Environ Resource Econ (2018) 69:75–101
https://doi.org/10.1007/s10640-016-0066-7

General Equilibrium Tragedy of the Commons

Dale T. Manning[1] · **J. Edward Taylor**[2] ·
James E. Wilen[2]

Accepted: 6 September 2016 / Published online: 29 September 2016

Abstract Many poor economies depend on open access resources for their livelihoods. Households in resource-based economies allocate their time and other factors between resource extraction and other activities. As a result, factors may shift from one sector to another as marginal returns change. This has two important implications. First, it implies potentially strong linkages between resource and non-resource sectors. Second, it means that unmanaged resources cause inefficient allocations of inputs across *all* sectors, and the effects of resource management spill into other sectors. We construct a local general equilibrium model that accounts for inputs that over-allocate to an open access resource and create a general equilibrium tragedy of the commons. This model describes resource rent dissipation more adequately in economies with mobile factors than a model with slowly dissipating rents. Perfectly mobile factors dissipate rent in every period, but endogenous wages cause labor and capital allocations to change with the resource stock. We use the model to illustrate medium-run impacts of a limit on capital in an artisanal fishery in Honduras. Simulation results reveal that fishery management has economy-wide impacts on prices and wages. Managers in developing countries thus should consider these linkages when implementing policies to conserve fish stocks.

Keywords General equilibrium · Economic linkages · Open access natural resources · Artisanal fishery · Resource management

✉ Dale T. Manning
dale.manning@colostate.edu

J. Edward Taylor
taylor@primal.ucdavis.edu

James E. Wilen
wilen@primal.ucdavis.edu

1 Colorado State University, Clark Building, 1172 Campus Delivery, Fort Collins, CO 80523, USA

2 University of California-Davis, Davis, CA, USA

1 Introduction

Open access natural resource stocks provide an important source of income to many developing rural economies across the world. Economists have demonstrated the implications of resource rent dissipation in the context of slowly entering capital (Smith 1968) or harvesting effort that responds over space to the presence of resource rents (Sanchirico and Wilen 2005, 1999). While helpful in the context of capital-intense resource extraction such as commercial fisheries, these models may not adequately represent the allocation of effort across an economy when factors are mobile.

This paper presents a general equilibrium (GE) model of natural resource use with mobile factors. It uses the model to illustrate economic linkages between resource and non-resource sectors in the presence of imperfect market integration, mobile factors, and wage/price endogeneity. The model is calibrated to a Honduran fishing economy. To evaluate the economy-wide impacts of fishery regulation, we simulate the local-economy impacts of a restriction on capital (e.g., boats) permitted in the fishery. This generates negative economy-wide impacts on income and welfare in the short run but allows the fish stock to recover and incomes to increase in the medium run.

Our model highlights the short- and long-run tradeoffs in resource management for diversified local economies, including the short-run costs to households not involved directly in resource extraction. Understanding these tradeoffs in poor economies is critical, as global markets increasing rely on developing countries to source seafood and as large retailers and processors promise to obtain their seafood from sustainable sources (Sampson et al. 2015).

1.1 Resource Management in a General-Equilibrium Setting

Despite their economic importance, many natural resources are inefficiently managed, especially developing country fisheries (Costello et al. 2012). Artisanal fisheries, often not managed at all (Jardine and Sanchirico 2012), employ up to 90 % of the world's fishermen (United Nations). They are a major source of seafood for global markets, in which large retailers and processers have committed to obtain seafood from sustainable sources in the future (Sampson et al. 2015). In many cases, property rights to fisheries resources are absent, and rules do not exist (or are not enforced) to regulate the activity of artisanal fishermen. Fishing effort operates under open access conditions and is thus over-allocated to the resource sector because no incentive exists to optimize the joint roles of effort and the fish stock in fishery production. This over-allocation represents the classic 'Tragedy of the Commons' (Hardin 1968; Ostrom 2008) and has been studied extensively in a partial equilibrium framework to demonstrate the loss of resource rent and gains from coordination (e.g., Gordon 1954; Janssen et al. 2011; Stavins and Robert 2011; Abbott and Wilen 2011; Cherry et al. 2013).

Small-scale fisheries are part of larger local and regional economies. Within these economies, non-fisher households depend upon the resource indirectly, both as consumers and because of the income fishing generates within the economy (Ruddle and Hickey 2008). Resource management typically involves limiting excess extraction effort, in order to achieve a larger, sustainable resource stock with a higher sustainable yield in the long run. Effort-limited management thus implies short-term costs in order to achieve long-term gains. Both have potentially large indirect spillovers in resource-based economies, and the distribution of costs and benefits of resource management is unclear and understudied. Compensating losers is likely to be a prerequisite to the successful implementation of sustainable resource management measures in poor economies (Wilen 2013). If regulation creates negative income and employment spillovers, compensation policies will need to consider impacts beyond the resource-extracting households.

The prevalence of open access resources in remote rural settings creates the need to quantify impacts of management while accounting for resource stock dynamics, mobile factors, and a misallocation of inputs across the local economy. There is also growing interest among development economists in evaluating both the direct and indirect spillover impacts of interventions (Taylor and Filipski 2014; Angelucci and De Giorgi 2009). In this paper, a resource (fish) stock is incorporated into a GE framework to illustrate a 'GE Tragedy of the Commons' and demonstrate the direct and indirect-spillover effects of resource regulation in a poor economy.

2 Background

The Tragedy of the Commons (TOC) is often represented as resource rent dissipation over time in unregulated resource sectors (Gordon 1954; Smith 1968; Smith and Crowder 2011). This dissipation leads to a reduction in resource value and leaves the economy with an inefficient allocation of inputs. As a result, an economy with access to a valuable common resource often remains poor (Gordon 1954). In resource economic models of open access, the net rents attributed to the resource stock go to zero over time. Yet, even when the resource rent dissipates, natural resource stocks may continue to influence the allocation of factors across an economy as households allocate their factors to the sectors in which they produce the most value. At the same time, non-resource sectors influence the allocation of factors to resource extraction. Because of this, resource management impacts the returns to inputs broadly across the local economy, and the optimal management of resources in turn may differ across local economic contexts.

The application of this paper is to an artisanal fishery in Northern Honduras. Artisanal fisheries represent an important source of food in the developing world. There is a gap in understanding of how socioeconomic systems interact with fish biology in these settings (Johnson et al. 2013). Developing country fisheries provide a vital source of employment for poor households (Béné et al. 2010). Some studies have begun to examine the factors that determine labor allocation to resource collection and how this allocation depends on market access and the opportunity cost of time (Liese et al. 2007; Bluffstone 1995; López-Feldman and Edward Taylor 2009; Manning and Taylor 2015). In practice, the value of open access fish stocks to artisanal fishermen derives from the sector's ability to employ inputs. Many artisanal fishermen also work in other sectors of the local economy. If fishing were not an option, these individuals would allocate more of their time to other sectors, for example, agriculture. Understanding economic linkages between fishing, fish stocks, and the rest of the local economy thus is critical for assessing the welfare implications of small-scale fishery regulation as well as designing optimal management strategies. Establishing the theoretical linkage from non-resource sectors to natural capital stocks represents an important step towards incorporating ecosystem services into assessments of economic development (Fisher et al. 2009).

A local, economy-wide general equilibrium (GE) model (Taylor and Adelman 2003) is well-suited to capture linkages across economic sectors. In traditional computable GE models, natural capital (resource stocks) is often ignored, especially in the case of open access or restricted access sectors, because the resource does not receive an explicit payment. For example, Seung and Waters (2009) investigate the impacts of fishing harvest reductions on multiple sectors in an economy but do not explicitly model resource stocks. Their study provides a useful tool for impact analysis; however, it does not capture the resource dynamics that partially determine the medium-term effects of fishery-management policies. In order to account for the fish stock in production, Manning et al. (2014) assume that the fishery production function has diminishing returns to scale in non-resource inputs; however, this approach does not offer a way to evaluate the impacts of a change in the fish stock.

