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ABSTRACT

This paper analyzes the impact of reducing a subsidy on fuel in a general equilibrium model for a fishery with heterogeneous fishing plants (vessels). It considers the impact of the stock effect, which determines the participation of fishing plants in a likely increased stock abundance. In equilibrium, the productivity of the fleet is endogenous as it depends on the stock of fish along the equilibrium path. The model concludes that any impact of a fuel subsidy drop will depend on the stock effect. If that effect is large, fishing firms will benefit from the stock recovery and the elimination of the subsidy will increase future returns on investment. The model is particularized to industrial shrimp fisheries in Mexico. It is shown that the complete elimination of a subsidy increases biomass, capitalization, marginal productivity, and consumption and reduces inequality when the effect of the induced increase in the stock is considered. However, if that effect is not considered capital and consumption decrease, and inequality increases, increasing the social costs of a fuel subsidy drop.

Keywords: Subsidies, General equilibrium model, Fisheries, Social Costs

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1 Introduction

Subsidies in the fishing industry involve important resources and have implications on capitalization and on the effort of fleets. For example, Sumaila et al. (1) show that total subsidies on fisheries were about 35 billion dollars in 2009. This is close to the earlier estimate for 2003 subsidies after adjustment for inflation (2). According to this analysis, fuel subsidies accounted for 22% of total subsidies in fisheries. They also conclude that subsidies provided by developed countries are greater (65% of the total) than those by developing countries (35% of the total) and that Asia is the greatest subsidizing region (43% of the total), followed by Europe (25% of the total) and North America (16% of the total). Japan provides the highest amount of subsidies (19.7% of the total), followed by the United States and China at 19.6% of the total. In the European Union (EU) total subsidies to the fishing sector are equivalent to 50% of the value of the total fish catch that year (EUR 6.6 billion) and fuel subsidies amount to half of all EU fishery subsidies. In the EU fuel subsidies take the form of tax exemptions on fuel used for fishing.

Subsidies on fisheries have been discussed in recent meetings of the World Trade Organization (WTO). They are seen as a threat to the sustainability of many of the world's fisheries (3). In these discussions the social consequences of fishery subsidies have been considered as one of the main barriers to their removal. Those consequences are particularly relevant in less developing countries. When analyzing these social consequences the heterogeneity of agents is an important aspect, given that this heterogeneity is the source of inequality.

This paper analyzes the impact of reducing a subsidy on fisheries in a general equilibrium framework, for a fishery with heterogeneous fishing plants (vessels). General equilibrium analysis of fisheries can also be found in studies of multiple uses of the ecosystem (4). General equilibrium models can also explain how inputs are over-allocated to an open access resource and create a general equilibrium tragedy of the commons in artisanal fisheries (5). The model selected extends the one used in Da-Rocha et al. (6) to include fishing firms' investment decisions endogenously. Furthermore, the model is a dynamic version of Angeletos (7), in which there are incomplete markets where fishing firms cannot insure against their future productivity realizations.not insure against their future productivity realizations.

The analysis performed is related to that of Sumaila et al. (8), who provide a theoretical analysis of an exogenous increase in fuel prices in a bioeconomic model. They conclude that an increase in fuel prices (equivalent to a reduction in fuel subsidy) shifts the total cost function upwards, whch means a reduction of effort in the competitive equilibrium where total cost equals total revenue. They also show a similar effect of a subsidy reduction in the single owner maximization problem. Munro and Sumaila (9) also analyze subsidies in fisheries and show that the introduction of cost reduction subsidies has a negative impact on the resource. They conclude that subsidies imply overexploitation even in a well-managed fishery (by a fishery manager or in a fishery in which a fully fledged system of property rights that rules out the commons effect has been introduced). Overall, the literature shows that subsidy elimination has important social costs. In this paper the same result is obtained, although as a particular case in which the stock effect is not considered. However, when fishermen are forward-looking (that is, if the size of future stocks affects today's decisions) results may differ. When the stock effect is significant a reduction in overcapitalization can be compatible with an increase in the marginal productivity of physical capital. This makes returns more similar across fishing plants, so social costs (measured in terms of inequality) are also reduced.

Our results provide insights that should be considered by any central authority managing a fishery; first, in terms of how to provide management advice of future natural capital (fish-stocks) and second on how to manage the physical capital of a fishery (fishing plants or vessels). This gives an important message on the size of the social costs of fuel tax reductions that supplements earlier studies (1; 2; 8; 10). To provide a numerical example, the model is particularised to the o provide a numerical example, the model is particularized to the industrial shrimp fishery in Mexico, which is one of that country's most valuable fisheries (10).

The rest of the paper is organized as follows: Section 2 presents the model. Section 3 presents the general results from a subsidy reform obtained from the model. Section 4 shows a numerical illustration. Section 5 discusses the policy implications and Section 6 concludes.

