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Understanding Livelihoods of Artisanal Fisheries in Marine Protected Areas in the Colombian Caribbean

A Fishing Household Production Model

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Abstract

In developing countries, artisanal fishing communities typically exhibit high poverty, vulnerability levels and a marked dependence on fishing resources for their subsistence. Nevertheless, there does not exist sufficient information about these relationships and their dynamics. This study contributes to (i) understanding artisanal fisheries' livelihoods located in the influence zone of a marine protected area in the Colombian Caribbean and (ii) identifying how key economic parameters affect fishing household decisions, including the use of marine resources. We propose a fishing household production model, where households make simultaneous decisions about consumption and production. Fishing plays a central role in those decisions as a source of income and food security. The theoretical model is validated with information collected every month during one year from fishing households in the village of Barú (Colombia). The calibrated model permits us to simulate the effects of different policies on the use and management of artisanal fisheries and on the fishing household's wellbeing. Our findings offer insights for the design of policies aimed at both the sustainable use of marine resources and the social development of these communities.

Keywords*:* artisanal fisheries; sustainability; livelihoods; developing countries.

JEL Codes: C63, C83, D13, J22, O13, Q22, Q56, Q57

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INTRODUCTION

The importance of sustainable small-scale fisheries has become increasingly recognized as a challenge in fishing economics (Lancker et al., 2019; FAO & World Fish Center, 2008). Small-scale fisheries are responsible for about half of the annual marine catch worldwide (FAO, 2020), and represent 90% of the employment in the fishery sector (FAO, 2020). Part of this employment rate includes the many communities that are highly dependent on fishing resources for their subsistence (Allison & Ellis, 2001; Olale & Henson, 2013). In Colombia, between 67,000 and 150,000 fishers and their households depend on fish resources, and one-third of these fishers depend on fish stocks in coastal areas (OECD, 2016).

Although the production of marine fishing, in terms of catch quantity, has tended to remain more or less constant in temperate and outcropping areas and to increase slightly in tropical areas, the percentage of species populations exploited at biologically unsustainable levels increased from 10% in 1974 to 34.2% in 2017 (FAO, 2020). This is of importance in tropical countries such as Colombia, which have a great diversity of species, but little abundance.

For the specific case of marine fisheries in Colombia, Rueda et al. (2019) report a decline in landed catch since 2006. This result may be associated with the reduction in the profitability of the fisheries of some species and low competitiveness (Merino et al., 2013), the degradation of the fishing resource evidenced in a considerable number of marine species under some category of threat (Ardila et al., 2002), and the increase in the ecological footprint of their fisheries (Vargas-Morales et al., 2013).

The degradation of marine-coastal ecosystems, coupled with disturbances such as climate change and high levels of poverty in coastal areas, increases the vulnerability of artisanal fishing communities (Salas et al., 2011). It affects not only their food security but also the ability of the households to obtain other goods and services. For this reason, understanding artisanal fishers' livelihoods and identifying key economic parameters that affect fishing household decisions – including the use of marine resources – is essential to design policies aimed at the sustainable use of marine resources and the social and economic development of fishing communities.

This study seeks to answer two research questions: (i) how economic decisions of fishing households define their livelihoods, and (ii) what policies could be implemented to promote sustainability in marine-resources use while improving local communities' living standards.

Following the model developed by Singh et al. (1986), this study proposes a Fishing Household Production Model (FHPM) that recognizes the nature of the common-pool resource of the artisanal fisheries. To develop an empirical simulation of the model and identify the key economic parameters affecting the livelihoods of fishers, monthly socioeconomic data was collected in Barú village, a fishing community in the Colombian Caribbean, from July 2018 to September 2019. We carried out a baseline survey, followed by monthly surveys applied to 100 fishing households.

Located close to Cartagena, Barú is an island inhabited by traditional communities and is a major tourist destination, which exposes it to demands for different ecosystem services such as seafood and recreation. In addition, Barú is located within the limits of a natural park, created in 1977 to protect strategic marine ecosystems. These features create a conflict among local communities, authorities, and the tourism industry that threatens social and environmental sustainability and communities' livelihoods.

This document is organized as follows. After this introduction, we present a discussion on the use of a household production model in this framework. In section three, we present our theoretical approach to the FHPM, from which we estimate the demand and supply functions and the corresponding elasticities to key parameters. Section four introduces the study site, the survey, and some descriptive statistics of the population in Barú. In section five, we develop the model calibration and simulation, followed by section six, where we analyze the implications of a set of policy interventions on the key variables associated with the livelihoods of fishing households. Section seven discusses the main results, and we conclude the study in section eight.

1. HOUSEHOLD PRODUCTION MODELS – HPM

1.1 DEFINING HPM

Rural households in semi-market economies produce goods and services partly for sale and partly for self-consumption; they consume market goods and inputs while utilizing family labor for production and for sale in the market (Singh et al., 1986). One way to approach the complex dynamics of rural households is by applying household production models (HPMs). HPMs combine production, consumption, and labor force supply decisions of rural households that are semi-integrated into markets. Under a recursive structure, the HPM combines the components of utility and profit maximization.

HPMs address the decision-making process in rural households, whose behavior as producers affects their behavior as consumers and in the labor force, and vice versa. In particular, these models allow us to identify how government interventions (e.g., policies on input or output prices, decisions on social investment projects, conservation policies) affect households' decisions on how much to consume, how much to produce, how much labor to devote to their main productive activity, and how much of that labor to sell to the market. These decisions affect food security, income generation, and diversification of productive activities within the household.

HPMs differ from traditional consumer theory models. In particular, while the latter consider the substitution effect and the income effect to make predictions about household behavior when a change in the price of a good occurs, the HPM also considers the profit effect (Singh et al., 1986). Because of this, the results in an HPM, in terms of consumption and labor supply, may or may not be the same as those found using a conventional model. For example, if there is an increase in the price of a good produced – but also consumed – by the household, the traditional consumer model would reflect only the substitution and income effect of the price change. The substitution effect is unequivocally negative. In addition, an increase in the price of a good will reduce real income, and, therefore, consumption of a normal good is expected to decrease as a result of the income effect. For both reasons, the traditional model predicts a reduction in the consumption of the good as a result of an increase in its price.

However, an HPM allows for a profit effect, which implies that, if the price of the produced good increases, the household's income increases, and therefore so do its profits. This increase in earnings generates a greater demand for all types of goods, including the goods produced in the household. Thus, in an HPM, the demand for the good produced (and at the same time consumed) in the household does not necessarily decrease in response to increases in its price. The demand for this particular good will be "subject to two forces pushing in opposite directions" (Singh et al., 1986). The final effect on consumption can only be deciphered empirically and in each particular case.

The profit effect also affects the labor supply of households. While typically an increase in the price of a produced good implies an increase in the family's labor supply, HPMs anticipate a reduction in the household's labor force supply, because, as their income increases, households are willing to give up some income in exchange for more leisure, decreasing the effort to produce the good (Singh et al., 1986). That is, there are two forces pushing in opposite directions: as producers, they might want to work more, while as consumers they would want to consume more leisure.

Another difference between conventional models and HPMs is found in the effects of changes in wages on labor supply. In consumer-only models, an increase in wages implies an increase in household income and therefore in the consumption of goods, whereas the labor force supply may either increase in response to the higher price paid for labor or decrease as the household consumes more leisure. In HPMs, higher wages may increase the opportunity costs of labor time allocated to household production, reducing self-production earnings.

In terms of production decisions, HPM leads to the same results as those derived from using conventional firm-theory models (Singh et al., 1986).

1.2 Applying HPM to Fishing Households

Artisanal fishers are, by definition, rural households and are part of a family farming or peasant economy (Firth, 1946; Forero, 2003; Foster, 1972; Machado et al., 1993; Maldonado et al., 2007; Pérez and Pérez, 2002; United Nations, 2018). Following Garay et al. (2009), some characteristics of this type of household are: (i) land and capital are limiting factors;

fishing households usually don’t have access to land, (ii) the family's labor force is the main factor of production; (iii) the product of its extractive activities is used for both household self-consumption and sale, (iv) the households do not seek to maximize monetary profits but to guarantee food and income to satisfy other basic household needs and to acquire other goods; (v) household income is low and comes from a multiplicity of productive activities; and (vi) households are integrated into the market through their sale of harvested products and labor, and the purchase of inputs and other goods and services.