There are several examples of GE models that include non-market environmental goods (e.g., Espinosa and Smith 1995; Carbone and Smith 2010). They highlight the important demand linkages between market and non-market (environmental) goods. Perroni and Wigle (1994) include environmental externalities in a global GE model to investigate the impacts of trade on environmental outcomes. Our model builds on the modeling contributions of Finnoff and Tschirhart (2008). They develop a GE model which includes a multi-species ecosystem to show the linkages between fisheries management and tourism in Alaska. It includes a fish stock as an input to production in a rent-dissipated, regulated open access fishery which is managed with a season length [linked to a total allowable catch (TAC)], as in Homans and Wilen (1997). Rent dissipation means that labor and capital collect all production value from the resource. These inputs are allocated to the fishery to minimize the cost of catching the TAC, conditional on the fish stock and the fishing season length. Others (e.g., Goodman 2000; Peterson et al. 2005; Velázquez et al. 2007) have explicitly modeled water as a natural input into economic activities, especially agriculture. These modeling frameworks are informative because they include a natural resource input. They do not, however, explicitly treat the lack of regulation and property rights present in a pure open access resource sector.

The model presented here includes an open access natural resource in a GE framework and explicitly accounts for the open access market failure. The absence of regulation means that modeling rent dissipation with multiple inputs is operationalized in a different way than in a model of regulated open access. Here, capital and labor inputs can allocate freely to the fishery throughout the year. Therefore, each input equates its marginal earnings across sectors. In an open access setting, resource sector inputs collect a share of the product generated by scarce natural capital in addition to their own marginal product. As a result, the marginal products of inputs do not equate across sectors in the economy. Instead, the value of the marginal product of inputs is lower in the resource sector than in the other sectors. This results in the 'GE tragedy of the commons.' In addition, we do not restrict that labor and capital split resource value in a particular way.

Modeling natural resource use in remote developing country village economies requires a GE model in order to capture all the direct and indirect impacts of resource use on households. The existence of high transaction costs in rural areas creates local prices and wages that transmit management impacts across multiple sectors of the economy. The partial equilibrium assumption of exogenous opportunity costs of fishing effort is not appropriate in these settings because it ignores the importance of economic linkages between sectors. In fact, the opportunity cost of resource collection is tightly linked to returns and factor employment in other sectors of the economy. Without considering these spillover impacts, we miss important economy-wide impacts of fishery management and risk designing and implementing the wrong kinds of fishery-management measures.

Modeling open access fishery value requires the inclusion of natural capital in a general equilibrium framework. In the following section, a 2-sector GE model is used to illustrate the basic concepts used to calibrate a model to an economy with an open access fishery. In Sect. 4, we calibrate a 7-sector, 7-factor model to household survey data from Northern Honduras to illustrate the economy-wide impacts of fishery management. This is followed by a discussion of the sensitivity of results to model parameters and a conclusion.

3 General Equilibrium Model with Open Access Resource

A two-sector model with a representative consumer highlights the GE production inefficiencies in an economy with an open access natural resource. It also demonstrates the linkages between resource and non-resource sectors.

Without significant loss of generality, it is assumed that the economy has 3 factors: labor (L), capital (K), and a natural capital/fish stock (x). In the context of rural Honduras, many households allocate both labor and capital to multiple sectors. It is common for one individual to work in many sectors (for example, someone may fish, farm, and work construction). Therefore, the units of labor and capital are best thought of as the amount of labor or capital time dedicated to each activity.

There are two outputs, y_1 (resource production—the fishery) and y_2 (other production) with exogenous prices p_1 and p_2. Two-commodity models have been used in other contexts to illustrate the general equilibrium implications of common property resources (Scott 1957; Samuelson 1974; Smith 1974; Weitzman 1974; Hannesson 2010; Wilen 2013). Plourde (1971) uses a similar model to solve for the optimal exploitation of a renewable resource. We extend this model setup to include multiple non-resource stock inputs and to motivate the calibration of an empirical general equilibrium model.

A representative consumer demands amounts q_1 of the resource and q_2 of the other good. L and K are used in both sectors while x, the resource stock, is used only in the production of y_1. The economy takes the natural capital stock as exogenous when allocating inputs and has endowment $\bar{L}$ and $\bar{K}$ of each input. Let w_L and w_K be the prices paid for L and K. Wages could be endogenous if high transaction costs prevent integration with outside factor markets. This differs from the conventional assumption that resource harvesting effort has an exogenous marginal cost (e.g., Gordon 1954; Robinson et al. 2008; Clark 1990). Output prices are assumed exogenous but this does not affect the qualitative presentation of the GE tragedy of the commons. The assumption is relaxed in the empirical section of this paper. Importantly, the resource sector is open access and so there is no explicit payment made to the resource stock despite its role in production. Time indicators are suppressed for conciseness but all input allocations and outputs are in period t.

3.1 Production

On the production side it is assumed that both output markets are competitive with no economic profit.

Non-resource production is:

$$y_2 = g\left(L_2, K_2\right), \tag{1}$$

with g homogenous of degree one, concave, and increasing in both inputs. Resource production is:

$$y_1 = f\left(L_1, K_1, x\right), \tag{2}$$

where f is also homogenous of degree one and concave, and increasing in all three inputs. Also, assume $\frac{d^2 f}{dxdL} > 0$ and $\frac{d^2 f}{dxdK} > 0$ so that as the resource stock increases, the marginal products of L and K increase. This occurs because a higher resource stock lowers search costs and increases the catch per unit applied of the other inputs. This assumption leads to higher demands for inputs in the resource sector as the stock recovers. The resource stock, treated as a parameter in the production of y_1, evolves through time according to the equation of motion:

$$x_{t+1} = x_t + b(x_t) - y_1, \tag{3}$$

and the resource is supplied for free (t indexes the time period). $b(x_t)$ represents the biological growth of the fish population and is assumed strictly concave with a maximum occurring at $x_t^m \in (0, C)$ where C is the carrying capacity of the natural system.

An important issue that must be dealt with in a GE analysis of natural resource use is what mechanisms determine payments to multiple inputs (Finnoff and Tschirhart 2008). Many resource economics analyses, especially in fisheries economics, ignore the issue by aggregating multiple inputs into a composite "effort." Wilen (1979), Weninger and McConnell (2000), and Campbell and Lindner (1990) discuss the implications of multiple inputs in a fishery. Abbott and Wilen (2009) model a recreational fishery and provide some rigorous conceptual modeling of input choice under open access with multiple inputs in a general production setting. But there is little empirical evidence for how resource value is divided among multiple inputs in real open access settings. Abbott et al. (2010) investigate the impact of an individual transferable quota in a formerly regulated restricted access Alaskan fishery on labor remuneration and find that rationalization results in fewer, better compensated jobs compared with regulated restricted access.

We assume that L_1 collects a proportion, $\theta \in [0, 1]$, of the resource's contribution to production and that K_1 collects the remainder $(1 - \theta)$. We assume that the value of θ is an empirical question and that it remains the same with and without management. In Finnoff and Tschirhart (2008), labor and capital inputs allocate to a fishery to minimize the cost of harvesting, conditional on the fish stock, which acts as a total factor productivity shifter for a production function that exhibits constant returns to scale (CRS) in capital and labor. The CRS assumption is relaxed in Finnoff and Tschirhart (2011). In our model, fishing production is not CRS in capital and labor and the remaining resource value is shared between non-resource inputs according to the value of θ. The role of θ is further explored in the empirical section of this paper.

3.2 Characterizing the Market Failure

In the base model, it is assumed that labor and capital ignore the contribution of the resource stock to production. This occurs because harvesters of open access resources face no incentive to internalize the impact of harvest on the resource stock when the number of harvesters is large (Brooks et al. 1999). Therefore, resource users behave as if L_1 and K_1 were the only inputs in the sector. Using Euler's theorem,

$$p_1 f(L_1, K_1, x) = L_1 p_1 \frac{\delta f}{\delta L_1} + K_1 p_1 \frac{\delta f}{\delta K_1} + x p_1 \frac{\delta f}{\delta x} \tag{4}$$

Note that $p_1 \frac{\delta f}{\delta z_1}$ should equate to the economy wage for all inputs, z, but labor and capital collect the last term instead of a resource owner.[1] Define the last term in Eq. 4 as Q. Then, the marginal unit of labor to enter the fishery collects:

$$p_1 \frac{\delta f}{\delta L_1} + \frac{\theta Q}{L_1} \tag{5}$$

This marginal payment has two components. The first is the additional value of production from the last unit of labor. The second is labor's share of the resource value, split evenly among labor (assuming that labor units are homogenous).

[1] Without the assumption of first-degree homogeneity (i.e., with decreasing returns to scale), a residual claimant would collect an additional value.