2 The dynamic general equilibrium model

As mentioned in Section 1, the model used is a continuous time version of Angeletos (7). There is a continuum of households endowed with one unit of labor which holds physical capital, k (i.e. a vessel or fishing plant with capacity k). There is idiosyncratic risk that affects each owner of capital, which reflects what happens in any privately-held business in a risky industry such as fishing. There are two markets in the economy: a market for final goods and a labor market which is required to produce the final good and in which wages are denoted by $w(t)$. Output price is considered as a numeraire. Finally, the government subsidizes production with a (negative) tax rate τ. Each fishing plant's output and profit depend on its production capacity as in Lazkano and Nostbakken (11). Their production function depends on the size of the stock(s), X, physical capital level, k, and use of variable inputs, n. It is assumed that natural (γ) and physical capitals (α) have the same elasticities when $\alpha = \gamma$. This assumption implies that in equilibrium the total harvested is given by a Schaefer type function (12):

$$y = z^{\alpha} k^{\alpha} n^{(1-\alpha)} X^{\gamma} \tag{1}$$

Individual abilities, z, are modeled as differences in individ-ual productivities between plants. They are assumed to follow a stochastic process $dz = \mu_z z dt + \sigma_z d\omega$, where $E\omega = 0$ and $d\omega^2 = \sigma^2 dt$

The representative household's utility function is given by:

$$\max \int_0^\infty e^{-\rho t} u(c) dt$$

where c is private consumption. It is assumed that $0 < \rho < 1$ and that utility (u) is continuously differentiable, strictly concave, and monotonically increasing. A constant relative risk aversion (CRRA) utility function is used:

$$u(c) = \frac{c^{1-\sigma}}{1-\sigma},$$

where the parameter σ measures the degree of relative risk aversion.

The intertemporal consumer's problem is given by:

$$\begin{aligned} v(z,k,t) = \max_{c,k} \mathbb{E}\left[\int_0^\infty e^{-\rho t} u(c) dt\right] \\ s.t: \\ dk = \left[\max_n \{(1+\tau)y - wn - \delta k\} + w - c + T\right] dt, \\ y = z^\alpha k^\alpha n^{(1-\alpha)} X^\alpha, \\ dz = \mu z dt + \sigma_z d\omega, \\ c, k \geq 0. \end{aligned} \tag{2}$$

Equation 2 shows how consumers maximize utility given their expectations on the natural capital stock of X. The stock of capital affects the total factor productivity of the industry at all times. A larger stock increases profitability and raises the incentives to invest.

It is assumed that fishing possibilities are managed by announcing a path of mortality of fish. This path is a harvest control rule (HCR) that supports the equilibrium. HCRs are a set of pre-agreed rules used to determine a management response to changes in the indicators of stock status with respect to reference points with the objective of moving or maintaining the exploitation level of stocks to pre-defined levels. There is an output path associated with the HCR that supports the beliefs of fishermen about the trajectory of the stock. Therefore, the role of the HCR in this model is to guarantee the unicity of equilibrium.

The natural resource follows an age structured dynamic model as in (6), with the following conservation law (13; 14):

$$\frac{\partial n(a,t)}{\partial t} = -\frac{\partial n(a,t)}{\partial a} - [m(a) + p(a)F(t)]n(a,t). \tag{3}$$

where $n(a,t)$ is the number of fish of age (a) at time t. Therefore, the stock abundance function is defined as:

$$X(t) = \int_0^A \omega(a)n(a,t)da. \tag{4}$$

where ω is the weight at age. Finally, it is assumed that fish die at age A.

3 Results

Conditional on z, k and X, individual profits are obtained by solving an intra-temporal optimization problem. Each fishing plant solves:

$$R(w,\tau,X)zk - \delta k \equiv \max_n (1+\tau)y - wn - \delta k$$

where $R(w,\tau,X) = \alpha(1+\tau)^{1/\alpha}\left[\frac{(1-\alpha)}{w}\right]^{(1-\alpha)/\alpha} X$ and δ is the depreciation rate. Notice that $R(w,\tau,X)$ is increasing in X. Note also that profit per fishing plant is given by:

$$\pi(\tau,z,k,X) = \underbrace{\alpha(1+\tau)^{1/\alpha}\left[\frac{(1-\alpha)}{w}\right]^{(1-\alpha)/\alpha} X}_{R(w,\tau,X)} zk$$

Yield per fishing plant is given by

$$y(\tau, z, k, X) = \frac{\pi(\tau, z, k, X)}{\alpha(1+\tau)} = \frac{R(w, \tau, X)}{\alpha(1+\tau)} zk = \underbrace{q(\tau, w)zkX}_{\simeq \text{ Schaefer (1954)}}$$