The definition of artisanal fishing in Colombia, established in Article 12-2.4.1 of Decree 2256 of 1991 (Ministerio de Agricultura, 1991), strengthens the relationship between fishers and peasants: artisanal fishing is an extractive activity “carried out by fishers in an individual or organized manner, in companies, cooperatives or other associations, with their independent personal work, with equipment appropriate to a small-scale productive activity and by means of small-scale fishing systems, gear and methods.”

There are several particularities that differentiate fishers from farmers. Pascual-Fernández (1997) argues that fishers are closer to hunters than to farmers, due to the harvesting-type nature of the activity (the prey must be sought, located and captured) and the fact that there is no control over the resource or the natural systems where the activity takes place. In fishing, unlike farming, the productive factor associated with natural capital does not constitute a private good – or collective property – but a common pool resource (CPR), characterized by rivalry and non-exclusion, where allocating and exercising property rights is complex.

Bearing this in mind, an adjusted HPM could appropriately explain the production and consumption decisions of fishing households, and can be used successfully to analyze how various policy interventions can affect those decisions and ultimately their wellbeing.

De la Montaña et al. (2015) follow the Singh et al. (1986) model to understand how key economic parameters affect the hunting of wild fauna in indigenous communities in the Ecuadorian Amazon. In particular, this model develops an application of HPM for hunters, assuming that the resource – wildlife – is a purely public good, characterized by non-rivalry and non-exclusion. De la Montaña et al. (2015) implicitly assume that the catch is lower than the rate of resource regeneration and therefore neither the stock nor the profits of the hunting households are affected by the joint extraction of all the hunters, allowing hunting to be treated as non-rival. Under this assumption, De la Montaña et al. (2015) do not include the effect of hunting on the resource stock in their model.

However, artisanal fisheries generally behave as the classic example of a common pool resource, characterized by rivalry, which leads to overexploitation of the resource such that profits eventually vanish (Gordon, 1954; Hardin, 1968). Therefore, unlike the model proposed by De la Montaña et al. (2015), who assume that the extracted resource is a pure public good, in an artisanal fishing model the profits from the activities depend on the stock.

Our fishing household production model is based on Singh et al. (1986) and De la Montaña et al. (2015). Our contribution is to include a fishing production function where the resource stock is a key variable in the generation of HPM profits.

2. THE FISHING HOUSEHOLD PRODUCTION MODEL – FHPM

2.1 DEFINITION OF VARIABLES

In this model, the fishing household catches a "representative" species with a "representative" fishing gear. The catch (Y) can be consumed in the household or sold in the market. Let's call γ the proportion of the catch dedicated to self-consumption, so that γY will be the consumption in the household and $(1-\gamma)Y$ the amount of fish sold. Although the main productive activity of the fishing household is fishing, it also conducts other activities to complement its income. This implies that the household has time available for productive activities $\bar{L}$, which it can dedicate to fishing L_y or to other activities L_{off}.

The household income is from the sale of fish and other productive activities: $P_y(1-\gamma)Y + wL_{off}$. In this expression, w and P_y denote, respectively, the wage obtained in other income-generating alternatives and the price of fish. The household's expenses are those related to the fishing activity costs and the purchase of consumer goods, F, which can be other food or provisions acquired on the market, including fish.

The costs of the fishing activity depend directly on the quantity of fish extracted Y, and inversely on the amount of resource in the sea, S. A functional form that reflects these characteristics would be $\frac{\theta Y}{S}$, where θ is a parameter that converts the relationship between the catch and the resource stock to monetary terms. We call this parameter the intensity of cost function. Also, $\frac{\theta}{S}$ reflects the marginal cost (and at the same time the average cost) of the catch.

The household consumption expenses are given by the quantities, F, and by their price P_f, that is: $P_f F$.

A fishing household exhibits a utility function that depends on fish consumption (γY) and the consumption of other goods (F) as presented in Equation (1):

$$\widehat{U} = F^{\alpha_f}(\gamma Y)^{\alpha_y} \tag{1}$$

This function can be transformed by applying the logarithm:

$$U = ln\,(\widehat{U}) = \alpha_f \, ln\, F + \alpha_y \, ln(\gamma Y) \tag{2}$$

where parameter α_f represents the weight of consumption of goods purchased on the market (F) for household utility, and α_y represents the weight of self-consumption of fish for household utility. This function can be transformed so that $\alpha_f + \alpha_y = 1$ without affecting the results.

The fishing household's utility shows – *ceteris paribus* – a positive but decreasing marginal utility of consumption of both goods acquired on the market (F) and fish consumption (γY)[1].

Household budget constraints require that income be equal to household costs; i.e.,

$$P_y(1-\gamma)Y + wL_{off} = P_f F + \frac{\theta Y}{S} \tag{3}$$

where the expression $P_y(1-\gamma)Y$ reflects the income received from fish sold, and the expression wL_{off} is the income the household receives from working in non-fishing activities.

In the fishing economy, it is typically assumed that the production function depends on two types of factors. The factors associated with human activity are grouped under fishing effort,

[1] In other words, the assumption about the concavity of the utility function must be fulfilled: $\frac{dU}{dF} \geq 0$; $\frac{dU}{dY} \geq 0$; $\frac{d^2U}{dF^2} \leq 0$; $\frac{d^2U}{dY^2} \leq 0$.

E. The natural factor is represented by the availability of the extracted resource or stock, S. Thus, the fishery production function can be represented by Equation (4):

$$Y = Y(E, S) \tag{4}$$

The effort (E) depends, in turn, on the labor involved in fishing, (L_y), and the capital invested, (K), as shown in Equation (5):

$$E = E\left(L_y, K\right) \tag{5}$$

If we assume that capital is constant, then we can explain effort as a function of labor, as represented by Equation (6):

$$E = E\left(L_y\right) \tag{6}$$

Therefore, production is a function of the resource stock and of the labor force involved in fishing (replacing equation (6) in (4)):

$$Y = Y\left(S, E\left(L_y\right)\right) = Y(S, L_y) \tag{7}$$

Assuming a non-linear production function, we propose the following functional form in Equation (8):

$$Y = \varphi L_y^{\beta} S \tag{8}$$

where φ is a parameter reflecting total factor productivity, typical of a Cobb-Douglas function, and β corresponds to a technical parameter that shows the efficiency of the fishing labor force.

Finally, another constraint is that the household's labor force available for productive activities is limited by the family's time allocation, $\bar{L}$, which must therefore be distributed between fishing and alternative work activities. Thus:

$$\bar{L} = L_{off} + L_y \tag{9}$$

$\bar{L}$ is the household labor force or time the household members spend on productive activities, and does not include time spent on leisure or rest.

In the FHPM, the household seeks to maximize its utility subject to a set of constraints, as follows:

$$Max_{F,\gamma,Y,L_y,L_{off}}\ U = \alpha_f\ ln(F) + \alpha_y ln(\gamma Y) \tag{10}$$

Subject to:

(i) $P_y(1-\gamma)Y + wL_{off} - P_f F - \frac{\theta Y}{S} = 0$

(ii) $Y = \varphi L_y^{\beta} S$

(iii) $\bar{L} = L_{off} + L_y \rightarrow L_{off} = \bar{L} - L_y$

2.2 HOUSEHOLD DEMAND AND SUPPLY FUNCTIONS

The maximization of the household's utility yields the functions of:

- labor supply for fishing (L_y),
- labor supply for non-fishing productive activities (L_{off}),
- fish supply (catch) (Y),
- proportion of fish for household consumption (γ),
- quantity of fish consumed in the household (γY), and
- demand for goods purchased on the market (F).

These functions are presented in Table 2-1. As expected, production variables (fish supply and labor supply for fishing and non-fishing activities) behave as conventional models would predict. For instance, the total fish catch (13) will depend directly on the resource stock (S), the productivity of the fishing-associated factors (φ), the efficiency of the fishing labor force (β), and the net profit per unit of fish ($P_y - \theta/S$), and inversely on the wage received from other productive activities (w).

Consumption variables (self-consumed fish and goods purchased on the market) exhibit the particular characteristic of a HPM.