Similarly for capital, marginal earnings equal:

$$p_1 \frac{\delta f}{\delta K_1} + \frac{(1-\theta)\,Q}{K_1} \tag{6}$$

3.3 Factor Market Equilibrium

Factors allocate across the two sectors until marginal earnings equate. With perfect markets, this means that marginal value products equate across sectors (through the economy wage). In sector 2, there is no market failure and profit is maximized by setting the value marginal product of each input to its opportunity cost. Without a market for the resource input, this does not occur in the resource sector because inputs in the open access resource sector earn more than their marginal product. The inputs have no incentive to value the resource stock contribution.

Therefore, because there are no costs to transitioning between sectors, the input market equilibrium conditions are:

$$p_1 \frac{\partial f}{\partial L_1} + \frac{\theta Q}{L_1} = p_2 \frac{\partial g}{\partial L_2} = w_L \tag{7a}$$

$$p_1 \frac{\partial f}{\partial K_1} + \frac{(1-\theta)\,Q}{K_1} = p_2 \frac{\partial g}{\partial K_2} = w_K \tag{7b}$$

Note that $p_1 \frac{\delta f}{\delta L_1} < p_2 \frac{\delta g}{\delta L_2}$ and $p_1 \frac{\delta f}{\delta K_1} < p_2 \frac{\delta g}{\delta K_2}$ and so inputs are inefficiently allocated in the economy. This occurs because $Q > 0$ as long as $x > 0$ and because f is strictly concave in capital and labor (holding x fixed). Static efficiency would equate the value marginal products of inputs across the two sectors. With the open access market failure, both inputs are over-allocated to the resource sector relative to the statically efficient factor allocation because a given resource stock level increases the perceived marginal productivity of other inputs in the fishery.

3.4 Solving the Model

To determine w_L and w_K, market clearing conditions state that $L_1 + L_2 = \bar{L}$ and $K_1 + K_2 = \bar{K}$.

The resource and non-resource outputs are assumed tradable and so have exogenous prices. Consistent with incomplete credit markets in developing countries (Boucher et al. 2008), it is assumed that the household cannot borrow and so the value of household consumption cannot exceed the value of production. Combining this information and assuming an interior solution, the household's objective is to maximize utility subject to a budget constraint that the value of consumption cannot exceed the value produced in the economy. This can be expressed as:

$$\max_{q_1, q_2} u\left(q_1, q_2\right) \quad s.t. p_1 q_1 + p_2 q_2 = p_1 f\left(L_1, K_1, x\right) + p_2 g\left(L_2, K_2\right) \tag{8a}$$

$$L_1 + L_2 = \bar{L} \tag{8b}$$

$$K_1 + K_2 = \bar{K} \tag{8c}$$

$$p_1 \frac{\partial f}{\partial L_1} + \frac{\theta Q}{L_1} = p_2 \frac{\partial g}{\partial L_2} \tag{8d}$$

$$p_1 \frac{\partial f}{\partial K_1} + \frac{(1-\theta)\,Q}{K_1} = p_2 \frac{\partial g}{\partial K_2} \tag{8e}$$

where q_1 and q_2 are the quantities consumed of the resource and non-resource good respectively and x is treated as exogenous. $u(q_1, q_2)$ is assumed increasing in both arguments and concave. Because of the assumption of exogenous output markets, additional market clearing conditions are not needed. Note that capital and labor decisions are not free because 8b through 8e completely determine the allocation that satisfies the open access market failure described above. This inefficient labor allocation determines the economy-wide income available to be spent on the consumption of resource and non-resource goods.

The difference between quantities demanded and supplied can be imported (or exported) from the local economy. The open access market failure is built in using Eqs. 8d and 8e. Full utility maximization with labor and capital free would also maximize the value produced by equating the value of marginal products of inputs.

To solve this problem, we set up the Lagrangian, using multipliers, λ, μ, ρ, δ and γ, all strictly positive because of the assumption of an interior solution. The problem becomes:

$$\begin{aligned}\max_{q_1,q_2,\lambda,\mu,\rho,\delta,\gamma} L = u(q_1,q_2) - \lambda(p_1q_1 + p_2q_2 - p_1 f(L_1,K_1,x) - p_2 g(L_2,K_2)) \\ - \mu(L_1 + L_2 - \bar{L}) - \rho(K_1 + K_2 - \bar{K}) - \delta\left(p_1\frac{\partial f}{\partial L_1} + \frac{\theta Q}{L_1}\right. \\ \left. - p_2\frac{\partial g}{\partial L_2}\right) - \gamma\left(p_1\frac{\partial f}{\partial K_1} + \frac{(1-\theta)Q}{K_1} - p_2\frac{\partial g}{\partial K_2}\right)\end{aligned} \tag{9a}$$

Taking first-order conditions:

$$u_{q_1} - \lambda p_1 = 0 \tag{9b}$$
$$u_{q_2} - \lambda p_2 = 0 \tag{9c}$$
$$L_1 + L_2 = \bar{L} \tag{9d}$$
$$K_1 + K_2 = \bar{K} \tag{9e}$$
$$p_1\frac{\partial f}{\partial L_1} + \frac{\theta Q}{L_1} = p_2\frac{\partial g}{\partial L_2} \tag{9f}$$
$$p_1\frac{\partial f}{\partial K_1} + \frac{(1-\theta)\,Q}{K_1} = p_2\frac{\partial g}{\partial K_2} \tag{9g}$$
$$p_1q_1 + p_2q_2 = p_1 f\,(L_1,K_1,x) + p_2 g\,(L_2,K_2) \tag{9h}$$

This system of 7 equations can be solved for $q_1, q_2, L_1, L_2, K_1, K_2$, and λ as a function of exogenous parameters, $\left(p_1, p_2, \bar{K}, \bar{L}, \theta, x\right)$. Note that $w_L \equiv p_2\frac{\partial g}{\partial L_2}$ and $w_K \equiv p_2\frac{\partial g}{\partial K_2}$ and Eqs. 9d to 9g solve for factor allocations. Then 9b, 9c, and 9h can be solved for q_1, q_2, and λ conditional on the income from non-optimal factor allocation.

Combining 9b and 9c, $\frac{u_{q_1}}{u_{q_2}} = \frac{p_1}{p_2}$ so the marginal rate of substitution of q_1 and q_2 equate to their price ratios. Therefore, the consumer optimally trades off consumption conditional on income but does not allocate inputs to production across the economy to maximize net income (Eqs. 9f, 9g).

3.5 Natural Resource Rent in the GE Model

We can now consider the role of traditional resource rent in this GE framework.

Proposition *Conventional resource rent* $R^c = p_1 f\,(L_1, K_1, x) - L_1 w_L - K_1 w_K$*, is always equal to zero.*

Proof Combining the definition of conventional resource rent with Eqs. 7a and 7b,

$$R^c = p_1 f(L_1, K_1, x) - L_1 w_L - K_1 w_K \tag{10}$$

$$= p_1 f(L_1, K_1, x) - L_1 \left(p_1 \frac{\partial f}{\partial L_1} + \frac{\theta Q}{L_1} \right) - K_1 \left(p_1 \frac{\partial f}{\partial K_1} + \frac{(1-\theta) Q}{K_1} \right) \tag{11}$$

$$= p_1 f(L_1, K_1, x) - L_1 p_1 \frac{\partial f}{\partial L_1} - K_1 p_1 \frac{df}{dK_1} - Q = 0 \tag{12}$$

Therefore, resource rent is always dissipated in the economy, even if the resource stock is not at steady state. Both capital and labor earn their opportunity cost but neither collects the additional value associated with the opportunity cost of the fish stock. This follows from a direct application of Euler's theorem as seen in Eq. 4. Rent dissipation in every period differs from models in which effort slowly enters a resource sector (Smith 1968; Smith and Crowder 2011). □

3.6 Resource Stock Over Time

Over time, the resource stock changes, meaning that the amount of labor and capital in the sector shifts in response to changing earnings in resource extraction (not in response to conventional resource rents). The steady state of the system occurs when conditions 7a and 7b are satisfied, output market conditions hold, and fish harvest equates to biological growth ($f(L_1, K_1, x_{ss}) = b(x_{ss})$) where x_{ss} is the steady state resource population. If $x_t > x_{ss}$, harvest exceeds the resource growth and the resource stock decreases in the next period, leading to less sector employment of labor and capital. If an economy's natural capital stock begins at the carrying capacity, it attracts a relatively large share of the economy's inputs. As the resource stock is depleted, it provides employment to less labor and/or capital until it arrives at the steady state (the approach path depends on fish growth parameters and fisher productivity). As this occurs, an economy with imperfectly integrated factor markets experiences downward pressure on wages, at least for one factor.[2] Of course, if the signs of $\frac{\partial^2 f}{\partial x \partial L}$ and $\frac{\partial^2 f}{\partial x \partial K}$ were non-positive, decreasing resource stocks could increase input marginal productivity throughout the local economy. The dynamic story that follows from this model offers an alternative to the case in which aggregate effort increases in a resource sector over time until rents are dissipated (the system can approach the steady state as a dampening oscillation). Here, the lack of adjustment costs causes rents to dissipate in every period, but decreased productivity in the sector causes effort to exit over time. If capital and labor are complementary, both exit the fishery over time. If, on the other hand, they are substitutable, it is possible that only one input decreases over time. In this GE model, the opportunity cost of capital is endogenously determined and differs from zero. Therefore, returns to capital are positive despite zero *net* return in the resource sector.[3]

The theory presented here demonstrates how an open access resource sector can be integrated into a GE framework. In the following section, the principles developed here are applied to remote fishing villages in Northern Honduras. In this context, it is possible to explore the economy-wide implications of restrictions placed upon the fishery.