And, given a measure $g(z, k, t)$, total effort is given by:

$$K = \int zkg(z, k, t)dkdz.$$

Therefore, capital evolves according to:

$$dk = \left[R(w, \tau, X)zk - \delta k + w - c + T\right] dt.$$

Given $X(t)$, $w(t)$ and τ, $R(w, \tau, X)$ can be computed and a representative household chooses its consumption, c and physical capital, k, by solving the following Hamilton-Jacobi-Bellman equation:

$$\begin{aligned} \rho v(z, k, t) = u(c) + i(z, k, t)\frac{\partial}{\partial k}v(z, k, t) + \\ +\mu\frac{\partial}{\partial z}v(z, k, t)\frac{\sigma_z^2}{2}\frac{\partial^2}{\partial z^2}v(z, k, t) + \frac{\partial}{\partial t}v(z, k, t) \\ where, \\ u'(c) = \frac{\partial}{\partial k}v(z, k, t). \end{aligned} \tag{5}$$

where $i(z, k, t)$ is the investment rate, given by

$$i(z, k, t) = R(w, \tau, X)zkX - \delta k + w + T - (u')^{-1}\left[\frac{\partial}{\partial k}v(z, k, t)\right]$$

The distribution of fishing plants is determined endogenously by the optimal investment decisions made by fishing-plants themselves. To find the mass of plants, $g(z, k, t)$, the

$$\begin{tikzcd}
 & \epsilon\ \ g(z,k,t)\quad \text{death} \\
\begin{array}{c}\textbf{Incumbents at time t}\\ g(z,k,t)\end{array} \arrow[ur] \arrow[dr] & \\
 & (1-\epsilon)\ \ g(z,k,t)\quad \text{survivors} \arrow[d] \\
 & \begin{array}{c}\textbf{Incumbents at time t+dt}\\ (1-\epsilon)\ g(z,k,t)+\epsilon\ g^{\text{ss}}(z,k)\end{array} \\
 & \text{entrants}\quad \epsilon\ \ g^{\text{ss}}(z,k) \arrow[u]
\end{tikzcd}$$

Figure 1: Fleet dynamics explained: how new entrants have the productivity level of the fishing plants in the steady state.

Kolmogorov-Fokker-Planck (KFP) equation is applied:

$$\frac{\partial}{\partial t}g(z,k,t) = -\frac{\partial}{\partial k}[i(z,k,t)g(z,k,t)] - \frac{\partial}{\partial z}[\mu z g(z,k,t)] + \frac{\partial^2}{\partial z^2}\left[\frac{\sigma_z^2}{2}g(z,k,t)\right] \\ +\epsilon\ \ [g(z,k,t) - g^e(z,k,t)] \tag{6}$$

They entry decisions of new fishing plants are based on future (expected) productivity (Figure 1): $g^e(z,k,t) = g^{\text{ss}}(z,k)$. This function depends on stock and is therefore endogenously determined by the decisions of fishing plants.

3.1 Subsidy drop with no stock effect

Assume that in Eq. (1) $\gamma = 0$, which implies no stock effect (see, for example, Clark and Munro (15) for some economic implications of this assumption). Define $H(\hat{X})$ as the harvest level compatible with keeping the stock at $\hat{X}$. Figure 2 presents the equilibrium effects of a drop in the subsidy if the stock has no effect on fishermen's decisions. The drop in the subsidy reduces profits and total catches (from $Q^*_{\tau>0}$ to $Q^*_{\tau=0}$). After the subsidy reduction

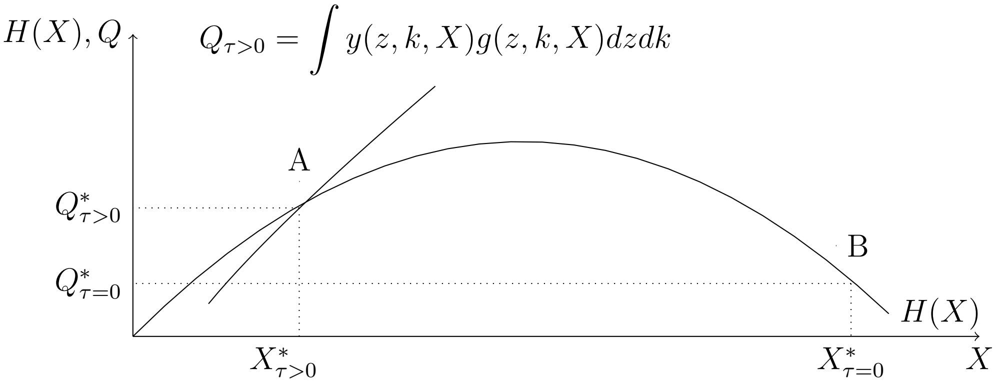

Figure 2: General equilibrium impact of a subsidy drop with no stock effect. *A* is the steady state equilibrium with positive subsidies and *B* is the steady state without subsidies.

