Understanding Livelihoods of Small-Scale Fishing Communities: A Dynamic Fishing Household Production Model

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Abstract

Small-scale fishing (SSF) communities in developing countries typically face high levels of poverty and vulnerability, coupled with a strong dependence on fishing resources. Fishing plays a central role as both a source of income and a means of ensuring food security. However, there is limited information on the relationships between household wellbeing, resource sustainability, and their interactions. This study contributes to a deeper understanding of SSF livelihoods by examining how key economic parameters influence the decision-making of fishing households. We develop a dynamic fishing household production model in which households make simultaneous decisions regarding consumption and production, incorporating the fact that fishing depends on a common-pool resource that fluctuates over time. The theoretical model is validated using data from the village of Barú, located in the Colombian Caribbean. The calibrated model allows for simulations of various policy scenarios affecting SSF management and household wellbeing, both with and without considering changes in fish stock. Our findings offer valuable insights for designing policies that support the sustainable use of marine resources while fostering the socioeconomic development of these communities.

Keywords*:* artisanal fisheries; sustainability; common-pool resources; intertemporal effects; developing countries.

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

1. INTRODUCTION

The sustainability of small-scale fisheries (SSF) has become an increasingly prominent issue in fisheries economics (Lancker et al., 2019; FAO & World Fish Center, 2008). SSF are responsible for approximately half of the annual global marine catch (FAO, 2024) and account for 90% of employment in the fisheries sector (FAO, 2024). Many of these jobs are concentrated in communities that depend heavily on fishing resources for their subsistence (Olale & Henson, 2013; Allison & Ellis, 2001).

In Colombia, up to 150,000 fishers and their households rely on fish resources, with one-third depending specifically on coastal fish stocks (OECD, 2016). These fishers typically lack access to formal employment, working independently and informally, with limited human and physical capital. Labor informality is widespread across Latin America, affecting more than half of the workforce. In the primary sector, informality is even more pronounced, exceeding 75%, largely due to the absence of adequate labor markets.

Although marine fishing production, in terms of catch volume, has generally remained stable in temperate and outcropping areas and has shown a slight increase in tropical areas, the percentage of species populations exploited at biologically unsustainable levels rose from 10% in 1974 to 37.7% in 2021 (FAO, 2024). In the case of Colombia's marine fisheries, Rueda et al. (2019) report a decline in landed catch since 2006. This trend may be linked to reduced profitability in certain fisheries and low competitiveness (Merino et al., 2013), the degradation of the fish stocks—evident in a considerable number of marine species under some threat category (Ardila et al., 2002)—, and the increasing ecological footprint of fishing activities (Vargas-Morales et al., 2013).

The degradation of marine-coastal ecosystems, combined with stressors 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 their ability to access other essential goods and services. For this reason, understanding the livelihoods of artisanal fishers and identifying key economic factors that affect fishing household decision-making is essential for designing policies that promote both the sustainable use of marine resources and the socioeconomic development of fishing communities. However, SSF are typically associated with local households living in poverty, with limited access to alternative sources of income, land, capital, and labor markets. These households are often dependent on fish stocks managed under open-access regimes. In this context, fishing serves as both a source of income and as a source of food, making production and consumption decisions at the household level inseparable.

This study seeks to answer two research questions: (i) How do key economic parameters affect livelihood decisions of fishing households, given their dependence on stocks that function as a common-pool resource (CPR)? (ii) What policies could be implemented to promote the sustainable use of marine resources while improving local communities' living standards, considering the implications of managing these stocks as a CPR.

To answer these questions, this study proposes a Dynamic Fishing Household Production Model (DFHPM) that accounts for the nature of the common-pool resource of the artisanal fisheries within a dynamic framework. For the model's empirical simulation, socioeconomic data were collected in Barú village, a fishing community in the Colombian Caribbean, close to Cartagena. Barú is an island inhabited by traditional communities and is also a major tourist destination, offering various ecosystem services such as seafood and recreation. The conditions in Barú reflect those found in many other artisanal fishing communities across the country and throughout the developing tropics.

This document is organized as follows. After this introduction, we present a discussion on the use of a household production model within this framework. Section Three outlines our theoretical approach to the DFHPM, from which we derive demand and supply functions, along with their elasticities with respect to key parameters. Section Four describes the model's calibration and simulation, used to understand the responses of artisanal fishers in the context of a CPR. Section Five examines the effects of implementing different policies to manage fisheries or improve livelihood conditions, when dynamic changes in fish stock are taken into account. Section Six discusses the main findings, emphasizing the importance of policies that incorporate stock dynamics to enhance both community wellbeing and resource sustainability.