[2] It is possible that some inputs not in the resource sector are less productive when inputs are over-allocated to resource extraction. As inputs exit the resource sector, productivity can increase for one input.

[3] With optimal factor allocation, the resource would receive a payment equal to its (dynamic) opportunity cost so while this is referred to as resource rent, it really refers to a factor payment required for efficiency (Manning and Uchida 2016).

4 Empirical Setting: Northern Honduras Artisanal Fishing Villages

Artisanal fishing villages in two national parks near the city of Tela in Northern Honduras have access to a potentially valuable stock of natural capital. The villages fish in two brackish lagoons and within 3 km of the coast, where they have driven local fish stocks to low levels. While some regulations exist, they are inconsistently enforced. Anecdotal evidence suggests that many local fishermen have stopped fishing as fish stocks have fallen. This setting represents a case of the tragedy of the commons in which resource rent is dissipated.

We model this remote economy with a mix of integrated sectors (e.g., agricultural output, hired labor) and local sectors with endogenous prices (e.g., services, family labor). While definitive evidence on the price endogeneity of each sector does not exist, a substantial development economics literature has highlighted the importance of transaction costs in creating local prices in some sectors, both in theory and in practice (De Janvry et al. 1991; Taylor and Adelman 2003). The possibility of local labor markets (Jacoby 1993) is especially relevant in this setting because of institutional constraints that limit the number of households that can move to the study area. Therefore, the supply of local labor is restricted, creating an endogenous local wage. At the same time, hired labor comes from outside, leading to the decision to model hired labor with an exogenous wage.

The communities in the national park also have infrastructure in place to export the output from some sectors, including agriculture (particularly African Palm) as well as fish (refrigerated trucks can access some of the communities while boats with motors may choose to land fish where outside buyers are present). These sectors are considered tradable. Despite this, remoteness and a lack of good road infrastructure limits the ability of many households to participate regularly in outside markets, leading to non-tradability and price endogeneity for retail and services.

In this setting, the open access market failure is modeled in a general equilibrium framework by incorporating the fish stock as an input in the fishery. Due to a lack of data on the fish population, a number of assumptions are required for model calibration. Therefore, results are meant as a qualitative presentation of GE resource modeling. Once key parameters are estimated, this model provides a tool for impact analysis that accounts for the creation and distribution of resource value over time and can be used to explore the economy-wide implications of fishery management.

4.1 Data

The data for this analysis come from a household survey carried out by the authors in May 2012. The survey gathered information about 2011 economic activities, including the amount and location of expenditures and earnings. These data were used to construct a social accounting matrix (SAM) "snapshot" of money flows through the local economy. The initial SAM includes 7 sectors (4 tradable: agriculture, fishing, fish resale, and tourism; 3 non-tradable: services, production, and retail), a representative household, government, and 6 factors (4 non-tradable: family labor, fishing capital (boats and gear), land, and physical capital; 2 tradable: low-skilled labor and high-skilled labor) that receive payments recorded in the household survey. No payments are made to fish stocks. It is assumed that land and (non-fishing) physical capital are fixed by activity. Other factors, including fishing capital, which can be used in fishing and tourism, are assumed mobile within the economy. This means that the opportunity cost of allocating capital to fishing is that the capital cannot be used to transport tourists. Production and consumption totals differ because of sampling error, so the SAM was balanced using the balancing procedure described in Schneider and Zenios (1990),

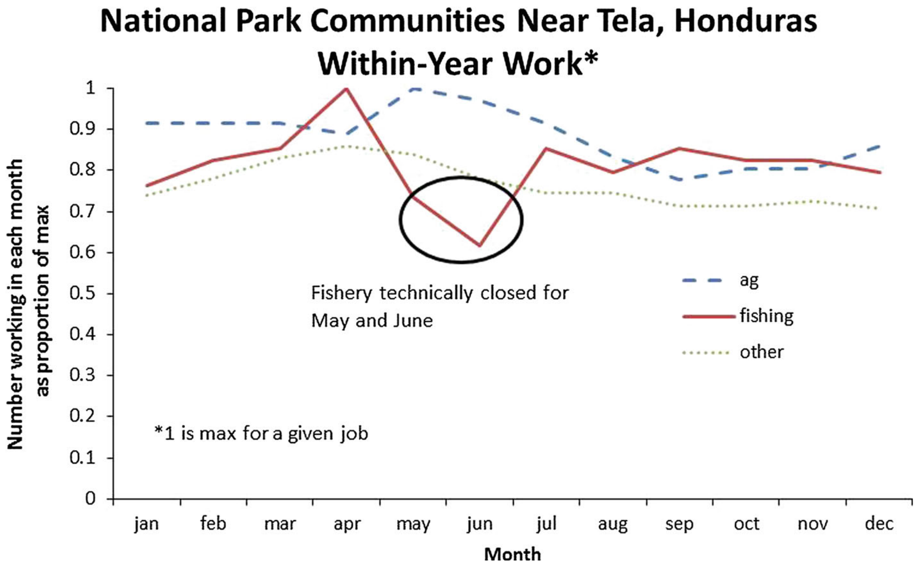

Fig. 1 Workers in each sector in each month, as a proportion of the maximum number of workers

commonly referred to as RAS.[4] 154 households were interviewed and of these, 58 had at least one fisherman. There were also 7 households that fished previously but had stopped either because of a lack of fish, increased opportunity elsewhere (e.g., African palm production or tourism), or both.

The Honduran setting is different than the fishery modeled in Finnoff and Tschirhart (2008) because there is no regulator determining the season length. As seen in Fig. 1, the fishery provides year-round employment for local fishermen. There is a period of two months (May and June) when part of the fishery officially closes, though enforcement is inconsistent. Some fishermen come from outside the local communities to fish. Therefore, the fishery is close to pure open access. The model here captures this feature by assuming an infinitely elastic supply of outside labor. Also seen in Fig. 1, households bordering the fishery tend to participate in multiple activities, including fishing and farming. As returns in different activities change, households can reallocate inputs into the activity with higher returns. This creates strong factor market linkages between different economic activities in the area.

The challenge for modeling natural resource value in an empirical open access sector is that there is no explicit payment to the natural capital. The SAM only contains payments to non-natural capital inputs, which include the natural capital value. Therefore, to calibrate the model we must assume, as in Manning et al. (2014), a production-fish stock elasticity (we use 0.40). The remaining value of production can then be attributed to labor and capital inputs. The model's sensitivity to this assumption is discussed below. In the SAM, an account is created for natural capital, and part of the payment to labor and capital is attributed to the natural capital stock, which makes a payment to the household that owns the factor that collects the resource value. The allocation of the value to each input depends on an assumption of the

[4] The term RAS is used because of common notation for the procedure. Specifically the procedure starts with a matrix, A_0 and produces a new matrix A_1 by solving for row and column multipliers, r_i and s_j subject to the restriction that corresponding row and column totals are equal. In matrix notation, this can be expressed as $A_1 = RA_0S$, giving it the name, RAS.