$H(X) > Q^*_{\tau=0}$, this increases the stock up to $H(X) = Q^*_{\tau=0}$. However, as the stock has no effect on the decisions of fishing plants the new equilibrium corresponds to a higher stock $X^*_{\tau=0}$ with the same catches $Q^*_{\tau=0}$. In Figure 2 this is represented by point B.

With no stock effect after taxes catches are reduced (if the number of fishing plants is constant) and income per plant is lower than the pre-subsidy level reform.

3.2 Subsidy drop with stock effect

Consider now that in Eq. (1) $\gamma = \alpha$, (Figure 3) in which the stock effect plays a role. In equilibrium, X is given by the stationary population and profits are:

$$\pi(\tau, X_0) = (1+\tau)^{1/\alpha} \left[\frac{(1-\alpha)}{w}\right]^{(1-\alpha)/\alpha} z(t)k(t)X_0$$

If $\tau = 0$, profits would be the same as before if $X_1 = (1+\tau)^{1/\alpha}X_0$ as

$$\pi(0, X_1) = \left[\frac{(1-\alpha)}{w}\right]^{(1-\alpha)/\alpha} z(t)k(t)\underbrace{(1+\tau)^{1/\alpha}X_0}_{X_1}$$

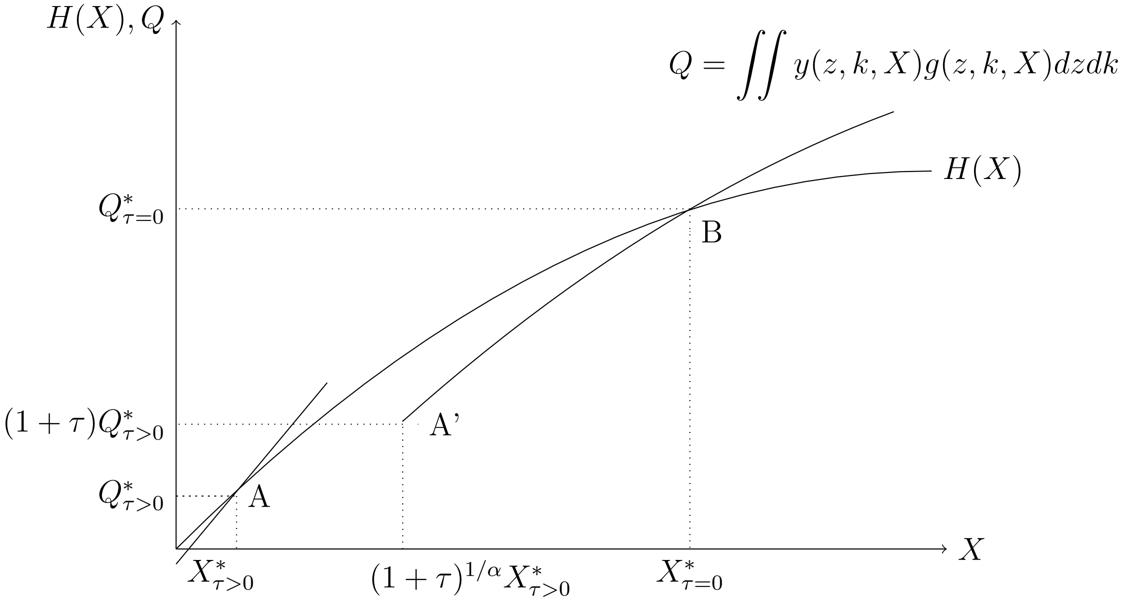

Figure 3: General equilibrium impact of a subsidy drop with stock effect. A is the steady state equilibrium with positive subsidies, A' is the non-equilibrium situation if investment is constant, and B is the steady state without subsidies.

Catches are increased by a factor of $(1+\tau)$ (as yield per fishing plant is given by $y(\tau, X) = \frac{\pi(\tau,X)}{\alpha(1+\tau)}$, and in this case $\tau = 0$ but profits are kept constant). In other words the subsidy is dropped and there is an increment in the stock that generates the same decisions on capital and employment (with the same investment decisions) but more output due to the stock effect. However, in this case all revenues come from catches, as there are no subsidies.

3.3 Comparing a subsidy drop with and without stock effect

In Figures 2 and 3, points A are the steady state equilibrium with positive subsidies. If the subsidy is eliminated investment will be constant if $\hat{X}(t) = (1+\tau)^{1/\alpha}X(t)$. But that implies that catches increase to $(1+\tau)Q^*_{\tau>0}$. This would correspond to point A'. This cannot be an equilibrium given that $H((1+\tau)^{1/\alpha}X^*_{\tau>0}) > (1+\tau)Q^*_{\tau>0}$ implies that $\Delta X > 0$. The new steady state without subsidies is reached at point B , where the stock and catches are higher. Finally, it should be noticed that final catches are higher with the stock effect than without it.