The quantity of fish caught that the household leaves for its own consumption (γY) – Equation (15) – depends directly on the weight of fish consumption for household utility (α_y), on resource availability (S), on the time available for work ($\bar{L}$), on the productivity of fishing φ, and on the marginal net benefit of fishing $\left(P_y - \frac{\theta}{s}\right)$. The relationships of the price of fish and wages are not directly observable. This is because the price of fish plays a double role: on the one hand, the effect is negative because it reduces demand for the good; on the other, it is positive through the profit effect, since it increases income from the sale of fish, providing more possibilities for consumption. Something similar occurs with wages. On the one hand, the income from alternative activities increases along with wages, leading to a greater consumption of goods, including fish. On the other, a higher wage reduces the incentive to fish and therefore reduces the quantity of fish for consumption.

Table 2-1. Summary of the optimal supply and demand functions resulting from the FHPM

Demand/ Supply	Mathematical expression	Equation
L_y = Fishing labor supply	$L_y = \left(\frac{\beta\varphi S}{w}\left(P_y - \frac{\theta}{s}\right)\right)^{\frac{1}{1-\beta}}$	(11)
L_{off} = Non-fishing labor supply	$L_{off} = \bar{L} - \left(\frac{\beta\varphi S}{w}\left(P_y - \frac{\theta}{s}\right)\right)^{\frac{1}{1-\beta}}$	(12)
Y = Fish supply: Total catch	$Y = \left(\varphi S\left(\frac{\beta}{w}\left(P_y - \frac{\theta}{s}\right)\right)^{\beta}\right)^{1/1-\beta}$	(13)
γ = Proportion of fish for household consumption	$\gamma = \frac{\alpha_y}{P_y}\left[\bar{L}\left(\frac{w}{\varphi S\left(\beta\left(P_y - \frac{\theta}{s}\right)\right)^{\beta}}\right)^{1/1-\beta} + \left(P_y - \frac{\theta}{s}\right)(1-\beta)\right]$	(14)
γY = Demand for fish for household consumption	$\gamma Y = \frac{\alpha_y}{P_y}\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{s}\right)\right)^{1/1-\beta}\right]$	(15)
F = Demand for other consumption goods	$F = \frac{\alpha_f}{P_f}\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta} S\varphi\left(P_y - \frac{\theta}{s}\right)\right)^{1/1-\beta}\right]$	(16)

The demand for goods acquired on the market (F) (Equation (16)) depends directly on the price of fish (P_y) (through the income effect), on the weight of the consumption of goods other than fish for the household's utility (α_f), on the marginal net profit of fishing $\left(P_y - \frac{\theta}{s}\right)$ and on resource availability (S). This demand for other goods depends inversely on their price (P_f), which is the normal effect of price on demand. The effect of wages is ambiguous because it increases the income from alternative activities, but reduces the incentive to fish as a source of income generation.

Note that resource availability plays a central role in household wellbeing, since it increases the possibility of the consumption of both fish and other goods.

2.3 COMPARATIVE STATICS: ELASTICITIES

Comparative statics identify how the estimated supply or demand functions change in response to changes in key parameters; these can be derived by using estimates of the relevant demand and supply elasticities. We calculated the elasticities of the functions estimated by the model (L_y, L_{off}, F, Y, γ, γY), in the face of changes in several key economic parameters: prices (P_f, P_y, w), technical and cost parameters of the fishing activity (φ, θ), the availability of the extracted resource (S), and the households' time availability for productive activities ($\bar{L}$). The sign of the elasticity shows whether the supply or demand of the good increases or decreases when faced with an increase in the key parameter analyzed. In some cases, this sign is unequivocal; in others, it is ambiguous and the final value depends on the context. As discussed above, some parameters have effects that act on variables in two different ways, so the final sign will depend on the balance between the effects. Similarly, the magnitude of the elasticities is an empirical question and comes from household survey data.

2.3.1 Fishing labor supply (L_y)

Table 2-2 presents the elasticities for the household labor force supply for fishing (Ly). The signs of the elasticities tell us that a one percent increase in the price of fish (17), in the productivity of fishing-associated factors (20) and in the resource stock (21) increases household's labor force available for fishing, while a one percent increase in the wage from productive non-fishing activities (18) and in the intensity of fishing costs (19) reduces the household's fishing labor force.

In this model, decisions on using the labor force for fishing do not depend on the price of other goods or on the household's total time engaged in productive activities.

Table 2-2. Elasticities of the fishing labor supply (L_y) in response to changes in key parameters

Parameter	Elasticity	Equation
$P_y =$ fish unit price	$\eta_{L_y,P_y} = \dfrac{P_y}{(1-\beta)\left(P_y - \frac{\theta}{S}\right)} > 0$	(17)
$w =$ wage	$\eta_{L_y,w} = \dfrac{-1}{1-\beta} < 0$	(18)
$\theta =$ intensity of fishing costs	$\eta_{L_y,\theta} = \dfrac{-\theta}{(1-\beta)S\left(P_y - \frac{\theta}{S}\right)} < 0$	(19)
$\varphi =$ productivity of fishing-associated factors	$\eta_{L_y,\varphi} = \dfrac{1}{1-\beta} > 0$	(20)
$S =$ resource stock	$\eta_{L_y,S} = \dfrac{P_y}{(1-\beta)\left(P_y - \frac{\theta}{S}\right)} > 0$	(21)

Assumptions: $\left(P_y - \frac{\theta}{S}\right) > 0$; $0 < \beta < 1$.

2.3.2 Labor supply for other activities (L_{off})

As shown in Table 2-3, increases of one percent in the wage (23), in the intensity of the cost of fishing (Eq. 24), and in the available household labor force supply (Eq. 27) increase the household's labor force for other activities. Increases of 1% in the price of fish (Eq. 22), in the productivity of fishing-associated factors (Eq. 25), and in resource stock (Eq. 26), reduce the household labor force dedicated to non-fishing income-generating activities. As with fishing labor force-related decisions, non-fishing labor force decisions do not depend on the price of consumer goods, P_F.

Table 2-3. Elasticities for labor for non-fishing activities (L_{off}) in response to changes in key parameters

Parameter	Elasticity	Equation
P_y = fish unit price	$\eta_{L_{off},P_y} = \frac{-P_y}{(1-\beta)} \frac{\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)^{\beta}\right)^{\frac{1}{1-\beta}}}{\bar{L}-\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)\right)^{\frac{1}{1-\beta}}} < 0$	(22)
w = wage	$\eta_{L_{off},w} = \frac{1}{1-\beta} \frac{\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)\right)^{\frac{1}{1-\beta}}}{\bar{L}-\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)\right)^{\frac{1}{1-\beta}}} > 0$	(23)
θ = intensity of fishing costs	$\eta_{L_{off},\theta} = \frac{\theta}{1-\beta} \frac{\left(\frac{\beta\varphi}{w}\left(S\left(P_y-\frac{\theta}{S}\right)\right)^{\beta}\right)^{\frac{1}{1-\beta}}}{\bar{L}-\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)\right)^{\frac{1}{1-\beta}}} > 0$	(24)
φ = productivity of fishing-associated factors	$\eta_{L_{off},\varphi} = \frac{-1}{1-\beta} \frac{\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)\right)^{\frac{1}{1-\beta}}}{\bar{L}-\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)\right)^{\frac{1}{1-\beta}}} < 0$	(25)
S = resource stock	$\eta_{L_{off},S} = \frac{-P_y}{1-\beta} \frac{\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)^{\beta}\right)^{\frac{1}{1-\beta}}}{\bar{L}-\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)\right)^{\frac{1}{1-\beta}}} < 0$	(26)
$\bar{L}$ = available household labor force	$\eta_{L_{off},\bar{L}} = \frac{\bar{L}}{\bar{L}-\left(\frac{\beta\varphi S}{w}\left(P_y-\frac{\theta}{S}\right)\right)^{\frac{1}{1-\beta}}} > 0$	(27)

Assumptions: $\left(P_y - \frac{\theta}{S}\right) > 0$; $0 < \beta < 1$.

2.3.3 Fish supply: Total catch (Y)

Table 2-4 presents the elasticities of the fish supply (total catch) in response to changes in parameters. Specifically, equations (28), (31), and (32) indicate that an increase of 1% in the price of fish, in the productivity of fishing-associated factors, and in the resource stocks will generate an increase in the catch, while an increase of 1% in the parameter associated with fishing costs (Eq. 30) and in the wage offered for non-fishing productive activities (Eq. 29) will reduce the catch. On the other hand, the catch does not depend on the price of consumer goods, P_F, or on the total labor force supply for productive activities.