2. HOUSEHOLD PRODUCTION MODELS – HPM

2.1 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 using family labor for both production and sale in the market (Singh et al., 1986a). One way to address the complex dynamics of rural households is by applying household production models (HPMs), which integrate production, consumption, and labor force supply decisions. This perspective, which emphasizes the dual role of households in the economy, also draws attention to the frequent underestimation of their productive contributions in national accounts (Becker, 1990; Marszałek, 2025).

Under a recursive structure, the HPM combines the components of utility and profit maximization (Singh et al., 1986a). HPMs are based on the idea that households are not only consumers of goods produced in the market economy but also producers of their own goods. In these models, home-produced commodities and market goods are treated as close substitutes (Gronau, 1977; 1980; Melmed-Sanjak & Santiago, 1996). Moreover, this type of model allows for the recognition that goods produced and consumed by households may hold values different from market prices—values shaped by cultural identity and social norms (Taylor & Adelman, 2003; Arslan & Taylor, 2009; Arslan, 2011). In such settings, a portion of household production is intended not for market exchange, but for self-consumption, including friends and neighbors. This distinction has proven useful in analyzing household demand, particularly for food, by differentiating between home-produced food and food consumed away from home (Hamermesh, 2007; Huffman, 2010, 2011).

HPMs examine the decision-making processes of rural households, whose behavior as producers influences their behavior as consumers and labor suppliers—and vice versa. These models help identify how government interventions (e.g., policies on input or output prices, decisions related to social investment projects, or conservation policies) affect household choices regarding how much to consume, how much to produce, how much labor to allocate to their main productive activity, and how much of that labor to sell in the market. These decisions, in turn, influence food security, income generation, and the diversification of productive activities within the household. Furthermore, a clear understanding of these dynamics contributes to more effective conservation planning (Shone & Caviglia-Harris, 2006; Guerrero, Albers & Langpap, 2025).

HPMs differ from conventional consumer theory models. While the latter rely on substitution and income effects to predict household behavior in response to a change in the price of a good, HPMs also incorporate the profit effect (Singh et al., 1986b). As a result, the outcomes in terms of consumption and labor supply in an HPM, may or may not align with those predicted by conventional models. For example, if the price of a good produced—and also consumed—by the household increases, a traditional consumer model would predict a decrease in the consumption due to the price rise. However, an HPM accounts for the profit effect, meaning that an increase in the price of the good also raises the household income and profits. This income gain can lead to higher demand for various goods, including those produced by the household itself. Thus, under an HPM, the household’s demand for the self-produced good does not necessarily decrease with a price increase. Instead, demand is "subject to two forces pushing in opposite directions" (Singh et al., 1986b). The final effect on consumption can only be determined empirically and on a case-by-case basis. In terms of production decisions, HPM leads to the same results as those derived from using conventional firm-theory models (Singh et al., 1986b).

2.2 Applying HPM to Fishing Households

Artisanal fishers are, by definition, rural households and are part of a family farming or peasant economy (United Nations, 2018; Maldonado et al., 2007; Forero, 2003; Pérez & Pérez, 2002; Machado et al., 1993). Following Garay et al. (2009), these households are typically characterized by the following features: (i) land and capital are limiting factors—artisanal fishing households generally lack access to land, (ii) the family labor force is the primary factor of production; (iii) the output from extractive activities is used for both household self-consumption and market sale, (iv) households do not seek to maximize monetary profits but rather to secure food and income to meet basic needs and acquire other goods; (v) household income is low and derived from a range of productive activities; and (vi) households are integrated into the market through the sale of harvested products and labor, as well as through the purchase of inputs and other goods and services.

Pascual-Fernández (1997) argues that fishers are more similar to hunters than to farmers, due to the harvesting nature of the activity—where prey must be sought, located, and captured—and the absence of control over the resource or the natural systems in which the activity takes place (Smith, 1980; McCay & Ingold, 1988). Unlike farming, in fishing the productive factor associated with natural capital does not constitute a private good—or even collective property—but rather a common pool resource (CPR), characterized by rivalry and non-exclusion, where allocation and enforcement of property rights is complex (López-Martinez, Schriewer & Mesenguer-Sánchez, 2021)

Bearing this in mind, an adapted HPM could effectively explain the production and consumption decisions of fishing households. It can also be used to analyze how different policy interventions may influence those decisions and, ultimately, their wellbeing—particularly among fishing households with a profile of local wild harvesters living in remote, asset-poor, and less-developed villages, where dependence on fish resources is especially high (Wells et al., 2024; Guerrero, Albers & Langpap, 2025).