With the stock effect (Figure 3) catches and income per vessel are increased if stock is greater than $(1+\tau)^{1/\alpha}X^*_{\tau>0}$. After the subsidy reform total harvest, $Q^*_{\tau=0}$ and the biomass recovery, $X^*_{\tau=0}$), are higher (lower) with the stock effect than without it.

In order to understand the role of the stock effect, assume that fish stock has no effect on fleet productivity. That is, with no stock effect vessel productivity after the tax reform remains constant and the transitional dynamic of the competitive equilibrium is independent of the stock path recovery. The impact of the subsidy drop on the fleet is therefore determined by its effect on individual investment, and the immediate effect of the change in the subsidy is a reduction in individual investment. In the model the equilibrium outcome for each individual is independent of the number of vessels (given that there are no fixed costs). Capital and output will be lower and consumption will fall, both during the transition and in the final stationary state.

The effect on total capital will depend on whether or not entry in the fishery is incentivized. If the number of vessels is kept constant, output will be reduced and there will be a larger stock. However, this larger stock does not benefit the fleet. Fishermen's income is lower given that they lose the subsidy. In that case, the redistributive impact of the subsidy drop will be regressive. Reducing investment increases inequality because investment is the way of reducing idiosyncratic inequality. Therefore even though overcapitalization of firms is reduced, agents are worse off after the subsidy reduction. Therefore the social cost of eliminating the subsidy is high.

When the stock of fish affects fleet productivity, in equilibrium, the stock is endogenous (and so is the productivity of the firms). Therefore, the impact of a drop in the subsidy will actually depend on the stock effect. If this effect is large, individuals will benefit from stock recovery, as the elimination of the subsidy will increase future returns on investment. The effect on fishing plants is similar to an increase in their permanent income. Part of future revenues is used to increase present consumption and can offset the drop in income resulting from the elimination of the subsidy. Finally, as shown in the numerical illustration below, when the stock effect is considered inequality is also reduced.

4 A numerical illustration

The model presented is illustrated using the industrial shrimp fishery, which is one of the most valuable fisheries in Mexico (10). The stock dynamic is calibrated using data from Gracia and Vazquez-Bader (16). The calibration strategy used is based on the assumption that the benchmark economy is at half of the maximum sustainable yield mortality level, $Y_{sq} = \frac{1}{2} Y_{msy}$, (17).

Table 1: Calibration of the Benchmark Economy

Parameter	Value	Statistic
α	1/3	Capital share (Gollin (18))
σ	2.5	Moderate risk aversion (Bluffstone and Khlin (19))
ϵ	0.04	Vessel Lifetime (FAO (20))
$corr(z_t, z_{t-1})$	0.8031	$MgPK \simeq 1\%$
σ_z^2	0.0121	Variance (Da-Rocha and Sempere (21))
δ	0.1181	$R(w, \tau, X) - \delta \simeq \rho$
τ	0.25	Subsidy (Cisneros et al. (10))

The capital share, α, is 1/3 (18); the discount rate, ρ, is 0.04, (6); and the relative risk aversion parameter, σ, is 2.5, corresponding to a situation of moderate risk aversion (19). It is assumed that the cross section productivity heterogeneity is generated by an Ornstein-Uhlenbeck process, i.e. an AR(1) in discrete time, with variance of 1.21%, (21). The productivity process correlation is equal to 0.80 to generate a low capital return, $\frac{\partial Y}{\partial K}$, of 1.03%. Note that this value implies the existence of an overcapitalized fleet in the baseline economy, i.e.

$\frac{\partial Y}{\partial K} = \alpha \frac{Y}{K} < \hat{\rho}$. The depretiation rate, δ, is set at 11.81% to generate a profitability per unit vessel close to the discount rate, i.e. $R(w, \tau, X) - \delta \simeq \rho$. Each fishing plant is considered to have a life span of 25 years (20), which implies an entry rate, ϵ, of 0.04. Finally, the subsidy (τ) is set equal to 0.25 (10). Table 2 summarizes the calibration paramethers.