Table 2-4. Elasticities of the fish supply (Y) (total catch) in response to changes in parameters

Parameter	Elasticity	Equation
$P_y =$ fish unit price	$\eta_{Y,P_y} = \frac{\beta}{(1-\beta)} \frac{P_y}{\left(P_y - \frac{\theta}{S}\right)} > 0$	(28)
$w =$ wage	$\eta_{Y,w} = \frac{-\beta}{1-\beta} < 0$	(29)
$\theta =$ intensity of fishing costs	$\eta_{Y,\theta} = \frac{-\beta\theta}{(1-\beta)S\left(P_y - \frac{\theta}{S}\right)} < 0$	(30)
$\varphi =$ productivity of fishing-associated factors	$\eta_{Y,\varphi} = \frac{1}{1-\beta} > 0$	(31)
$S =$ resource stock	$\eta_{Y,S} = \frac{1}{1-\beta}\left(\frac{\beta\theta}{S(P_y - \frac{\theta}{S})} + 1\right) > 0$	(32)

Assumptions: $\left(P_y - \frac{\theta}{S}\right) > 0; 0 < \beta < 1.$

2.3.4 *Proportion of fish for household consumption* (γ)

Table 2-5 presents the elasticities related to the decision regarding the proportion of fish the household itself consumes. Equations (34) and (38) indicate that a 1% increase in the wage and availability of household labor force increases the proportion of fish that households keep for their own consumption. On the other hand, if the productivity of fishing-associated factors is increased by 1%, the proportion allocated to household consumption is reduced (Eq. 36), perhaps because selling the product carries more weight than consuming it. Note that the signs associated with the resource stock effect (Eq. 37), the intensity of fishing costs (Eq. 35) and the fish price effect (Eq. 33) cannot be determined theoretically. Particularly for the price of fish, this ambiguity shows the dilemma between reducing consumption because of the effect on fish demand or consuming more via the profit effect as a result of the increase on the market price of fish.

Table 2-5. Elasticities for the proportion of fish intended for household consumption (γ)

Parameter	Estimated elasticity	Eq.
$P_y =$ fish unit price	$\eta_{\gamma,P_y} = \dfrac{\dfrac{\theta(1-\beta)}{S} - \dfrac{\bar{L}}{1-\beta}\left(\dfrac{w}{\varphi S\left(P_y-\frac{\theta}{S}\right)\beta^{\beta}}\right)^{1/1-\beta}\left(\dfrac{SP_y-\theta(1-\beta)}{S}\right)}{\left[\bar{L}\left(\dfrac{w}{\varphi S\left(\beta\left(P_y-\frac{\theta}{S}\right)\right)^{\beta}}\right)^{1/1-\beta}+\left(P_y-\frac{\theta}{S}\right)(1-\beta)\right]} \lesseqgtr 0$	(33)
$w =$ wage	$\eta_{\gamma,w} = \dfrac{\dfrac{\bar{L}}{(1-\beta)}\left(\dfrac{w}{\varphi S\left(\beta\left(P_y-\frac{\theta}{S}\right)\right)^{\beta}}\right)^{1/1-\beta}}{\left[\bar{L}\left(\dfrac{w}{\varphi S\left(\beta\left(P_y-\frac{\theta}{S}\right)\right)^{\beta}}\right)^{1/1-\beta}+\left(P_y-\frac{\theta}{S}\right)(1-\beta)\right]} > 0$	(34)
$\theta =$ intensity of fishing costs	$\eta_{\gamma,\theta} = \dfrac{\dfrac{\theta}{S}\left[\dfrac{\beta\bar{L}}{(1-\beta)}\left(\dfrac{w}{\varphi S\beta^{\beta}\left(P_y-\frac{\theta}{S}\right)}\right)^{1/1-\beta}-(1-\beta)\right]}{\left[\bar{L}\left(\dfrac{w}{\varphi S\left(\beta\left(P_y-\frac{\theta}{s}\right)\right)^{\beta}}\right)^{1/1-\beta}+\left(P_y-\frac{\theta}{S}\right)(1-\beta)\right]} \lesseqgtr 0$	(35)
φ = productivity of fishing-associated factors	$\eta_{\gamma,\varphi} = \dfrac{-\dfrac{\bar{L}}{(1-\beta)}\left(\dfrac{w}{\varphi S\left(\beta\left(P_y-\frac{\theta}{S}\right)\right)^{\beta}}\right)^{1/1-\beta}}{\left[\bar{L}\left(\dfrac{w}{\varphi S\left(\beta\left(P_y-\frac{\theta}{S}\right)\right)^{\beta}}\right)^{1/1-\beta}+\left(P_y-\frac{\theta}{S}\right)(1-\beta)\right]} < 0$	(36)

Parameter	Estimated elasticity	Eq.
$S =$ resource stock	$$\eta_{Y,S} = \frac{\frac{\theta(1-\beta)}{S} - \frac{\bar{L}}{1-\beta}\left(\frac{w}{\varphi S\left(P_y - \frac{\theta}{S}\right)\beta^{\beta}}\right)^{1/1-\beta}\left(\frac{SP_y - \theta(1-\beta)}{S}\right)}{\left[\bar{L}\left(\frac{w}{\varphi S\left(\beta\left(P_y - \frac{\theta}{S}\right)\right)^{\beta}}\right)^{1/1-\beta} + \left(P_y - \frac{\theta}{S}\right)(1-\beta)\right]} \lesseqgtr 0$$	(37)
$\bar{L} =$ available household labor force	$$\eta_{Y,\bar{L}} = \frac{\bar{L}\left(\frac{w}{\varphi S\left(\beta\left(P_y - \frac{\theta}{S}\right)\right)^{\beta}}\right)^{1/1-\beta}}{\left[\bar{L}\left(\frac{w}{\varphi S\left(\beta\left(P_y - \frac{\theta}{S}\right)\right)^{\beta}}\right)^{1/1-\beta} + \left(P_y - \frac{\theta}{S}\right)(1-\beta)\right]} > 0$$	(38)

Assumptions: $\left(P_y - \frac{\theta}{S}\right) > 0$; $0 < \beta < 1$.

2.3.5 *Demand for fish for self-consumption (γY)*

The elasticities for final household demand for fish caught, shown in Table 2-6, indicate that a 1% increase in the productivity of fishing-associated factors, resource stock and labor force availability increases the quantity of fish consumed in the household (Eq. 42, 43, and 44). A 1% increase in the intensity of fishing costs reduces this quantity (Eq. 41). Again, we see that the relationships with the price of fish and the wage are ambiguous (Eq. 39 and 40), since they simultaneously affect production and consumption decisions, and the final effect will depend on the value of the parameters in each case.

Table 2-6. Elasticities in the demand for fish for household consumption (γY)

Parameter	Estimated elasticity	Equation
$P_y =$ fish unit price	$$\eta_{\gamma Y,P_y} = \frac{P_y S\left(\varphi\left(\frac{\beta S}{w}\left(P_y - \frac{\theta}{S}\right)\right)^{\beta}\right)^{1/1-\beta}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} - 1 \lesseqgtr 0$$	(39)

Parameter	Estimated elasticity	Equation
w= wage	$\eta_{\gamma Y,w} = \dfrac{w\bar{L} - \left(\frac{\beta S\varphi}{w^{\beta}}\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}}{w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}} \lesseqgtr 0$	(40)
θ = intensity of fishing costs	$\eta_{\gamma Y,\theta} = \dfrac{-\theta\left(\varphi\left(\frac{\beta S}{\omega}\left(P_y - \frac{\theta}{S}\right)\right)^{\beta}\right)^{1/1-\beta}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{\omega}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} < 0$	(41)
φ = productivity of fishing-associated factors	$\eta_{\gamma Y,\varphi} = \dfrac{\left(\left(\frac{\beta}{\omega}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{\omega}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} > 0$	(42)
S = resource stock	$\eta_{\gamma Y,S} = \dfrac{SP_y\left(\varphi\left(\frac{\beta S}{\omega}\left(P_y - \frac{\theta}{S}\right)\right)^{\beta}\right)^{1/1-\beta}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{\omega}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} > 0$	(43)
$\bar{L}$ = available household labor force	$\eta_{\gamma Y,\bar{L}} = \dfrac{w\bar{L}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{\omega}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} > 0$	(44)

Assumptions: $\left(P_y - \frac{\theta}{S}\right) > 0; 0 < \beta < 1.$

2.3.6 Demand for goods purchased on the market (F)

The elasticities in Table 2-7 indicate that an increase of one percent in the price of fish (Eq. 45) increases the demand for goods purchased on the market, showing that the goods are substitutes. As expected, the elasticity of demand with respect to the price itself is negative, and in this case unitary (Eq. 46). Elasticities also show that the fishing activity is a source of income generation; therefore, if it becomes more expensive (Eq. 48), the consumption of other goods is reduced, while, if it becomes more productive (Eq. 49), or resource availability increases (Eq. 50), consumption will increase. Finally, an increase in the available labor force will also increase the consumption of other goods (Equation 51).