De la Montaña et al. (2015) follow the model proposed by Singh et al. (1986b) to examine how key economic parameters influence the hunting of wild fauna in indigenous communities of the Ecuadorian Amazon. In particular, this model develops an application of HPM for hunters, assuming that the resource—wildlife—is a public good, characterized by non-rivalry and non-exclusion. De la Montaña et al. (2015) implicitly assume that the catch is substantially 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. This assumption allows hunting to be treated as non-rival. Consequently, the model does not include the impact of hunting on the resource stock.

However, artisanal fisheries typically represent the classic case of a common pool resource—characterized by rivalry—where harvest might exceed growth, leading to overexploitation of the resource (Hardin, 1968; Gordon, 1954).

Our fishing household production model builds on the frameworks developed by Singh et al. (1986b) and De la Montaña et al. (2015). However, it introduces a dynamic component in which household decisions depend on fish stock that may vary exogenously due to aggregated fishing (or even external factors such as climate change or water pollution). This variation influences both consumption and production functions within the household.

This dynamic model allows for the analysis of how different policies may impact household wellbeing and exert pressure on fish stocks. It is particularly applicable to households engaged in the informal production of goods or services in the primary sector, relying on natural resources that are difficult to exclude from use.

3. THE DYNAMIC FISHING HOUSEHOLD PRODUCTION MODEL – DFHPM

3.1 DEFINITION OF VARIABLES

In this model, the fishing household catches a given species with a given 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 allocated to self-consumption, so that γY will be the consumption in the household, and $(1-\gamma)Y$ the amount of fish sold. Although fishing is the household's primary productive activity, it also engages in other activities to supplement its income. The household has a total available time for productive activities $\bar{L}$, which can be allocated either to fishing L_y or to other income-generating activities L_{off}:

$$\bar{L} = L_{off} + L_y \tag{1}$$

The household income is generated from the sale of fish, other productive activities, and transfers from the government: $P_y(1-\gamma)Y + wL_{off} + T$, where w, P_y and T denote the wage rate obtained by other income-generating alternatives, fish price, and the amount of transfers provided by the government, respectively. Household expenses include the purchase of consumer goods, F, which can be other food or provisions acquired on the market, at a price P_f. Other costs that the household needs to consider arise from the fishing activity itself, which depends (directly) on the quantity of fish extracted Y, and inversely on the stock of resource in the sea, S, that is $C = C(Y,S)$. Therefore, total household expenses are: $P_f F + C(Y,S)$.

A fishing household exhibits a utility function that depends on the self-consumption of fish (γY) and the consumption of other goods (F) as presented in Equation (2):

$$U = U(F, \gamma Y) \tag{2}$$

Household budget constraints require that income equals household costs; i.e.,

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

In fishing economics, it is typically assumed that the production function depends on two types of factors: those related to human activity—grouped under the term fishing effort, E—, and the natural factor, represented by the availability of the extracted resource or stock, S. Accordingly, the fishery production function can be expressed as $Y = Y(E, S)$.

The effort (E) depends, in turn, on the labor involved in fishing, (L_y), and the capital invested, (K), $E = E\left(L_y, K\right)$. Therefore, the production function can be expressed as $Y = Y\ (L_y, K, S)$.

In order to consider the dynamic nature of the fish stock, we propose a two-period model $[t = 0.1]$, in which the stock evolves according to the natural ecological conditions, through the natural growth function $F(S_0)$, and the aggregated fishing activity, $\hat{Y} = \sum_i Y_i$:

$$S_1 - S_0 = F(S_0) - \widehat{Y_0} \tag{4}$$

In this setting, the household seeks to maximize the discounted sum of its utility subject to the discounted budget restriction in the two periods, and the restrictions associated with time endowment and the production function:

$$\text{Max} \sum_{t=0}^{1} \delta^t\, U_t(F_t, \gamma_t Y_t) = \max u_0\,(F_0, \gamma_0 Y_0) + \delta u_1\big(F_{1,}\gamma_1 Y_1\big)$$

$$\text{Subject to} \qquad P_y(1-\gamma_t)Y_t + wL_{off_t} + T_t - P_f F_t - C(Y_t, S_t) = 0$$