Table 1 Division of resource value into payments to other inputs

	(1) Fishing, reported payments Lempira, Millions	(2) Proportion of value-added	(3) Fishing, resource payment explicit Lempira, Millions	(4) Proportion of value-added	(5) Share of resource value collected
Agriculture					
Fishing					
Fish resale					
Retail	15.40		15.40		
Services					
Production					
Tourism					
Government					
Households					
Family labor	35.75	0.29	21.45	0.17	0.29
Low-skilled labor	21.28	0.17	12.77	0.10	0.17
High-skilled labor					
Fishing capital	65.89	0.54	39.53	0.32	0.54
Land					
Fish population			49.17	0.40	
Physical capital					
External trade					
Total	138.32	1.00	138.32	1.00	1.00

Values in columns 1 and 3 represent payments from the fishing sector to the row title. Columns 2, 4, and 5 describe the division of this value between factors of production. Fishing capital includes returns to boats and other gear

proportion of resource value collected by each input (i.e., θ from the theoretical model). In the base case, it is assumed that inputs ignore the resource stock contribution to production, and resource value is shared according to relative contributions to production. This is consistent with the production structure used in Finnoff and Tschirhart (2008) where the resource value acts as a total factor productivity shifter in the fishery. The modified SAM with a resource account is then used, in combination with the open access equilibrium conditions (Eqs. 7a and 7b), to calibrate the model. (The complete modified SAM appears in the Appendix). Table 1 illustrates the flows of value in the fishery from the original SAM compared to the modified version with an explicit resource account.

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. We also assume no net migration over the modeled time horizon.

The first column in Table 1 shows the payments to non-resource inputs that are recorded in a conventional SAM. Normally, constant returns to scale in the factors that receive payments is assumed and factor shares from column 1 are used (e.g., Taylor and Adelman 2003). In the case of a resource sector, this omits the natural capital stock input (Fish Population). Therefore, column 3 divides the observed payment into payments attributable to the factor that creates the value, including 40 % of total value-added to the resource stock. The remaining 60 % of value-added in the fishery is divided among the three non-resource inputs in proportion to collection of total value (sensitivity to this division is discussed below). The fourth column presents the factor shares used to calibrate the model. The final column of Table 1 displays the assumed proportion of resource value collected by each input (note the equivalence to column 1 because of the assumption on how resource value is split in the base case).

4.2 Model Parameterization

Calibration of the GE model requires parameterizing production and demand functions as well as establishing factor endowments and determining the tradability of each sector. Demand functions are assumed to be derived from a Cobb-Douglas utility function for a representative consumer. Production sectors have constant returns to scale Cobb-Douglas production functions, including the resource stock in the fishery production function (sensitivity to the elasticity of substitution is discussed below). The model is calibrated using Generalized Algebraic Modeling System (GAMS). Budget shares were obtained from household expenditure in the SAM and factor shares for non-fishery sectors are derived from the observed factor payments. All prices and wages are assumed to equal one and the units of factors and outputs adjust so that the price of one unit is one. The payments to factors in the fishery include a value-added payment plus a share of the payment to the resource. Therefore, the amount of each factor in the fishery (valued at a wage of 1) is not equal to its value-added payment; instead the fishery employs each factor in a quantity equal to the value-added payment plus the share of resource value collected by the factor. As a result, the marginal value of inputs in the fishery is less than one. Non-traded inputs are supplied with an elasticity of 1.5 in the base model but qualitative results are not sensitive to this assumption. Traded inputs have infinitely elastic supplies.

Actual fish stock abundance for our case study is unknown and so it is assumed to be at steady state at 20 % of its carrying capacity. This assumption is based on conversations with local fishermen, and sensitivity to this assumption is discussed below. Common species caught in the area include Mackerel, Common Snook, and Mullet. While there were no data available for the Northern Honduran populations of these species, Fishbase estimates a range of intrinsic growth rates for a related species (Atlantic Mackerel) of 0.33–0.56 (Fishbase 2009). In addition, the Fishbase Manual suggests that 0.5 is the cut-off between high and medium productivity fish populations. Therefore, we specify the fish population intrinsic growth rate as 0.5.[5] Assuming logistic growth and harvest of 138.32, the steady state fish stock is 345.79 units where the units match the output of the production function (priced at 1). The carrying capacity is 1,729 units based on the assumption that the current stock is 20 % of carrying capacity. Assuming a stock elasticity of 0.4, 49.17 million Lempira is the value of production attributable to the fish stock. The calibrated fishery production function for each period becomes:

[5] Analysis of the sensitivity to this assumption can be made available upon request. The intrinsic growth rate affects the magnitude of management impacts but all qualitative results hold for intrinsic growth rates between 0.2 and 0.8.

$$y_{fish} = A_{fish} L_{family}^{.174} L_{hired}^{.104} K^{.322} x^{.4} \tag{13}$$

where K is the amount of capital in the fishery and x is the fish stock in a given period. Labor is either family or hired labor. The calibrated value for A_{fish} is 1.35.

Given this model calibration, and the equilibrium conditions described in the theoretical section, the model is solved to produce baseline outcomes that match the observed behavior. This produces a local economy-wide annual income of 425 million Lempira (∼\$22 million in 2012 dollars, or \$1300 per capita).[6]

4.3 Economy-Wide Impacts of Capital Restriction

The calibrated model is used to investigate the impacts of potential new fishery management policies in this region of Northern Honduras. Local groups, including fishermen, PROLANSATE (the non-governmental organization that manages the national parks[7]), and DIGEPESCA (the government body charged with regulating the fishery), have called for more strict management of the fishery and even temporary closures. While gear restrictions exist, Honduran law states that the country's natural resources (e.g., fish) belong to all and access cannot be restricted. Without placing a limit on the fishermen that can enter the fishery, boat restrictions can potentially limit access. Therefore, the management policy investigated here is a hypothetical restriction on capital in the fishery. We interpret this capital restriction as a reduction in boats in the fishery by assuming a Leontieff relationship between boats and other capital. In practice, fishermen may respond to a limit on boats by increasing the use of other capital or increasing the size of boats (Wilen 1979). This modeling exercise illustrates the extent to which limiting the amount of fishing capital allowed in fisheries can improve fish stocks, fishermen livelihoods, and local incomes over the medium run. It also demonstrates the spillovers into non-fishery sectors. This exercise considers the income and welfare of households that live within the study region. It does not consider, for example, the incomes of households that live outside the national parks but send labor to work in them.

To simulate a boat restriction, a binding cap is placed on the amount of capital allowed in the fishery. A cap is not likely to be economically efficient because of the potential substitutability between capital and other inputs (Wilen 1979; Campbell and Lindner 1990). Despite this, a limit on the number of boats can be relatively easily enforced and does not require direct monitoring of fishing output. Other policies could be explored similarly. With the cap in place, all equilibrium conditions hold with the exception that fishing capital is given exogenously by the cap. The remaining fish capital works in the tourism industry. Fishery rent is captured by capital in the fishery but the restriction prevents further entry. Labor continues to earn its marginal product plus a share of the resource stock value, because the cap restricts the number of boats but does not internalize the role of the resource stock in fishery production. As the resource stock recovers, higher labor productivity in the fishery allows economy-wide labor wages to increase.

For all experiments investigated here, an initial 20 % cut in fishery capital causes the fish stock to grow. This cap is increased after 5 periods to the original level of capital (though the fish stock and sustainable harvest levels are higher). It is assumed that the capital stock does not depreciate over this period. Table 2, Column 1 presents the open access steady-state outcomes for the economy without resource management. Column 2

[6] Nationwide, Honduras had a per-capita income of US\$1,880 in 2010; see IFAD, Rural Poverty in Honduras, http://www.ruralpovertyportal.org/country/home/tags/honduras.

[7] In this setting, PROLANSATE is charged with monitoring the national parks, including fishing that occurs within park boundaries, but cannot legally enforce park rules. They report violations to appropriate authorities.

Table 2 Impacts of input restriction in the fishery

	After 20 periods				First period of restriction	
	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	Capital restriction	Percent change from base	Restriction lifted, high fish stock	Capital restriction	Percent change from base
Fishery factor employment						
Family labor	35.75	42.80	19.72	45.31	33.14	−7.30
Hired labor	21.28	26.77	25.77	28.87	19.39	−8.88
Fishing capital	65.89	65.89	0.00	79.29	52.71	−20.00
Fish stock	345.79	541.13	56.49	541.13	345.79	0.00
Harvest	138.32	174.84	26.41	188.95	125.82	−9.03
Fish stock growth	138.32	185.88	34.39	185.88	142.02	2.68
Wages						
Family labor	1.00	1.05	5.06	1.07	0.98	−1.70
Fishing capital	1.00	1.00	0.00	1.13	0.87	−13.27
Income*	425.23	454.84	6.96	466.21	415.68	−2.25
Compensating variation, annual flow*	26.61		36.95		−8.58	
Compensating variation, present value*^						
Discount rate = 0		247.86				
Discount rate = 0.05		123.32				
Discount rate = 0.10		30.78				
Discount rate = 0.30		−2.76				
Value from the fish stock*	49.17	61.84	25.77	66.70	44.80	−8.88
Fishery rent*	0.00	17.04	n.a.	0.00	14.32	n.a.