Table 2-7. Elasticities of demand for non-fishing goods on the market (F) in response to changes in key economic parameters.

Parameter	Elasticity	Equation
P_y = fish unit price	$\eta_{F,P_y} = \frac{P_y S\left(\varphi\left(\frac{\beta S}{w}\left(P_y - \frac{\theta}{S}\right)\right)^{\beta}\right)^{1/1-\beta}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} > 0$	(45)
P_F = unit price of other consumption goods	$\eta_{F,P_f} = -1 < 0$	(46)
w = wage	$\eta_{F,w} = \frac{w\left(\bar{L} - \left(\frac{\beta\varphi S}{w}\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right)}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} > 0$	(47)
θ = intensity of fishing costs	$\eta_{F,\theta} = \frac{-\theta\left(\varphi\left(\frac{\beta S}{w}\left(P_y - \frac{\theta}{S}\right)\right)^{\beta}\right)^{1/1-\beta}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} < 0$	(48)
φ = productivity of fishing-associated factors	$\eta_{F,\varphi} = \frac{\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} > 0$	(49)
S = resource stock	$\eta_{F,S} = \frac{SP_y\left(\varphi\left(\frac{\beta S}{\omega}\left(P_y - \frac{\theta}{S}\right)\right)^{\beta}\right)^{1/1-\beta}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{\omega}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} > 0$	(50)
$\bar{L}$ = available household labor force	$\eta_{F,\bar{L}} = \frac{w\,\bar{L}}{\left[w\bar{L} + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi S\left(P_y - \frac{\theta}{S}\right)\right)^{1/1-\beta}\right]} > 0$	(51)

Assumptions: $\left(P_y - \frac{\theta}{S}\right) > 0;\ 0 < \beta < 1.$

Table 2-8 presents the summary of the signs of the elasticities estimated based on the FHPM model.

Table 2-8. Signs of estimated elasticities in response to changes in key parameters

Variable	P_Y	P_F	W	θ	φ	S	$\bar{L}$
L_y	+	0	-	-	+	+	0
L_{off}	-	0	+	+	-	-	+
Y	+	0	-	-	+	+	0
γ	?	0	+	?	-	?	+
γY	?	0	?	-	+	+	+
F	+	-	+	-	+	+	+

It is important to note that the demands estimated on the basis of the model correspond to the Marshallian demands, which depend on prices and the different forms of income generation, or their parameters. Now, the elasticity of these Marshallian demands is the sum of substitution, income and profit effects, so the outcomes of some decisions may differ from those found using a conventional consumer model.

3. EMPIRICAL STRATEGY

3.1 SAMPLE

The data for this report comes from primary information collected from fishing households settled in Barú village. We define fishing households as those whose primary economic activity is or has been fishing and are recognized as fishing households by the community. This category might include households that fished as their primary economic activity but have now switched to other activities, and households of elders who were fishers but no longer fish.

According to a census of households that we carried out between June and July of 2018, the population was made up of 801 households, 158 of them fishing households. From this census, we randomly selected a stratified sample of 97 fishing households.

We considered an oversampling of 10%, in order to prevent attrition during the information gathering process. The sample size allows a 95% confidence level and a margin of error of 5%.

3.2 COLLECTION INSTRUMENTS

We designed and applied a baseline survey and a follow-up survey. The baseline survey was conducted between July 26 and October 5, 2018. The follow-up surveys were conducted once a month for each household for the next 11 months, from October 5, 2018 to October 7, 2019.

Two members of the Barú community were trained to administer the survey and became interviewers and co-researchers for the project. This made it easier for the community to accept the researchers and thus be collaborative in offering information. The interviewers were trained in the topics related to the application of the survey and the objectives of the project. The co-researchers also contributed to adjusting the language used for the survey and the questions. Before starting the survey, we ran a pilot to adjust the final formats and guarantee full understanding.

3.3 SOCIO-DEMOGRAPHIC PROFILE AND LIVELIHOODS OF FISHING HOUSEHOLDS IN BARÚ

Barú's fishing households typically have four members, with an average age of 26 years and a gender distribution slightly dominated by men. These households exhibit an illiteracy rate of 14%, which is higher (22%) if only the heads of household are considered. 75-80% of people aged between 5 and 18 years are studying. Fishing household heads have on average 4.7 years of education.

With respect to the percentage of adults who have completed secondary education, we found that, in fishing households, only 18% of their adult members finished high school. It should be noted that a higher percentage of women than men finished high school: 26% versus 10%.

In terms of economic activity, the working-age population of these households is 40 years on average, with an education level of 5.8 years.

The ratio between working-age members and dependent persons is 2 to 1: for every two people of potential working age there is one economically dependent person. The employment rate in fishing households reaches 56.3%. Fishing households have 1.75 economically active people.

Fishing households have higher labor participation in the youngest strata (15-19 years old) and in the oldest strata of the population (over 60 years old) than non-fishing households. In fact, more than half (56%) of adults over 60 in fishing households continue to contribute to the household income.

Practically everyone who works in Barú does so informally (98.5%). Sectors such as fishing and the sale and leasing of equipment associated with it, agriculture, leasing of goods, repair and maintenance, and the exploitation of raw materials are associated with 100% informality.

In terms of diversification, fishing households in Barú report, on average, 1.71 different activities per household from which they derive income. The most frequent main activities of the heads of fishing households are fishing, maritime transport, fishing storage, fish trade and rental of fishing equipment.

With respect to fishing, 100% of the people surveyed who fish are men, with an average age of 46 and an average of 4.3 years of education. Further, 58.3% of the heads of fishing households are engaged in fishing as their main activity.

The most popular fishing gears are handline and diving. When fishing is the main activity, 47% of fishing households choose handlining and 40% free diving. However, 76% of those who fish as a secondary occupation do so by diving and only 13% by handline. This suggests that handlining may require greater skill and experience, so it would be used mainly as a primary activity. A characteristic of the fishing activity is its flexibility to be assumed as a primary or secondary activity, and either full-time or part-time.

Fishing plays an important role in providing income not only for households that fish as a primary activity, but also as a coping strategy for those that fish as a secondary activity when faced with shocks.

On average, fishing households consume animal protein 10.3 times per week, mainly by self-consumption of fish and other seafood. On average, 85% of the fish caught is for sale, 13% is for household consumption and 2% is given as a gift to other households. The latter two represent about 15% of the catch, which is not sold on the market.

The average fishing household's monthly monetary expenditure in Barú is 836 $USD PPP,[2] while the average household expenditure per capita is US$229 per month. The total income of the fishing households is around $1,233 USD PPP per month on average, representing 2.1 times the current legal monthly minimum wage in Colombia[3]. The fishing activity provides 37% of the income of fishing households directly and 5.8% indirectly (fishing trade and fishing equipment rental). The average monthly income of those who fish as their main or secondary occupation is $750 USD-PPP.

The headcount poverty index in Barú shows that 27.1% of fishing households are located below the Colombian poverty line, while 4.5% are located below the extreme-poverty line.

4. MODEL CALIBRATION AND SIMULATION

4.1 CALIBRATION

The FHPM is estimated and calibrated using the data collected from the Barú fishing households. The parameters were identified in two phases:

(i) Statistical phase: Parameter estimation through different statistical strategies: weekly averages of the variables, regression analysis for the production function and the fishing cost function, and the results of the Marshallian demand function proposed in economic theory.

(ii) Numerical phase: Calibration of the model using the demand and supply functions estimated by numerical methods, comparing the observed values of the model variables with the values calculated from the parameters estimated in the statistical approach, and adjusting the estimated values of parameters so that they approximate the average values observed.

[2] Purchasing power parity of USD to COP for 2019: 1,430 COP / 1 USD.