$$Y_t = Y(S_t, L_{y_t}, K_t) \tag{5}$$

$$\bar{L} = L_{off_t} + L_{y_t} \rightarrow L_{off_t} = \bar{L} - L_{y_t}$$

$$for\ t = 0, 1$$

The term δ^t refers to the discount factor, which is $\delta^t = \frac{1}{(1+r)^t}$, *r* being the discount rate. From that, the optimization requires:

$$\max u_0\,(F_0, \gamma_0 Y_0) + \delta u_1\big(F_{1,}\gamma_1 Y_1\big) + \lambda_0\big(T_0 + P_y(1-\gamma_0)Y_0(\cdot) + w(\bar{L} - L_{Y0}) - P_f F_0 - C(Y_0, S_0)\big) + \delta\lambda_1\big(T_1 + P_y(1-\gamma_1)Y_1(\cdot) + w(\bar{L} - L_{Y1}) - P_f F_1 - C(Y_1, S_1)\big)$$

In this model, prices are assumed to remain constant over time, and the household is not allowed to borrow or lend money between periods. As a result, decisions made in period 0 are independent on those made in period 1. The only variable influencing intertemporal decisions is the change in the stock.

From the first-order conditions, two central equalities emerge. First, the marginal rate of substitution between market-purchased goods and self-consumed fish must equal the price ratio of these two goods, regardless of the period:

$$P_F/P_Y = MRS_{F_0,\gamma_0 Y_0} = MRS_{F_1,\gamma_1 Y_1}$$

Second, the value of the marginal productivity of labor must equal the external wage, regardless of the period:

$$\left(P_Y - \frac{\partial C}{\partial Y_0}\right)\frac{\partial Y_0}{\partial L_{Y_0}} = \left(P_Y - \frac{\partial C}{\partial Y_1}\right)\frac{\partial Y_1}{\partial L_{Y_1}} = w$$

To operationalize these expressions, specific functional forms are required for the utility function, the production function, and the cost function. For the utility function, we assume a Cobb-Douglas specification with a logarithmic transformation:

$$U = ln(\widehat{U}) = \alpha_f\, ln\, F + \alpha_y\, ln(\gamma Y) \qquad (6)$$

Where parameters α_f and α_y represent the weight of the goods on household utility, and $\alpha_f + \alpha_y = 1$.

The production and cost functions must exhibit characteristics consistent with economic production theory. The Cobb-Douglas specification for the production function ensures factor substitutability and has demonstrated robust performance in simulation analyses (Yang, Chiang & Liu, 2022; Campbell, 1991):

$$Y = \tilde{\varphi}\, L_y^{\beta_1} K^{\beta_2} S \tag{7}$$

From the theoretical analysis, cost minimization using this type of functional form implies the following expression for the minimum cost function:

$$C(w,r,Y,S) = \left(\frac{Y}{\varphi S}\right)^{\frac{1}{1+\beta_2}} \left(\frac{w^{\beta_1}}{r^{\beta_2}}\right)^{\frac{1}{\beta_1+\beta_2}} \left[\!\left[\left(\frac{\beta_1}{\beta_2}\right)^{\frac{\beta_2}{\beta_1+\beta_2}} + \left(\frac{\beta_2}{\beta_1}\right)^{\frac{\beta_1}{\beta_1+\beta_2}}\right]\!\right] = \left(\frac{Y}{\varphi S}\ \frac{w^{\beta_1}}{r^{\beta_2}}\right)^{\frac{1}{\beta_1+\beta_2}} A$$

If the production function exhibits constant returns to scale in anthropic factors (L, K), the cost function takes the following form:

$$C(Y,S) = \frac{AY}{\tilde{\varphi} S}\ \frac{w^{\beta_1}}{r^{\beta_2}} = \frac{\Theta Y}{S} \tag{8}$$

where θ reflects the intensity of cost function parameter while θ/S reflects the marginal and the average cost of the catch.

Data from the survey demonstrated that credit markets are highly restricted in this context and that capital (represented by vessels, engines, and gear) is not a variable factor. Therefore, we assume that capital is fixed in this model, and thus, the production function can be written as a function of labor allocated to fishing, the resource stock, and technological parameters:

$$Y = \tilde{\varphi}\overline{K}^{1-\beta} L_y^{\beta} S = \varphi L_y^{\beta} S \tag{9}$$

Using this assumption about the utility and production functional forms, we are able to estimate the household’s decision functions related to consumption and production.