As shown in Section 3, , the effects of the fish stock on the decisions of fishing plants are important for assessing the subsidy drop. The importance of this effect is an empirical question. In fact, the reports available on the size of the stock effect are ambiguous. The stock effect based on a Schaefer-type model (stock elasticity of 1) is the maximum effect (22). This implies that in real life situations weaker stock effects are to be found. The effect will depend on the target stock and/or the gear used. For example, the stock effect is weak for herring in the North Sea (23),] but significant for trawl fisheries in Norway (24). This is why three different scenarios are compared: a 0.25 subsidy ($\tau = 0.25$), which implies that 25% of output is subsidized, and two versions of a zero subsidy scenario ($\tau = 0$) which corresponds to a situation in where the subsidy is eliminated. The two altenatives assessed are with the stock effect ($\alpha = \gamma$) and without it ($\gamma = 0$).

Figure 4 shows the transitional dynamics of several variables when stock effect is not considered (upper panel) and when it is considered (lower panel). Expectations can be considered as rational if expectations on $X(t)$ satisfy stock dynamics given by Eq. 4). satisfy the stock dynamics given by Eq. 4). The main conclusion for the case with stock effect is that wages (after an initial drop), capital, consumption, profits (after an initial drop), and yield all increase. The upper panel of Figure 4 shows that if there is no stock effect capital, consumption, and captures decrease, and profits decrease and never reach the pre-subsidy reform level. Notice also that the transition is longer with the stock effect than without it.

Table 2 shows the numerical results in the steady state of a fuel subsidy reform. It provides results on stock sustainability, prices (i.e. wages), aggregates (capital and production), capital productivity, inequality (in terms of income and consumption), and total consumption.

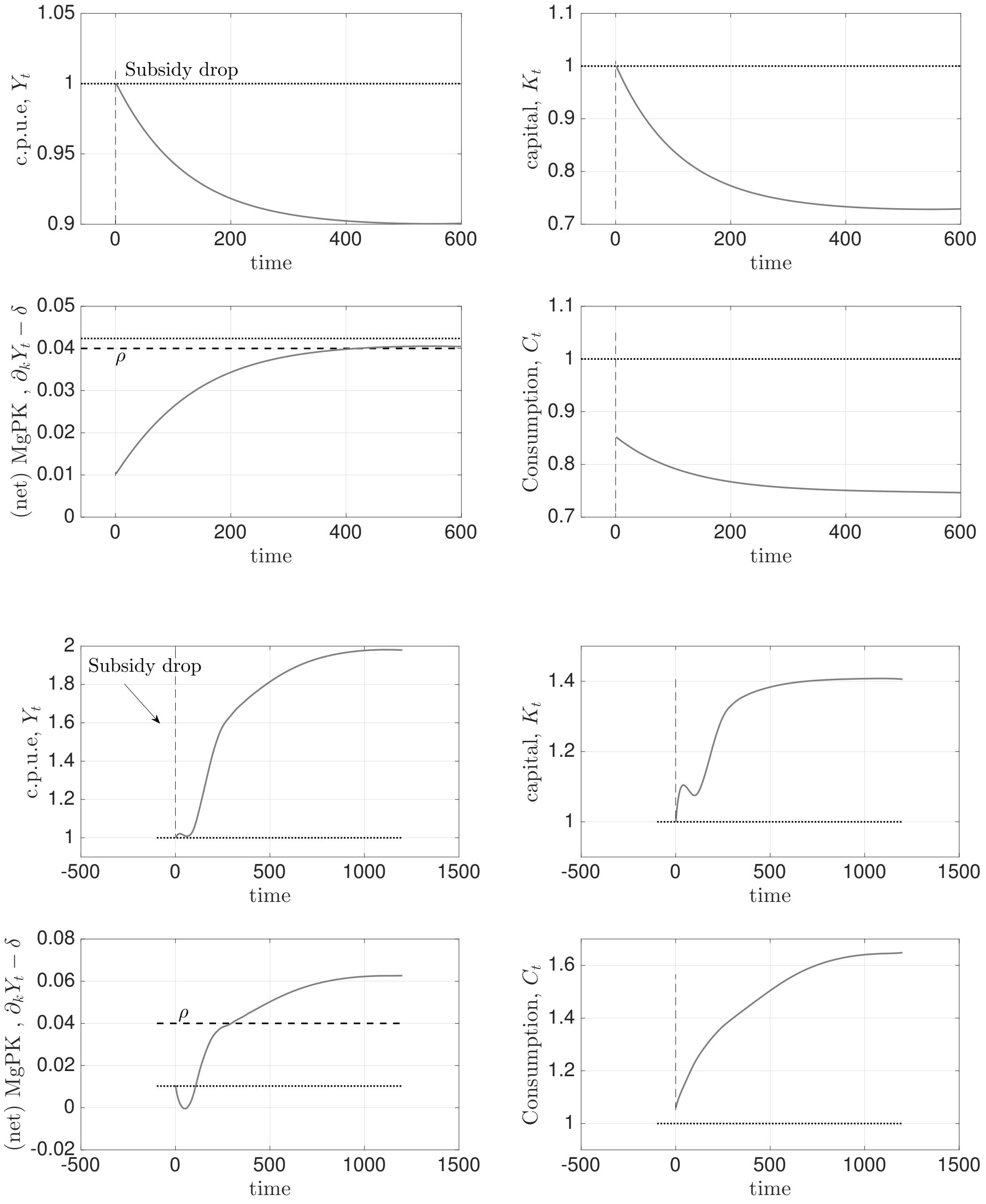

Figure 4: Transitions to the steady state from a subsidy drop. With no stock effect (upper panel) and with stock effect (lower panel), for production (Y), capital (K), productivity ($MgPK$), and consumption (C).