* Million Lempira
^ Present value CV is the discounted flow of CV across the 20 year period. Discount rates are per period. Input restriction cuts fishing capital by 20 % for 5 years before returning to original level. This represents a restriction on the number of boats in the fishery. Columns 1–4 present results after 20 years of fish stock growth. Columns 5 and 6 show policy impacts in the first year

presents the outcomes that result from restricting the number of boats allowed in the fishery after 20 periods using baseline assumptions. Note that while the number of boats is fixed, there is more labor per boat as the existence of rent incentivizes more intense use of the restricted input. This extra use of labor helps prop up wages. Economy-wide annual income increases by 6.96 percent (∼\$1.55 million) with the higher fish stock and resource rent generated by the policy. Currently, the fishery factor payments contribute almost 30 % of local income and so the increased fish stock and fishery rent increase economy-wide income substantially.

Family labor wages paid in the economy increase because the higher fish stock supports more fishing effort. The increase occurs because of the increased demand in the fishery and because of income effects that increase demand for labor in other non-tradable sectors (e.g., services). Returns to fishing capital do not change outside the fishery (i.e., boats in tourism).

This indicates no indirect impact on the demand for fishing capital through demand linkages. This occurs because the non-fishery use of fishing capital includes only tourism, and tourism demand is exogenous. In other circumstances (e.g., if boats are also used widely for local transportation), the demand for capital could increase and cause the economy-wide capital wage rate to increase.

Capital that remains in the fishery collects a quasi-rent generated from the policy. Rent earned by fishing capital may present an opportunity to fund monitoring and enforcement efforts. Local managers could charge for boat licenses or registration and use the proceeds to coordinate monitoring efforts. It is important to create transparent mechanisms through which the fees can be collected and monitoring efforts can be directly observed by fishermen. This would minimize the opportunity for inefficient use or theft of license fees.

Compensating variation in column 2 shows that the restriction improves the welfare of the representative consumer relative to the base period. Specifically, after 20 years the representative local consumer could lose 26.6 million current value Lempira to return to the utility level associated with an unmanaged fishery at steady state. Unregulated factor employment increases in the fishery. Importantly, over the long run, compensating variation is positive but in the first 5 periods with the tighter restriction (and before fish stocks recover), there is an economic loss that occurs as economy-wide factor demand decreases. For example, in the first year of the capital restriction, labor and capital in the fishery are not very productive, even with restricted capital. As a result, labor and fishing capital wages decrease. Overall, consumers are worse off in the first year and willing to pay 9 million Lempira (∼\$475,000) to remove the regulation. Of course, this is a one-year measure of well-being; dynamic households may anticipate future earnings increases.

Once the restriction is loosened in period 6, compensating variation is positive relative to the base year. To account for the potential dynamic welfare tradeoffs associated with fishery management, we create a present value measure of compensating variation over the 20-year period, all relative to the base (steady state) no-management scenario. At low discount rates, this measure is positive, indicating a gain over time. As the discount rate increases, the benefits become smaller and become negative when the per-period rate exceeds 0.28. Note that the compensating variation reported here applies only to local households, and not households that send labor from other areas to work in the fishery.

Column 4 of Table 2 demonstrates that, if the restriction were lifted completely after 20 years with the higher fish stock, more capital and labor would enter the fishery, resulting in higher annual catch, wages, and income, but the catch would exceed fish stock growth and so this income level would not be sustainable. 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.

An important outcome of the policy simulated here (a capital restriction) is that fishery management does not have to decrease long-term incomes for factor suppliers in the fishery. If the cap is set to maximize sustainable yield, capital wages decrease to 95 % of the original level. Maximizing per-period rent sees a drop in capital wages to 2/3 the original level[8], consistent with the predictions of Scott (1957), Weitzman (1974) and Samuelson (1974). Therefore, the capital restriction keeps factor earnings in the economy higher than under privatization.

[8] Results derived from finding the cap level that achieves maximum physical yield or rent at the new steady state.

Table 3 Economy-wide impacts of fisheries management, year 20

	Percent changes						
	(1) Agriculture	(2) Fishing	(3) Fish-resale	(4) Retail	(5) Services	(6) Production	(7) Tourism
Consumption	7.02	7.00	7.00	2.83	4.19	5.56	n.a.**
Price	n.a.*	n.a.*	n.a.*	4.02	2.68	1.35	n.a.*
Output	−21.24	26.64	−0.33	7.23	1.40	1.01	0.00

Impacts are are from boat restriction that cuts fishery capital to 80 % of base value for 5 years before returning to original levels
* Prices do not change because the sectors are tradeable and prices are exogenous
** No local consumption of tourism

Indirect effects increase labor demand in other sectors, leading to less downward pressure on wages. In this case, even without counting the rent captured by remaining boats in the fishery, all suppliers of mobile capital and labor in the economy earn the same or more when the fishery is managed. In the Honduran model, the only input that experiences a decreased rental payment is land in agriculture. This occurs as labor captures a higher share of output (because of higher wages) and production decreases slightly as family labor earns more in the fishery. The economy imports more food as a result. Table 3 describes the changes that occur in all sectors after 20 periods of boat restrictions. Consumption of all locally consumed goods and services increases because of higher wages and incomes. Endogenous output prices also increase. Output, on the other hand, is not as uniformly impacted. Because wages and the returns to fishing go up, labor is pulled out of agriculture, causing agricultural production to fall. Land rent also falls as a result. Tourism production falls as boats and labor can earn more in the fishery with higher stocks. Note that the price of output in tradeable sectors is not affected by changes in the local economy.

Tables 2 and 3 show a snapshot of the economy after 20 years of fishery management but do not show the paths taken by the system. Figure 2 demonstrates the path of fish stock growth and harvest as well as the fish stock level. In year 20, the fish stock continues to grow and approaches a managed steady state after approximately 60 years that is nearly double the unmanaged level.

5 Discussion and Robustness

The model presented here provides a conceptual contribution to the literature by incorporating an open access market failure and resource dynamics into a GE framework. It is shown that fishery management has the potential to increase incomes for artisanal fishermen in Northern Honduras, and economic linkages spread impacts from the fishery to other sectors through factor markets and consumer demand. An economy which contains an unregulated resource sector receives a free input to production, despite the scarcity of that input. As a result, inputs are over-allocated to resource use, and this drives the resource stock to low levels. With higher resource stocks, household incomes increase in the medium and long run, despite initial income decreases before the fish stock recovers.

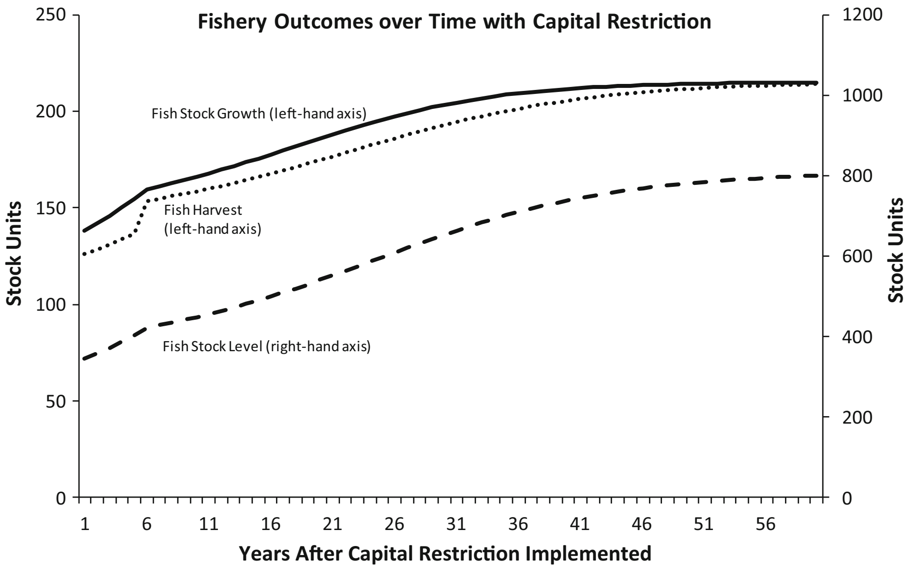

Fig. 2 Long-run impacts of fishery management of fish stock and harvest

5.1 Importance of Parameter Assumptions

Due to lack of data, some assumptions were made in order to parameterize our model, and so the exercise presented in this paper does not represent a precise impact assessment of fishery management in Northern Honduras. Despite this, important lessons can be learned using a sensitivity analysis that varies assumed parameters.