[3] The minimum wage for Colombia in 2019 was $828,116 COP, which converted with the PPP is $579 USD.

Once the parameters have been identified, the values of household supply and demand are calculated, together with the associated elasticities. Confidence intervals of ±5% in the defined parameters are also estimated to analyze their sensitivity to changes in the estimates.

4.1.1 *Phase 1: Statistical approach to parameters*

The data presented in this section are averages reported at household level, in weekly terms and, for monetary values, in USD adjusted by the 2018 PPP. Table 4-1 lists the variables and parameters considered in the FHPM, along with the basic descriptive statistics for the observed data and the method used to estimate them.

Table 4-1. Variables and parameters for the FHPM

Variable/ parameter	Symbol	Mean (s.d.)	Estimation method
Variables			
Labor supply for fishing (hours per week)	L_y	35.43 (18.54)	Direct observation of the data from the survey
Labor supply for other productive activities (hours per week)	L_{off}	33.10 (34.52)	
Fish catch (kg per week)	Y	20.80 (21.42)	
Proportion of fish caught for home consumption and gifted (percentage)	γ	0.18 (0.17)	
Amount of self-consumed fish (kg per week)	γY	3.72 (2.29)	
Demand for goods purchased on the market (USD PPP per week)	F	125.4 (109.68)	
Observed parameters			
Market price of fish (USD PPP per kg)	P_y	11.73 (5.57)	Average of observed values
Hours spent working per household (hours per week)	$\bar{L}$	69.98 (37.64)	
Wage for other activities (USD PPP per hour)	w	2.52 (3.94)	

The value of one (1) was assigned to the parameter relating to the price of other consumption goods (P_f), assuming other goods as a numeraire.

The value of the resource stock is unknown and cannot be obtained from the observed data. For simulation purposes, a reference value of *S=1* is assumed, which can be interpreted as the total available stock of the resource during the study period.

In order to estimate the parameters associated with the production and cost functions, regressions were designed to provide the best fit for each case. For the production function, the functional form with the best goodness of fit was the Cobb-Douglas:

$$Ln(Y_i + 1) = a_i + \beta Ln(Ly_i\ ) + u_i$$

where a_i is a fixed household effect that captures the time-invariant factors affecting household catch and β is a coefficient that denotes the percentage change in catch given a 1% increase in fishing hours.

The linear functional form was proposed as the best fit to find the parameters associated with the cost function. The function is:

$$C_i = b_i + \frac{\theta Y_i}{S} + u_i$$

where b_i is a fixed household effect that captures the time-invariant factors that affect the costs of fish catch within the household. This coefficient can also be considered the fixed cost of the fishing activity. The parameter θ indicates how an increase of one kilogram in the catch amounts to an increase in the costs associated with the fishing activity, given a constant resource stock level, i.e., the marginal cost of the activity.

For the utility function parameters, whose functional form is assumed to follow a Cobb-Douglas specification, with $\alpha_y + \alpha_f = 1$, a Marshallian demand function was used to estimate the parameters α_y and α_f associated with fish self-consumption and consumption of other goods, respectively:

$\alpha_y = \frac{P_Y \gamma Y}{M};\ \alpha_F = \frac{P_F F}{M},$

where M represents the household income. In this case, M represents the value of the household consumption or expenditure: $M = FP_F + \gamma Y P_Y$, where consumption of other goods (F) includes consumption of other sources of protein (i.e., pork, beef, chicken, eggs), including the value of the fish received as a gift and purchased fish.

4.1.2 Phase 2: Numerical model calibration

Calibration consists of adjusting the values of the estimated parameters to find values for the variables of interest that are as close as possible to observed values of those variables, when replacing the parameters in the supply and demand functions. The estimated values used to calibrate the demand and supply system, along with the calibrated values, are presented in Table 4-2. The value of P_F, originally expected to be 1 (numeraire good) is calibrated to 1.9, as here we include only protein consumption.

Table 4-2 Estimated parameters for the FHPM and final calibrated value

Variable/ parameter	Symbol	Mean	Estimation method	Calibrated value
Unobserved parameters requiring estimation				
Weight of consumption of other goods for household utility	α_f	0.75-0.95	Marshallian demand function	0.865
Weight of fish self-consumption for household utility	α_y	0.05- 0.25		0.135
Total fishing-factor productivity	ϕ	1.919 – 2.953	Production function regression	2.8
Labor efficiency in fishing	β	0.469 – 0.595		0.5
Marginal cost, given constant stock	θ	0.176– 0.221	Cost function regression	0.4 [a]

[a] The 0.4 figure is estimated by dividing the fixed costs by the average catch and adding them to the variable cost, as an approximation of the average cost of fishing.

4.2 HOUSEHOLD SUPPLY, DEMAND AND UTILITY FUNCTIONS

The results for supply, demand, and utility functions in the FHPM based on the calibrated parameters are presented in Table 4-3. This table shows that the estimated values are quite close to the observed values and always fall in a range no greater than 15%. That is, with these values, we are confident that the parameters represent the behavior of Barú's fishing households.

Table 4-3 Simulation of results for supply, demand, and utility functions

	Symbol	Mean (s.d.)	Median	Calibrated parameters	-10%	+10%
Labor supply for fishing (hours per week)	L_y	35.43 (18.54)	35	39.62	31.9	39.0
Labor supply for other productive activities (hours per week)	L_{off}	33.10 (34.52)	32	30.38	29.8	36.4
Fish catch (kilograms per week)	Y	20.80 (21.42)	15	17.62	18.7	22.9
Proportion of fish caught for self-consumption (percentage)	γ	0.18 (0.17)	0.14	0.18	0.16	0.20
Quantity of self-consumed fish (kilograms per week)	γY	3.72 (2.29)	2.50	3.18	3.35	4.09
Market demand for food (USD PPP per week)	F	125.4 (110)	126	125.8	113	138

4.3 ELASTICITIES

Table 4-4 shows the elasticities for supply and demand in the FHPM with respect to the estimated parameters. The yellow boxes show the variables that have an elastic relationship with the parameters, the purple boxes contain the variables that have an inelastic relationship with these parameters, and the green boxes show the variables that have a unitary elasticity. The theoretically expected sign is presented in parentheses.

The estimated elasticities are consistent with the theoretical prediction in terms of the signs. In the case of elasticities whose sign is theoretically ambiguous, the following results were found. A negative sign was obtained for the elasticity for fish consumption within the household (and the proportion of fish dedicated to self-consumption) in relation to the price of fish. Let us remember that the FHPM has two opposing forces: on the one hand, the household as a consumer will reduce consumption in response to price increases. However, as a producer, a price increase would result in greater income for the household, in turn allowing it to consume more goods, thus, a positive effect. In this case, the estimated sign of elasticity is negative, which implies that the standard consumer effect is greater than the profit effect.

Table 4-4 Value of estimated elasticities. The theoretically expected sign in parentheses

Variable	P_Y	P_f	w	θ	φ	S	$\bar{L}$
L_Y	+2.071 (+)	0 (0)	-2.000 (-)	-0.071 (-)	+2.000 (+)	+2.071 (+)	0 (0)
L_{off}	-2.700 (-)	0 (0)	+2.608 (+)	+0.092 (+)	-2.608 (-)	-2.700 (-)	+2.304 (+)
Y	+1.035 (+)	0 (0)	-1.000 (-)	-0.035 (-)	+2.000 (+)	+2.035 (+)	0 (0)
γ	-1.287 (?)	0 (0)	+1.277 (+)	+0.010 (?)	-1.277 (-)	-1.287 (?)	+0.639 (+)
γY	-0.252 (?)	0 (0)	+0.277 (?)	-0.026 (-)	+0.723 (+)	0.748 (+)	+0.639 (+)
F	+0.748 (+)	-1.000 (-)	+0.277 (+)	-0.026 (-)	+0.723 (+)	+0.748 (+)	+0.639 (+)

An increase in the wage for activities other than fishing has two opposite effects. On the one hand, household income increases due to increased work in these alternative activities. On the other, a reduction in the time dedicated to fishing reduces the catch, which in turn reduces income. Consumption is expected to increase in the former case, while it should decrease in the latter. Thus, the increase in income derived from alternative work is greater in proportion to the lost income resulting from lower fish sales, and this effect finally generates an increase in the demand for both self-consumption of fish and consumption of other goods. Faced with a reduced catch due to wage increases, fishers decide to keep more fish for self-consumption.