3.2 HOUSEHOLD DEMAND AND SUPPLY FUNCTIONS

The solution to the model 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), for each period. As a result of the temporal independence, these functions share the same functional form across periods, but their value depends on the contemporaneous fish stock. Estimated functions are presented in Table 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 (12) 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 ($SP_y - \theta$), 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 an HPM. The amount of fish caught that the household allocates for self-consumption (γY)—Equation (14)—depends directly on the weight of fish consumption for household utility (α_y), on the time available for work ($\bar{L}$) and the transfers (T), on the productivity of fishing φ, and on the marginal net benefit of fishing ($SP_y - \theta$). The signs of the effects of the fish price and wages, however, are not directly observable. This ambiguity arises because fish price plays a dual role: on one hand, it has a negative effect by reducing demand for the good; on the other, it has a positive effect through the profit channel, as higher prices increase income from fish sales, thereby expanding the household's capacity 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 caught and used for consumption.

Table 1. Summary of the optimal supply and demand functions resulting from the DFHPM. As the functions exhibit the same functional form in both periods, we omit the sub index t.

Demand/ Supply	**Mathematical expression**	**Eq.**
L_y = Fishing labor supply	$L_y = \left(\frac{\beta\varphi}{w}\left(SP_y - \theta\right)\right)^{\frac{1}{1-\beta}}$	(10)
L_{off} = Non-fishing labor supply	$L_{off} = \bar{L} - \left(\frac{\beta\varphi}{w}\left(SP_y - \theta\right)\right)^{\frac{1}{1-\beta}}$	(11)
Y = Fish supply: Total catch	$Y = \varphi S\left(\frac{\beta\varphi}{w}\left(SP_y - \theta\right)\right)^{\frac{\beta}{1-\beta}}$	(12)
γ = Proportion of fish for household consumption	$\gamma = \frac{\alpha_y}{SP_y}\left[(w\bar{L} + T)\left(\frac{w}{\beta\varphi^{\frac{1}{\beta}}\left(SP_y - \theta\right)}\right)^{\beta/_{1-\beta}} + \left(SP_y - \theta\right)(1-\beta)\right]$	(13)
γY = Demand for fish for household consumption	$\gamma Y = \frac{\alpha_y}{P_y}\left[w\bar{L} + T + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi\left(SP_y - \theta\right)\right)^{1/_{1-\beta}}\right]$	(14)
F = Demand for other consumption goods	$F = \frac{\alpha_f}{P_f}\left[w\bar{L} + T + (1-\beta)\left(\left(\frac{\beta}{w}\right)^{\beta}\varphi\left(SP_y - \theta\right)\right)^{1/_{1-\beta}}\right]$	(15)

Assumptions: $\left(SP_y - \theta\right) \geq 0$; $0 < \beta < 1$.

Note that resource availability plays a vital role in household wellbeing, as it enhances the potential for consuming both fish and other goods.

3.3 COMPARATIVE STATICS: ELASTICITIES

We calculated the elasticities of the functions estimated by the model ($L_y,\ L_{off},\ F,\ Y,\ \gamma,\ \gamma Y$), in response to changes in several key economic parameters: prices ($P_f,\ P_y,\ w$), technical and cost parameters of the fishing activity (φ, θ), direct transfers (T), the households' time availability for productive activities ($\bar{L}$), and the availability of the extracted resource (S). These are presented in SM1. In some cases, the sign of elasticities is unequivocal; in others, it is ambiguous, and the final value depends on the context. As discussed above, some parameters influence variables in opposite directions, so the final sign will depend on the relative strength of each. Similarly, the magnitude of the elasticities is an empirical matter, determined using household survey data. Table 2 summarizes the signs of the elasticities estimated based on the DFHPM. Among the various parameters, the available resource stock plays a central role in household decision-making. Higher fish stocks lead to increased time allocation to fishing (and reduced time spent on other activities), greater harvests, and higher levels of fish self-consumption. The additional income generated from larger fish harvests also enables greater consumption of other goods.

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

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

However, the variable γ, which represents the proportion of fish allocated to self-consumption, has an indeterminate sign. This reflects the inherent trade-off in the household production model: a larger harvest lead to increased fish consumption, but it also provides more opportunities to generate income through market sales. As a result, the final value is context-specific and empirically defined.

4. MODEL SIMULATION

4.1 DATA

The theoretical model is validated using data collected from fishing households in the village of Barú. According to a household census conducted between June and July of 2018, the village comprised 801 households, of which 158 were identified as fishing households. From this population, we randomly selected a stratified sample of 97 fishing households—sufficient to achieve a confidence level above 95% with a 5% margin of error. A set of monthly surveys was designed and administered between July 2018 and October 2019.

