, Lls6.L, Lhs7.L, Kf7.L ;
display wf.L, wkf.L, wT.L, wkp3.L, wkp4.l, wkp5.l, wkp6.l, wkp7.l;
display pva1.l, pva2.l, pva3.l, pva4.l, pva5.l, pva6.l, pva7.l;
display  lhsg.l, gd8.l ;
display y.l, yd.l ;
display cd1.l, cd2.l, cd3.l, cd4.l, cd5.l, cd6.l, cd8.l;
display ex1.l, ex2.l, ex3.l, ex5.l, ex6.l, ex7.l,lls8.l, lhs8.l;


*#### TEST ####
*We now test the 20% fishing capital restriction.
```

```
*
*This changes the Fishing capital demand function.
*It also changes the HH income function, since fishing capital no longer
*has the same wage in the Fishery and Toursim

SET  v /1*30/

loop(v,

         SOLVE oa MAXIMIZING bogus USING NLP;
         display Kf2.L, Kf7.L, wKf.L, x, Q2.L, Lf2.L, Lls2.L, wF.L;

         REPORT_TABLE_SECTOR(v,"family labor") = Lf2.L;
         REPORT_TABLE_SECTOR(v,"hired labor") = Lls2.l;
         REPORT_TABLE_SECTOR(v,"fishing capital") = kf2.L;
         REPORT_TABLE_SECTOR(v,"fish stock") = x;
         REPORT_TABLE_SECTOR(v,"harvest") = Q2.L;
         REPORT_TABLE_SECTOR(v,"Wage family") = wf.l;
         REPORT_TABLE_SECTOR(v,"Wage Fishing capital") = wKf.L;
         REPORT_TABLE_SECTOR(v,"total LS labor") = Lls;
         REPORT_TABLE_SECTOR(v,"agri LS labor") = Lls1.l;
         REPORT_TABLE_SECTOR(v,"retail LS labor") = Lls4.l;
         REPORT_TABLE_SECTOR(v,"serv LS labor") = Lls5.l;
         REPORT_TABLE_SECTOR(v,"prod LS labor") = Lls6.l;
         REPORT_TABLE_SECTOR(v,"exog LS labor") = Lls8.l;
         REPORT_TABLE_SECTOR(v,"income") = Y.l;
         REPORT_TABLE_SECTOR(v,"yd") = YD.l;
         REPORT_TABLE_SECTOR(v,"tour Kf") = Kf7.l;
         REPORT_TABLE_SECTOR(v,"Q7") = Q7.l;
         REPORT_TABLE_SECTOR(v,"GD8") = GD8.l;
         REPORT_TABLE_SECTOR(v,"Q1") = Q1.l;
         REPORT_TABLE_SECTOR(v,"Q2") = Q2.l;
         REPORT_TABLE_SECTOR(v,"Q3") = Q3.l;
         REPORT_TABLE_SECTOR(v,"Q4") = Q4.l;
         REPORT_TABLE_SECTOR(v,"Q5") = Q5.l;
         REPORT_TABLE_SECTOR(v,"Q6") = Q6.l;


         x = x + 0.5*x*(1-(x/1728.95)) - Q2.L;

);


EXECUTE_UNLOAD "TESTnofix.GDX", REPORT_TABLE_SECTOR ;
Execute 'GDXXRW.EXE TESTnofix.GDX O=TESTnofix.XLS
PAR=REPORT_TABLE_SECTOR rng=REPORT_TABLE_SECTOR!B2';


$EXIT
```