As expected, increased fishing costs reduce the effort dedicated to this activity and therefore the catch. This in turn means a decrease of income and therefore in the consumption of goods and, although the proportion of fish dedicated to self-consumption increases, fish consumption in the household is reduced anyway because of the reduced fishing.

An increase in the resource stock leads fishers to increase their fishing effort, increasing their catch and allowing for greater consumption of fish and other goods at home, even when the proportion of the catch dedicated to self-consumption is less.

Finally, an increase in the available labor force within the household (e.g., by the arrival of new members with labor capacity) will be allocated to work in alternative activities, increasing the household's income. This income will be reflected in the increased consumption of all goods, including fish for self-consumption, which implies that a larger proportion of fish is kept for the household.

The values of the elasticities considering a ± 5% confidence interval in the estimated parameters show that, even with such changes in the value of the parameters, the sign and economic interpretation of the elasticities is maintained in all cases.

5. POLICY IMPLICATIONS ON KEY MODEL VARIABLES

The estimation of elasticities makes it possible to analyze the effect of some policies that affect parameters related to the variables of interest. It is thus possible to see the relationships between the impacts on standards of living and the pressure on resources caused by different policy options.

Table 5-1 presents different policy scenarios and their impact on the variables analyzed. The first case would be a policy that raises fish prices. An increased demand for fish resulting, for example, from policies that incentivize tourism could increase the price of fish. Note that in this simulation this price increase would not be associated with any management strategy aimed at reaching sustainable use of the fishery. Given that one assumption of the model is to have only one representative species with only one price, the possibility of consumers migrating to consume cheaper or smaller fish is not considered here. The simulation shows that this policy would have a negative effect on the resource stock, since it would increase the catch. Although it also would increase the wellbeing of fishing households in terms of both income and utility, a price increase would reduce self-consumption of fish, which could affect households' food security. Alderman (1986) establishes that greater income can be associated with greater consumption of staple food such as grain (which has lower-quality protein than fish); thus, larger catches and income may not always favor food security.

Kawarazuka and Béné (2010) posit the risk that food-insecure households choose to sell a greater proportion of their fish catch to ensure minimum amounts of basic goods that are often perceived as the priority. In this case, food consumption is achieved at the expense of nutritional security.

Table 5-1 Impact of selected policies on key model variables.

		Increase in fish prices		**Improved fishing technology**		**Fishing subsidy**		**Promotion of alternative activities**	
Parameter		P_y		ϕ		θ		w	
Variable	Observed value	10% increase in P_Y	Final value	10% increase in ϕ	Final value	10% reduction in θ	Final value	10% increase in w	Final value
$\boldsymbol{L_Y}$	35.4	20.7%	42.8	20.0%	42.5	0.7%	35.7	-20.0%	28.3
$\boldsymbol{L_{Off}}$	33.1	-27.0%	24.2	-26.1%	24.5	-0.9%	32.8	26.1%	41.7
$\boldsymbol{Y}$	20.8	10.4%	23.0	20.0%	25.0	0.4%	20.9	-10.0%	18.7
$\boldsymbol{\gamma}$	18%	-12.9%	0.16	-12.8%	0.16	-0.1%	0.18	12.8%	0.20
$\boldsymbol{\gamma Y}$	3.7	-2.5%	3.6	7.2%	4.0	0.3%	3.7	2.8%	3.8
$\boldsymbol{F}$	125.4	7.5%	134.8	7.2%	134.5	0.3%	125.7	2.8%	128.9
$\boldsymbol{U}$	77.99	6.1%	82.73	7.2%	83.63	0.3%	78.19	2.8%	80.15
Total income	283.9	9.6%	311.0	8.8%	308.9	0.0%	283.9	2.5%	291.1
Fishing income	200.5	24.8%	250.2	23.3%	247.3	0.4%	201.2	-12.5%	175.4
Off farm income	83.41	-27.0%	60.89	-26.1%	61.66	-0.9%	82.64	38.7%	115.7

A second policy involves improvements in fishing technology, which, in turn, would improve catch productivity and would increase the fishing effort. However, the simulation shows that the catch of those fishers who improve their technology increases more than proportionally, generating a negative effect on the resource stock. Although not included in the simulation, note that those fishers who do not have the new technology might experience a reduced catch because of the reduction in the resource stock. Here we do not contemplate technologies that promote sustainability but rather those that improve the fisheries' overall productivity. Examples of such policies would be the provision of larger vessels, more effective fishing gear, the subsidization of equipment, or the acquisition of assets such as fishing gear. The additional catch will be reflected in more income, although this increase will be less than proportional. While the proportion of the catch destined for self-consumption is reduced, its absolute amount increases, improving household food security, perhaps at the expense of resource conservation.

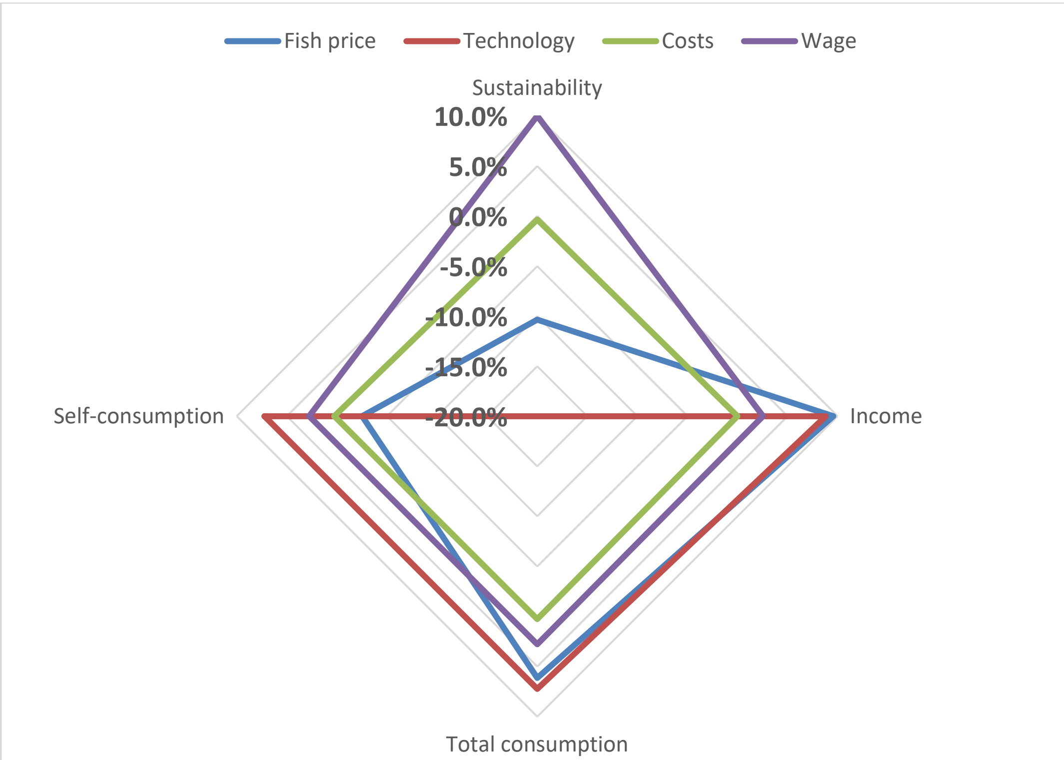
A third form of intervention would be to reduce fishing costs, through subsidies or reduced prices of variable factors. This policy has the least impact on both fishing decisions and earnings. It has no major effect on consumption.

A fourth possible policy is one that is geared toward strengthening alternative activities, such as independent productive projects or jobs – besides fishing – that provide income for the household. This policy can be simulated as a wage increase, *w*. In this case, this policy would have positive impacts on households' wellbeing, improving income and consumption, and reducing the pressure on the fishing resource. It also would serve to increase self-consumption of fish in the households, improving food security. Although income from fishing is significantly reduced, income from alternative activities increases more than proportionally, ensuring that total income does not decline.

This last policy seems to be the best because it delivers benefits in both environmental and social terms. Examples of this type of intervention include a wide range of alternatives. One option could be the creation of alternative formal jobs in activities related to ecosystem conservation, restoration and monitoring, as well as ecotourism. Another option could be the promotion and support of productive sustainable activities.