Fishing households in Barú typically consist of four members, with an average age of 26 years. These households have an illiteracy rate of 14%, which rises to 22% when considering only heads of household. On average, household heads have 4.7 years of formal education. In terms of labor diversification, fishing households in Barú report an average of 1.71 income-generating activities per household. The most common primary occupations among household heads include fishing, maritime transport, fish storage, fish trading, and rental of fishing equipment. Regarding fishing specifically, 100% of surveyed fishers were men, with an average age of 46 years and an average of 4.3 years of education.

The most commonly used fishing methods are handlining and diving. When fishing is the primary activity, 47% of fishing households prefer handlining, while 40% opt for free diving. A key characteristic of fishing is its flexibility—it can serve as either a primary or secondary activity and may be practiced on a full-time or part-time basis. Fishing plays a vital role in generating income, not only for households that rely on it as their main source of livelihood, but also as a coping strategy for those who engage in it as a secondary activity during times of hardship. On average, 85% of the catch is sold, 13% is consumed by the household, and 2% is gifted to other households. In Barú, the average monthly monetary expenditure of fishing households is approximately USD 836 (PPP[1]), while the average per capita household expenditure is USD 229 (PPP). The total average monthly income of these households is around USD 1,233 (PPP). Fishing contributes directly to 37% of household income and indirectly to an additional 5.8%. According to the headcount poverty index, 27.1% of fishing households in Barú fall below the national poverty line, and 4.5% are below the extreme-poverty line.

4.2 Model Parameters

The FHPM includes a set of parameters that need to be calibrated so that when they are included in the theoretically-estimated functions, the values coincide as close as possible with the observed values. The parameters can be grouped in categories:

- ***Market prices***. In this model, prices include fish price, P_y, wage rate, w, and price of other goods, P_F. Fish price was estimated from data at USD 11.73 ($\pm$5.57) PPP per kilogram, and wage for other activities at USD 2.52 ($\pm$3.94) PPP per hour. The value of P_F was set at 1, assuming it is a numeraire good.
- ***Household characteristics.*** Two parameters are needed to calibrate the model. The first is the total amount of time available to the household for work. Based on the survey data, we estimated this value $\bar{L}$, at approximately 70 hours per week (69.98$\pm$37.64). The second parameter is government transfers, also obtained from the survey, which were estimated at USD 18.44 (PPP).

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

- ***Production and cost function parameters***. As mentioned earlier, survey data showed that credit markets are highly restricted in this setting and that capital (represented by vessels, engines and gear) is not a variable factor. Therefore, we assume that capital is fixed in this model, and thus, the production function can be written as:

$$Y = \tilde{\varphi} L_y^{\beta} \overline{K}^{1-\beta} S = \varphi L_y^{\beta} S$$

Its estimation requires the calculation of parameters φ and β. Cost function, in its condensed formed can be written as $C = \Theta Y/S$, meaning that we need an estimate of parameter θ. In order to estimate the parameters associated with the production and cost functions, data from the survey can be used to econometrically estimate the parameters associated to the adopted functional forms. For the production function, the estimated model is:

$$\ln(Y_i + 1) = \varphi + \beta \ln(L_y) + u_i$$

As for the cost function, a linear functional form needs to be estimated:

$$C_i = \alpha_0 + \alpha_1 Y_i + u_i$$

where α_0 is a constant that captures the time-invariant factors that affect the costs of fish catch within the household, presumably the fixed costs. Parameter α_1 reflects the term θ/S. It is important to note that the resource stock is an unobservable variable in the model, and, as such, cannot be separated separately identified in the econometric estimation.

- ***Unobservable parameters***. Some parameters are not directly observable from the data. One such set relates to the utility function parameters. In our model, we assume that $\alpha_y + \alpha_f = 1$. For a Cobb-Douglas utility function, the resulting Marshallian demand functions take a standard form, generally expressed as $X = \alpha_x M/P_X$, where M denotes available income, and P_X the price of the good. From this relationship, we can derive that $\alpha_X = P_X X/M$. Applying this approach to our utility function and goods, we can assume that:

$$\alpha_{\gamma Y} = \frac{P_Y \gamma Y}{M}; \quad \alpha_F = \frac{P_F F}{M} \tag{16}$$

These parameters represent the proportion of household income allocated to the expenditure on each good. Their values can be inferred from the survey data.