Table 2: Steady state indicators calculated using the Shrimp fishery of Mexico, for the three scenarios analyzed: fuel sub-sidized (($\tau = 0.25$) and no subsidised ($\tau = 0$), with ($\alpha = \gamma$) and without stock effect ($\gamma = 0$).

	$\tau = 0.25$ Benchmark Economy	$\tau = 0$ with Stock effect	without Stock effect
Sustainability			
Relative Y	1.0000	1.9985	0.9006
Relative X (SSB)	1.0000	5.6986	13.7970
X/X_{max}	0.1614	0.9197	2.2266
Prices			
wage w	1.3488	2.1959	0.7201
$R(w, \tau, X) - \delta$	0.0410	0.0570	0.0389
Aggregates			
K	4.2033	5.9224	3.0642
Y	1.6185	3.2346	1.4576
Profitability			
K/Y	2.5970	1.8310	0.8469
MgPK=$\frac{\partial Y}{\partial K} - \delta$	0.0103	0.0640	0.0404
Inequality[1]			
Income (Gini)	1.0000	0.3476	1.5075
Consumption (Gini)	1.0000	0.5580	1.2382
Relative Total Human Consumption	1.0000	2.4220	0.7464

Table 1 should be read relative to the $\tau = 0.25$ scenario and it reflects the differences between considering and not considering the stock effect. Production when the stock effect is considered is almost doubled while stock size is increased. Over-capitalization (K/Y) is also clear with the fuel subsidy. When the subsidy is removed over-capitalization decreases, and the productivity of capital is higher when if the stock effect is considered than it is not. Finally, an important result for assessing the social costs of subsidy drops emerges from the Gini coefficient.[1] A subsidy drop when there is no stock effect increases inequality, but when

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[1] The Gini coefficient is a measure of statistical dispersion intended to represent the income and consumption distribution of among fishing plants and consumers, respectively, and is the most commonly used

there is a stock effect inequality decreases in terms of both income and consumption. This result may have important management and policy implications, as discussed below.

5 Policy implications

The World Bank (25) shows that the difference between the potential and actual net economic benefits from world marine fisheries is approximately 50 billion dollars per annum. It states that improvements in regulation of marine fisheries are needed to capture part of these losses. One of the World Bank's claims is that successful reforms will require reduction or elimination of some of the subsidies in the sector, especially those leading to overcapacity and over-fishing. This same background is one of the reasons that leads the WTO to analyze and propose the removal of such subsidies. It discusses differential treatment for developing countries and proposes technical assistance and transition periods to address their institutional and financial constraints in changing subsidy policies. WTO discussion on subsidies on fisheries continues with no definitive agreement to date. According to Sumaila et al. (26) the failure of the negotiations is due to the fact that WTO negotiators aim for results in an all-inclusive deal for all maritime WTO member countries and for all fisheries (independently of whether they are domestic or international, small or large scale and developing or developed country fisheries).Such an all-inclusive deal is hard to attain because it is difficult to align the incentives of all the parties involved.

The World Bank claims that the problem is based on the political economy of reform. Any successful reform needs to be built on a consensus among fishermen as to the transition process (especially as regards socially compensatory policies to manage transitions equitably). Convincing the parties involved that the elimination of subsidies does not entail major social costs would no doubt reduce the political obstacles to such reform and would align incen-

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measure of inequality. In the numerical example a relative Gini coefficient was used (possitve subsidy=1) to obtain the relative change to this basecase.

tives for governments. In fact, the dividends would be two-fold: On one hand, some of the "sunken billions" would be recovered and on the other hand the fiscal burden of subsidies would be reduced in many countries.