5.1.1 Sensitivity to Resource Stock Dynamics

The impact of a restriction on boats in the fishery depends on the parameters of the resource growth function. Table 4 demonstrates that the level of stock degradation under open access relative to a system's carrying capacity influences the impact of resource management. In each case, the initial fish stock and carrying capacity are adjusted so that the population begins at steady state at the corresponding proportion of carrying capacity. Harvest levels and the intrinsic growth rate remain constant. Results presented here are the impact of a capital restriction (20 % cut in capital followed by relaxation to the initial amount after 5 periods) after 20 periods under different assumptions on the initial stock's level relative to the carrying capacity. As the initial stock becomes more degraded, the gains from management increase (note that Table 4 presents percent changes). If the open access stock is highly degraded, with low fish growth, gains to management are large as sustainable harvests can increase substantially. This occurs because if the stock is low relative to carrying capacity, the carrying capacity and the maximum sustained yield in the fishery are higher. Management then has a bigger impact on the harvest levels that can be attained in the fishery and also has a bigger impact on input demands. Column 3 shows that impacts are smaller if the initial stock is higher. As the open access stock increases, the gains from management decrease.

Table 4 Impact of restriction on capital after 20 years, sensitivity to initial stock relative to carrying capacity (percent change)

Stock relative to carrying capacity	(1) 20 % of cc	(2) 10 % of cc	(3) 30 % of cc
Fishery factor use			
Family labor	19.72	54.74	6.19
Hired labor	25.77	78.89	7.80
Capital (boats)	0.00	0.00	0.00
Fish stock	56.49	216.91	15.70
Harvest	26.41	81.84	7.96
Wages			
Family labor	5.06	15.61	1.52
Fishing capital	0.00	0.00	0.00
Income	6.94	22.23	2.06

Restriction cuts fishing capital by 20 % for 5 years before returning to original level
Each column presents percent changes in variables under different assumptions about initial fish populations levels ($\times 0$) relative to carry capacity (cc)

5.1.2 Sensitivity to θ

An assumption was also required on the division of resource value between other fishing inputs. To explore sensitivity to this assumption, we vary θ from the base so that capital or labor collects all value, inputs split the value evenly, or only family labor and capital split the value evenly. Each case implies different units of fishing capital; thus, to make simulations comparable, the original amount of capital was cut to 80 % of baseline levels for the first 5 years of the simulation and then returned to the initial level after five years of fish stock growth. Overall, the income impact of management increases as capital (the regulated input) collects more of the resource value, though impacts are small (see Table 5). This occurs because the collection of resource value drives the inefficiency from common property. If capital collects all resource value, other inputs have no incentive to over-allocate to the sector. As expected, this also means that economy-wide labor wages are lowest if capital collects all resource value (column 2). On the contrary, if labor collects all of the resource value, regulating capital does less to remove the incentive for labor to enter the fishery. Nevertheless, all the resource income goes to local households in this case and incomes increase as a result. Also, labor and capital are not perfect substitutes so rent is still generated. In this case, there is still a misallocation of labor in the economy because the resource value provides an incentive for labor to work in the fishery beyond the optimal level. This scenario, while atypical in the literature, is consistent with one in which fishing labor hires restricted fishing boats but gets to keep the residual rents generated.

5.1.3 Sensitivity to Resource Contribution

Due to lack of data on fish stocks in Northern Honduran artisanal fisheries, an assumption was needed on the functional form of fisheries production. In the base, it is assumed that the production function is Cobb-Douglas with a fish stock elasticity of 0.4. Because there is little empirical evidence regarding the true value of this elasticity, Table 6 presents the

Table 5 Impact of fishery management* after 20 years, sensitivity to division of resource value (percent change)

Division of resource value	(1) Base	(2) Capital collects all resource value	(3) Even split between all inputs	(4) Family labor collects all resource value	(5) Even split between capital and family labor
Fishery factor use					
Family labor	19.73	20.63	19.66	18.24	19.13
Hired labor	25.79	25.65	25.79	25.89	25.81
Capital (boats)	0.00	0.00	0.00	0.00	0.00
Fish stock	56.46	55.59	56.52	57.91	57.06
Harvest	26.43	26.27	26.41	26.61	26.49
Wages					
Family labor	5.06	4.17	5.12	6.47	5.61
Fishing capital	0.00	0.00	0.00	0.00	0.00
Income	6.95	7.53	5.43	7.48	7.49

* Restriction cuts fishing capital by 20 % for 5 years before returning to original level
Table presents percent changes in variables under various assumptions about the capture of resource value, or theta from the theoretical presentation

sensitivity of results to this assumption. Each simulation assumes a different elasticity and restricts fishing capital to 80 % of initial levels for five years before returning to initial levels. As the fish stock elasticity increases, management impacts are reduced. This occurs because restricting more productive capital has a smaller effect on the fish stock growth over time. With an elasticity of 0.45, the fish stock does not reach a level of growth that can sustain the initial levels of productive capital. Once the initial restriction is relaxed, the additional capital begins to drive the stock back down towards its original steady state. With a lower elasticity, restricting capital reduces harvest more and allows the fish stock to reach a higher level before more capital enters the fishery. While the scenario in column two harvests at a level that allows the stock to grow even after 20 years, in column 3, the harvest exceeds fish population growth and will eventually push the harvest to its initial steady state. This exercise demonstrates that if fish production does not respond quickly to changes in regulated inputs, then managing the stock through an input restriction requires large decreases in inputs and more time for stock recovery.

5.1.4 Elasticity of Substitution

Finally, the impact of natural resource management can depend on the substitutability of inputs in the fishery and in other sectors of the economy. Increased substitutability can impact the ability for excluded fishery inputs to increase production in non-fishery sectors. In the fishery, as inputs are more substitutable, the capital restriction may not be as effective as labor enters in its place. Therefore, more substitutability means more labor inputs enter the regulated fishery in the short-run but over time this leads to a lower fish stock and diminished management impacts. This can be seen in Table 7, which demonstrates the sensitivity of management impacts to the elasticity of substitution between inputs in the economy. Cobb-Douglas production, used in the base model, assumes an elasticity of substitution equal to one. Table 7 demonstrates that increased input substitutability leads to lower stocks, lower factor

Table 6 Impact of fishery management, period 20, sensitivity to resource contribution to production (percent change)

Resource-output elasticity	(1) Base (0.4)	(2) 0.35	(3) 0.45
Fishery factor use			
Family labor	19.73	23.06	16.05
Hired labor	25.79	30.41	20.77
Capital (boats)	0.00	0.00	0.00
Fish stock	56.46	78.32	39.87
Harvest	26.43	31.20	21.26
Wages			
Family labor	5.06	5.98	4.07
Fishing capital	0.00	0.00	0.00
Income	6.95	8.23	5.57

* Restriction cuts fishing capital by 20 % for 5 years before returning to original level
Table presents percent changes in variables under different assumptions about the functional form of fishery production. In column 2, the fish stock has a smaller effect on output than in the base while in column 3 the fish stock has higher impact

Table 7 Impact of fishery management, period 20, sensitivity to elasticity of subsitution (percent change)

Elasticity of subsitution	(1) 0.7	(2) 1.5	(3) 2
Fishery factor use			
Family labor	28.47	9.52	6.79
Hired labor	48.42	13.36	8.92
Capital (noats)	0.00	0.00	0.00
Fish stock	93.48	14.05	9.17
Harvest	30.14	9.62	6.75
Wages			
Family labor	7.41	1.90	1.17
Fishing capital	0.00	0.00	0.00
Income	7.18	2.10	1.41

* Restriction cuts fishing capital by 20 % for 5 years before returning to original level
Table presents percent changes in variables under different assumptions about the functional form of production functions in the economy. In columns 2 and 3, inputs are more substitutable than in the base while in column 1, inputs are less substitutable

demands, and lower harvest levels in the medium term. If other inputs are not substitutable for the restricted capital, the result is a bigger decrease in harvest (conditional on the fish stock), leading to large increases in the fish stock over time. This can be seen in column 1 of Table 7, which presents management impacts with an elasticity of substitution equal to 0.7. The capital restriction leads to a large (93 %) increase in the stock over time because labor does not as readily substitute for capital in the fishery. This higher stock means that labor productivity and economy-wide wages are high after 20 years of management. On the other hand, with high elasticity of substitution, stocks do not recover as much and income impacts are smaller (column 3).