As for the resource stock, S, it is not directly observable from the survey or any other available data sources. Therefore, for calibration purposes, we assume a normalized value of 1.

4.3 Model Calibration

To identify the parameter values that best approximate the observed data, we apply a numerical calibration method. Table 3 presents the estimated values used for calibrating the demand and supply system, as well as the resulting calibrated parameters.

Table 3 Estimated parameters for the FHPM and final calibrated value

Variable/ parameter	Symbol	Mean	Approach	Calibrated value
Weight of consumption of other goods for household utility	α_f	0.75-0.95	Marshallian demand function	0.86
Weight of fish self-consumption for household utility	α_y	0.05- 0.25		0.14
Total fishing-factor productivity	φ	1.919 – 2.953	Production function regression	3.44
Labor efficiency in fishing	β	0.469 – 0.595		0.5
Cost parameter	θ	0.176– 0.221	Cost function regression	3.14

4.4 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. The estimated values closely match the observed values, consistently falling within 0.2 standard deviations. This level of accuracy gives us confidence that the parameters reliably reflect the behavior of Barú's fishing households.

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

	Symbol	**Mean (s.d.)**	**Median**	**Calibrated parameters**	**Std. dev. from the median**
Labor supply for fishing (hours per week)	L_y	35.43 (18.54)	35	34.38	.06
Labor supply for other productive activities (hours per week)	L_{off}	33.10 (34.52)	32	35.62	.07
Fish catch (kilograms per week)	Y	20.80 (21.42)	15	20.16	.03
Proportion of fish caught for self-consumption (percentage)	γ	0.18 (0.17)	0.14	0.17	.07
Quantity of self-consumed fish (kilograms per week)	γY	3.72 (2.29)	2.50	3.36	.16
Market demand for food (USD PPP per week)	F	205.87 (175.74)	176	242.06	.17

4.5 ESTIMATED ELASTICITIES

Table 5 shows the elasticities for supply and demand in the FHPM with respect to the estimated parameters. Yellow boxes show the variables that have an elastic relationship with the parameters.

Purple boxes contain the variables that are inelastic. Green boxes show the variables that have a unitary elasticity. The theoretically expected sign is presented in parentheses.

Table 5 Value of estimated elasticities. The theoretically expected sign in parentheses

Variable	P_Y	P_f	w	θ	φ	T	$\bar{L}$	S
L_Y	+2.73 (+)	0 (0)	-2.00 (-)	-0.73 (-)	+2.00 (+)	0 (0)	0 (0)	+2.73 (+)
L_{off}	-2.63 (-)	0 (0)	+1.93 (+)	+0.70 (+)	-1.93 (-)	0 (0)	+1.96 (+)	-2.63 (-)
Y	+1.37 (+)	0 (0)	-1.000 (-)	-0.365 (-)	+2.00 (+)	0 (0)	0 (0)	+2.37 (+)
γ	-1.47 (?)	0 (0)	+1.34 (+)	+0.125 (?)	-1.34 (-)	+0.07 (+)	+0.67 (+)	-1.47 (?)
γY	-0.10 (?)	0 (0)	+0.34 (?)	-0.24 (-)	+0.66 (+)	+0.07 (+)	+0.67 (+)	+0.90 (+)
F	+0.90 (+)	-1.000 (-)	+0.34 (+)	-0.24 (-)	+0.66 (+)	+0.07 (+)	+0.67 (+)	+0.90 (+)

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 allocated to self-consumption) in relation to fish price. 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.

A wage-rate increase 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 allocated 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. This effect finally generates an increase in the demand for both self-consumption of fish and the 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, leads to a decrease in income and, consequently, a reduction in the consumption of goods. Although the proportion of fish allocated to self-consumption increases, overall household fish consumption still declines due to reduced fishing.

Changes in lump-sum transfers do not affect fishing decisions. However, they do affect consumption decisions, by increasing them, albeit with very low elasticity—likely reflecting the relatively small value of transfers received by the population in Barú.

An increase in the household's available labor force (e.g., through the arrival of new members capable of working) tends to be allocated to alternative income-generating activities, boosting the household income. This additional income leads to increased consumption of all goods, including fish for self-consumption, meaning a larger proportion of the catch is retained for the household.

Finally, 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 if the proportion of the catch allocated to self-consumption decreases. This finding aligns with our analysis presented in SM2, which shows that a 1% reduction in fish stocks in South America has led to a 2.5% decrease in catches.