Figure 5-1 presents a comparison between the different policies for the selected indicators: income, total consumption (utility), self-consumption of fish, and sustainable resource use. We can see that, although technological improvements (labeled as *Technology* in Figure) bring about the greatest wellbeing for households in social terms, they would have the greatest impact on the resource, unless these technological innovations include sustainable practices for proper management of the resource. As already discussed, the subsidy to the variable costs of the fishing activity (labeled as *Costs* in the Figure) would produce a negligible effect on almost all the variables of interest, while the promotion of alternative sources of income (labeled as *wage* in the Figure) is what in aggregate yields the best results for the environment and for households' income, consumption and food security.

Figure 5-1. Effect of policies on sustainability of the resource, income, self-consumption and total consumption of households



Finally, we analyzed the implications of a case in which the stock of the resource falls by 10% due to, for example, external disturbances caused by climate change (e.g., increase in sea temperature or ocean acidification). The fishing household will experience income earning problems that are not offset by income from alternative activities. Overall profit and food security also will be affected, due to decreased consumption of both caught fish and other goods. Strategies aimed at building resilience in marine ecosystems and the sustainable management of fishing stocks are needed to avoid environmental and social impacts (Table 5-2).

Table 5-2 Simulation of a scenario in which the fish stock is reduced by 10% over the key variables of the model

	Observed value	S falls by 10%	Final value
L_Y	35.4	-20.7%	28.1
L_{Off}	33.1	27.0%	42.0
Y	20.8	-20.4%	16.6
γ	0.18	12.9%	0.20
γY	3.72	-7.5%	3.44
F	125.4	-7.5%	116.0
U	77.99	-7.5%	72.2
Total income	283.89	-8.0%	261.16
Fishing income	200.48	-22.6%	155.22
Other sources of income	83.41	27.0%	105.94

6. DISCUSSION

The main purpose of this study is to understand how fishing decisions affect livelihoods of local communities living in coastal areas. Specifically, the study is guided by two questions: (i) how economic decisions of fishing households define their livelihoods, and (ii) what policies could be implemented to promote sustainability in marine resource use while improving local communities' living standards. To do this, the project follows two methodological strategies. On the one hand, we propose a theoretical model of fishing household production, which serves to identify the key variables that affect fishing decisions and the livelihoods of fishing households. On the other, we conducted a longitudinal survey of fishing households in the village of Barú, to gather information on the households' livelihood strategies and socio-demographic profile. The information from these surveys is used to carry out an empirical simulation of the theoretical model, in order to identify the supply and demand functions.

The FHPM provides parameter estimates that can be used to simulate the behavior of households under different scenarios. The model calibration yields estimates of functions that are fairly close to the values observed based on the survey. The elasticities produce values that are consistent with the theoretically expected signs.

In general terms, the productive variables (total amount of fishing, Y, time spent fishing, L_Y, and time spent on other activities, L_{Off}) exhibit elasticities greater than one for changes in all the parameters, except for changes in fishing costs. In other words, parameter changes affect households' productive decisions more than proportionally. These elastic relationships play an important role for income generation within the household.

Consumption variables (food acquisition, F, and self-consumption of fish in absolute terms, (γY) tend to exhibit elasticities lower than one; that is, changes in the different parameters would affect consumption decisions for these goods less than proportionally.

It is key, then, to note the elasticity in the production variables, and the inelasticity in the consumption variables.

Now, the proportion of fish allocated to self-consumption, γ, is an elastic variable with respect to almost all of the parameters (except fishing costs and price of other goods). This variable plays an important role in the balance between consumption and production decisions, acting as a wildcard to ensure household wellbeing and reproduction. On the one hand, allocating a portion of fishing to self-consumption improves household food security. On the other hand, selling another part of the catch generates income that can be used to buy food for the household. Kawarazuka & Béné (2010) argue that there will typically be complementary relationships between these decisions. However, the integration of the FHPM may lead to complementarity effects in some cases and substitution effects between food sources in others. Hence, the variable gamma seems to be of high relevance to adjust household consumption decisions.

Our results confirm the presence of the profit effect described by Singh et al. (1986) and its interaction with substitution and income effects in household production models. The presence of these three effects means that, in some cases, the signs of elasticities are not evident from a theoretical standpoint and must be determined empirically in each case.

In general, the estimated elasticities are consistent with the theoretical predictions in terms of the signs. In the case of elasticities whose sign is theoretically ambiguous, the following empirical results are found. In the case of the elasticity of fish consumption within the household (and the proportion of fish dedicated to self-consumption) with respect to fish price, the empirically-determined negative sign implies that the standard consumer effect is greater than the profit effect generated by the increase in income.

Another case is the elasticity of demand for self-consumption of fish and other foods with respect to the wage of alternative activities. Although the reduction in the catch should result in a reduction in the consumption of fish caught as well as other goods, the positive sign of these elasticities shows that the profit effect generated by an increase in income derived from alternative work leads to both an increase in the consumption of other goods and an increase in the quantity of fish kept by the household; that is, despite a reduction in the catch, increases in wages induce fishers to keep more fish for self-consumption.

The results of the calibrated model can also be used to simulate the effect of different policies. In this case, four policies were analyzed that affect the key variables of the model: changes in the price of fish, changes in fishing technology, changes in the costs associated with fishing activities, and changes in the possibilities of generating income from alternative sources. Of these, the latter, simulated through a change in the value of the external wage, w, was the one that simultaneously showed benefits in food security and household wellbeing and a reduction in the pressure on natural resources, producing a positive effect on resource conservation. In the other options analyzed, there is always a trade-off between conservation and economic development of fishing communities. In particular, increases in fish prices can affect households' food security.

These results have prompted a discussion on the reasons for poverty in fishing communities and on the role of fisheries as a safety net or a last-resort activity, as discussed, for example, by Béné (2004). This author claims that there are at least two interpretations regarding the relationship between poverty and fisheries. The first is an *endemic* interpretation, supported by the works of Hardin (1968) and Gordon (1954), where it is argued that the fishers' poverty stems from the open access nature of the common pool resource, which leads to its overexploitation, the vanishing of the income produced, and the impoverishment of the fishers' households. According to this argument, open access is the reason for the impoverishment of these fisheries. The premise "they are poor because they are fishers" emphasizes that their poverty is related to the level of exploitation of the resource: *overexploitation = low catch = low income = poverty* (Copes, 1989).

In the second interpretation, the *exogenous* approach, it is assumed that poverty in fisheries is explained by limited alternative income opportunities. There is limited labor mobility between sectors. In this approach, poverty has its origin outside the fishing sector and is not necessarily related to the extent of resource exploitation or income dissipation, but rather to economic restrictions outside the fishery (Copes, 1989; Cunningham, 1993; Panayotou, 1988). In this second interpretation, “they are fishers because they are poor” highlights that poverty is related to limited capabilities.

Poverty may result from a combination of the open access tragedy and restricted income earning opportunities (Bailey & Jentoft, 1990). This approach is based on the fact that the scarcity of productive and economic opportunities and the simultaneous presence of open or semi-open access fisheries allow for the mobility of this typically low-skilled labor force, without access to other forms of capital and with few productive alternatives, resulting in poverty for those engaged in this activity. In this case, the fishing activity plays roles of both a last-resort activity and a safety net.

Open access functions as a safety valve to prevent poor households from falling into extreme poverty or becoming food insecure. Therefore, even if poverty is caused in part by open access, restricting access to fisheries can damage the wellbeing and food security conditions of these communities. Before formulating policies that restrict access to natural resources, it is essential to facilitate other forms of capital in order to promote other forms of income generation.

Reinforcing the exogenous approach, our FHPM model indicates that the best policy alternative is the promotion of income earning alternatives, through employment or personal ventures outside the fishery with sufficient remuneration to reduce catches without damaging the living standards of the households. Once these external factors are addressed, it is time to think of alternatives that control open access to make the fishing resource sustainable in the future.

For a community like Barú, with no access to land, low access to credit and few alternative income earning activities, strategies should be developed to address these limitations as part of planning for conservation and development in the region. As observed in the study, a significant proportion of the community’s fishing households exceed the poverty line and therefore do not receive direct support from the state, such as conditional cash transfers. Restrictions on fishing would lead to an increase in poverty and vulnerability, and would constitute a threat to food security. This, in turn, would require the state's attention in directing its social protection programs toward this population to alleviate the negative effects of reduced income and food security.

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