In light of these considerations, four policy implications arise in the modeling framework presented, related to the social costs of reducing fishery subsidies:

i) With the stock effect, a central authority plays the essential role of designing an HCR that selects the right equilibrium. That is, with endogenous fleet productivity the competitive equilibrium depends on the future stock path,which must be made sustainable through an HCR. A fishing policy using an HCR plays a role similar to that of monetary policy in macroeconomic models by ruling out multiple equilibria and selecting a single equilibrium. This role is not necessary in an economy with no stock effect;

ii) If the stock effect is significant it is important to allow the fleet to evolve, replacing old vessels by new ones. This is required to make the present effort reduction (whch contributes to stock rehabilitation) compatible with enjoying the future benefits of stock recovery. Increases in fleet capacity have to be take place through the substitution of less powerful small vessels by more powerful larger vessels as the stock is recovering;

iii) Inequalities in income and consumption when the stock effect is considered are reduced, which helps align the incentives of all parties involved in subsidy drop negotiations;

iv) Complete elimination of a subsidy increases capitalization, marginal productivity, and consumption if the effect of the induced increase in stock (biomass) is considered. However, if this effect is not taken into account capital and consumption decrease and never reach the pre-subsidy reform level. This implies that side compensation payments could be lower than expected if there is a stock effect.

6 Conclusions

Subsidizing fishing effort in an already overexploited ecosystem will further damage it, continually diminishing the long-term productivity of the system. This is why analyzing the impact of eliminating a fuel subsidy in a general equilibrium model with heterogeneous agents as presented in this paper is a relevant policy exercise. In equilibrium, fleet productivity is endogenous as it depends on the stock of fish along the equilibrium path. If the stock effect is large individuals will benefit from stock recovery, as the elimination of the subsidy will increase future returns on investment.

The model is applied to analyze the elimination of a subsidy in the industrial shrimp fisheries in Mexico and the results show that the complete elimination of a subsidy increases biomass, capitalization, marginal productivity, and consumption if the effect of the induced increase in the stock of shrimp is considered. However, if this effect is not taken into account capital and consumption decrease and marginal productivity never reaches the pre-subsidy level. Therefore, the effect of the increase in stock due to the removal of subsidies is a very important determinant of other relevant economic variables.

Once all effects are taken into account the social cost of removing a subsidy can be smaller in fishery industries than in other industries. This is because of the greater abundance of natural capital available to the fishing industry due to the subsidy reform, which creates a second general equilibrium effect. The political cost of a reform reducing subsidies would therefore also be smaller. Furthermore, if the stock effect is relevant it is important to allow the fleet to evolve, replacing old vessels by new ones. Increases in fleet capacity have to take place through the substitution of less powerful small vessels by more powerful larger vessels as the stock is recovering.

It can be concluded that if the stock effect is taken into account the change in socioeconomic conditions due to the subsidy drop will not be negative in general. This means that the need for socially compensatory policies may be lower than expected in traditional analyses of subsidies. Furthermore, all-in, inclusive negotiation can be further facilitated by the lower inequality obtained in terms of both income and consumption.

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A Mathematical representation of the economy

A.1 Market clearance

It should be noted that the labour market satisfies:

$$\int n(z,k,t)g(z,k,t)dkdz = 1 \tag{7}$$

and, total catches ($Q(t)$), are:

$$\int y(z,k,t)g(z,k,t)dkdz = Q(t) \tag{8}$$

A.2 Definition of equilibrium

Given a subsidy, τ, an equilibrium is a stock function, $X(t)$ (Eq. (4)), a measure of firms $g(z,k,t)$, wages $w(t)$, value functions $v(z,k,t)$, individual decision rules $n(z,k,t)$, $y(z,k,t)$, and investment rates $i(z,k,t)$, such that:

i) (Firm optimization) Given the stock dynamics process, $\nu(t)$, and prices $w(t)$, $v(z,k,t)$ solve the household problem, Eq. (6), and $n(z,k,t)$, $y(z,k,t)$ and the saving rates $s(z,k,t)$ are optimal policy functions.

ii) (Firm measure) $g(z,k,t)$, satisfies Eq. (7);

iii) (Market clearing-feasibility) Given individual decision rules, and the firms measure, we find w, solving Eq. (7).

iv) (Harvest Control Rule) Rational expectations on resource dynamics. Given aggregate harvest, $X(t)$ satisfies the stock dynamics (8).

A.3 Steady state

The economy in the steady state can be represented by the following system of equations:

$$\begin{aligned}
\rho v(z,k,X) &= u(c) + i(z,k,X)\frac{\partial}{\partial k}v(z,k,X) + \mu\frac{\partial}{\partial z}v(z,k,X) + \frac{\sigma_z^2}{2}\frac{\partial^2}{\partial z^2}{}^{2}\, v(z,k,X), \\
u'(c) &= \frac{\partial}{\partial k}v(z,k,X), \\
0 &= -\frac{\partial}{\partial k}[i(z,k)g(z,k,X)] - \frac{\partial}{\partial z}[\mu z g(z,k,X)] \\
&+ \frac{\partial^2}{\partial z^2}\left[\frac{\sigma_z^2}{2}g(z,k,X)\right], \\
1 &= \int n(z,k)g(z,k,X)dzdk.
\end{aligned}$$