This modeling exercise represents the overuse of an open access natural resource in an applied general equilibrium framework. Because wages are endogenous and factors are mobile across sectors, rent is always dissipated in the unregulated resource sector, but incomes depend on the resource stock. Lower natural resource stocks decrease wages paid in the economy as well as the overall value in the economy. Resource management can increase economy-wide value by creating resource rent and raising factor demands and wages across the economy.

5.2 Policy Implications of the GE Tragedy of the Commons

Placing a resource sector within the larger local economy has several important policy implications. First, in the short-run, resource management can hurt labor and capital earnings in all sectors. Therefore, a fishery management policy—including possible compensation for those who are adversely affected—needs to consider impacts beyond the fishery. For example, fishery managers could look for ways to employ excluded boats (e.g., for monitoring new rules) to mitigate the drop in local employment in the short run. Indirect local economic impacts of exclusion imply that the welfare implications for non-fisher as well as fisher households need to be taken into account when designing fishery management and compensation strategies.

Another important implication resulting from the GE tragedy of the commons is consistent with the fishery economics literature in that regulating one input does not eliminate inefficiencies. Here, regulating capital creates a rent in the fishery, and if labor captures some of this rent it continues to over-allocate to the fishery. While difficult in practice, most economists believe that creating property rights over the fish stock should be the ultimate goal of management. This could include top-down management through transferable quota systems or local management in which communities cooperate to generate value from local fisheries. The results presented here illustrate that medium term gains exist from implementable second-best forms of management.

Finally, the linkages between sectors indicate that effort supplied to the fishery sector does not occur in isolation. Returns in other sectors are integrally connected with fishing effort and value of production. Therefore, fishing policy could have important interactions with other development policies focused on sectors, such as agriculture or tourism. For example, increasing demand for local tourism can increase the value of boats and labor in tourism, which can pull effort out of the fishery. If this occurs concurrently with boat restrictions, the short run costs of management might be mitigated.

6 Conclusion

As the global demand for sustainably-harvested seafood continues to grow, new strategies will be needed to manage small-scale fisheries that are intimately connected with poor local economies. This paper presents a model of the tragedy of the commons in a GE framework. It demonstrates that, despite resource rent dissipation, resource stocks may play an important role in remote rural economies. This highlights the importance of using a GE model to examine the value of open access resources because in partial equilibrium, all fishery net value comes from resource rent. If a fishery is managed, value in the local economy increases in time as resource rent is generated from a recovered resource stock. Economic linkages transmit some of the increase in fishery value to other sectors of the economy. However, management generally implies exclusion from the fishery, and linkages also transmit the adverse impacts of this exclusion.

Challenges to calibrating this model illustrate the significant data shortages that exist in developing country fisheries and the local economies of which they are part, and they point to future priorities in data collection. Precise calibration requires parameterization of fishery production functions that account for the contribution of the resource stock. Ideally, this requires time series biological data on fish stocks, combined with economic data measuring fishery effort by different inputs as well as harvest (and its value) over time. Such data would also allow for better parameterization of fish growth, perhaps considering interactions between many species. Analyzing fisheries in the context of local economies requires micro-data from local surveys of non-fisher households and businesses as well as fisher households.

Research is needed to gain a clearer understanding of how non-resource inputs capture natural resource value. While contributing towards economy-wide resource modeling, such research can also reveal insights into why fishermen often oppose the rationalization of fisheries. One possible explanation is that rationalization takes resource value (not necessarily rent) from some inputs and allocates it to newly created resource owners.

The results presented above have important policy implications for resource managers and governments in resource dependent economies. The economy-wide value from natural resource stocks does not necessarily go to zero as rents dissipate. Instead, renewable natural resource collection represents an important source of employment that maintains wages and incomes in remote developing economies. While resource management increases resource value, rent dissipation does not imply zero resource value for the economy.

The Honduran case study illustrates that fishery policy could enhance incomes of poor households beyond the regulated fishery. It is important to note that in the first few years of the policy, incomes fall and so compensation may be required so that households do not fall into poverty and potentially be tempted to break regulations as their consumption drops. Despite this, as resource stocks recover, it is possible for resource management to contribute towards higher wages in the local economy. The benefits of management and increased harvests are more pronounced for fishermen when they have access to integrated markets, preventing a fall in the output price of fish. Therefore, management and market integration policies may be complementary (though market integration could adversely impact local consumers if it raises fish prices).

The numerical application presented here demonstrates the importance of considering GE effects of fishery management in rural village economies. The opportunity cost of fishing is derived from returns in other sectors of the economy. In the short-run, excluding fishing labor and capital from the fishery means that more labor and capital are employed in other sectors, pushing down wages across the rural economy. In the longer-term, fishery rent is generated but this represents only a small part of the overall increase in welfare in the economy that results from higher incomes. In fact, in our model, fishery rent generated represents just 64% of the compensating variation associated with the change from baseline to a managed fishery (Table 2). Using a partial equilibrium model or focusing only on the fishery would miss these additional long-term benefits of resource management.

In the presence of economic linkages, policymakers must consider management impacts on fishermen and non-fishermen because regulating the fishery changes the allocation of labor and capital throughout the local economy. Even if benefits exist for all in the long-run, poor households may not be in a position to wait for long-term benefits. High marginal utility of consumption can make the short run costs of regulation (demonstrated here) not worth the investment, especially if non-fishing households experience these costs but then do not collect resource rents as the resource recovers. In isolated rural economies, these distributional considerations are crucial for understanding the impacts of management and on obtaining buy-in from local households to implement policy.

The theoretical model presented in this paper predicts that employment in a resource sector decreases as the resource stock erodes. This contrasts with a model of rent dissipation in which fishing effort slowly increases until fish stocks are driven to low steady-state levels. Future empirical work should examine the behavior of resource collectors as resource stocks deplete over time. It is likely that in capital intense settings, slow rent dissipation leads to increased effort over time as fishing capital enters local economies. In smaller, isolated economies with a relatively fixed capital stock but lower transition costs between sectors, economic rents likely dissipate rapidly. As the resource sector provides lower returns for inputs over time, fewer inputs work in the sector.

Modeling open access resources represents a challenge because the resource receives no explicit payment. Building on previous literature that has tackled this problem in the context of regulated open access (Finnoff and Tschirhart 2008), we provide a framework to include an open access sector in GE models. Wage endogeneity and mobile factors produce a qualitatively different picture of how remote rural communities use open access resources over time. Policy implications that follow from this model differ from those based on a model depicting a fishery in isolation from the rest of the local economy.

Appendix: Modified Social Accounting Matrix for Northern Honduras Fishing Communities

See Table 8.

Table 8 Tela Bay area communities social accounting matrix (Millions of Lempiras)

	Agriculture	Fishing	Fish resale	Retail	Services	Production	Tourism	Government	Households	Family labor	Low-skilled labor	High-skilled labor	Fishing capital	Land	Fish population	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								132.10	138.32
Fish resale									6.92								6.36	13.28
Retail		15.40		1.01		0.34			67.60									84.34
Services	0.16					0.01			3.61								4.59	8.37
Production						0.02			10.38								46.78	57.17
Tourism																	7.68	7.68
Government									12.34									12.34
Households								0.22	0.19	63.11	31.70	37.89	40.76	2.45	49.17	22.36	177.39	425.23
Family labor	11.68	21.45	0.26	12.51	2.48	14.73												63.11
Low-skilled labor	2.42	12.77		1.15	0.01	5.39											9.97	31.70
High-skilled labor							3.49	0.17									34.23	37.89
Fishing capital		39.53					1.22											40.76
Land	2.45																	2.45
Fish population		49.17																49.17
Physical capital			3.85	13.80	1.35	0.38	2.97											22.36
External trade	8.23		7.63	49.31	4.53	32.59		11.95	319.66									433.90
Total	28.32	138.32	13.28	84.34	8.37	57.17	7.68	12.34	425.23	63.11	31.70	37.89	40.76	2.45	49.17	22.36	433.90	1456.37

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