4.6 INTERTEMPORAL EFFECTS

Households make decisions based on their private information. However, as the stock is a common pool resource, individual decisions aggregate and affect resource availability. Under open access, if the fishing households perceive positive benefits from fishing, the effort will increase to capture these rents. Household profits from fishing are defined by the term $\left(P_y - \theta/S\right)$, which denotes the marginal benefits. As this term is positive, effort will increase.

The aggregate behavior of the stock will respond to the evolution equation:

$$S_1 = S_0 + F(S_0) - \hat{Y}$$

$$S_1 - S_0 = \frac{\Delta S}{\Delta t} = F(S_0) - \hat{Y}$$

Where $\hat{Y}$ captures the aggregated harvest of all participating fishing households and *F(S)* denotes the growth function of the resource. If $\frac{\Delta S}{\Delta t} < 0$ the stock will decrease in period 1, and therefore, households will adjust their decisions. As shown in Table 5, a reduction in S, will lead to a decrease in harvest, time devoted to fishing, self-consumption, and consumption of other goods, while time allocated to other activities, and share of self-consumption will increase. According to FAO (2024), sustainable stocks have diminished from 90% in 1974 to 62.3% in 2021, implying an annual reduction rate of 0.59%. We performed a RAM Legacy Stock Assessment Database (see SM2) analysis and found that, in South America, fish stocks have reduced by 52.6% from 1990 to 2015, and 36.86% in the 2000-2016 period, meaning annual rates of reduction greater than 2%. Global data reveal similar trends. We use a conservative estimate of a 0.6% annual decline to simulate changes in fish stock for 10, 15, and 20 years. The results, shown in Table 6, are based on the outcomes from the last column of Table 5. As fish stocks decline, the labor dedicated to fishing drops significantly and is reallocated to alternative activities. While labor markets are imperfect, human capital is limited, and other constraints exist, it is assumed that fishers leaving the sector are able to find employment in other areas. Fish catches also decrease—at a more than proportional rate. Nonetheless, fishers choose to increase the share of the catch allocated to self-consumption. However, overall consumption of fish and of other goods declines. This outcome reflects a drop in income from fish sales, forcing fishers to reduce their overall consumption.

Table 6 Effect of changes in fish stock on model variables

Variable	**Estimated elasticities**	**Effect if stock change is (-11.88%), 20 years**	**Effect if stock change is (-8.84%), 15 years**	**Effect if stock change is (-5.89%), 10 years**
Fishing labor (Ly)	-2.7	-32.2%	-24.1	-16.1%
Alternative labor (Loff)	2.6	+31.0%	+23.3	15.5%
Harvest (Y)	-2.4	-27.9%	-20.9%	-13.9%
Share of harvest consumption (γ)	1.5	17.3%	13,0%	8.6%
Self-consumption (γY)	-0.9	-10.6%	-7.9%	-5.3%
Other consumption (F)	-0.9	-10.6%	-7.9%	-5.3%
Wellbeing (utility)	-0.9	-10.6%	-7.9%	-5.3%

5. POLICY INTERVENTIONS

The FAO declared 2022 as the year of artisanal fisheries and aquaculture and proposed a Global Action Plan to empower small-scale artisanal fisheries and secure a sustainable future for this sector (FAO, 2021). As the fish stock is affected by overexploitation, fishing communities' wellbeing is affected by reduced catches, affecting both self-consumption and sales, in turn, reducing the consumption of other goods as well. Following the FAO's Global Action Plan, Vargas-Morales (2023) compiled a set of policies designed to support fishing communities, which can be simulated using our model. These policies include either increases in fish prices, improvements in fishing technology, subsidies for fishing, lump-sum transfers to households, and higher remuneration for alternative activities. By simulating these policies, we can observe the relationships between the impacts on living standards and the pressure on resources caused by different policy options.

The first policy that we analyze is one that raises ***fish prices*** (P_y), which can increase due to various exogenous changes. Increased demand for fish resulting, for example, from policies that incentivize beach-tourism could increase fish prices. Note that a price increase would not necessarily be associated with any management strategy aimed at sustainable fishery use in this simulation. Given that having only one representative species with only one price, is a model assumption, the possibility of consumers migrating to consume more sustainable, cheaper, or smaller fish is not considered here. The simulation shows (Table 7) that—in gross terms—this policy would increase the catch (see column Direct effect), presumably harming the resource stock. Although it would also increase fishing households' wellbeing in terms of income and utility, a price increase would reduce fish self-consumption. Alderman (1986) argues that higher income and less self-consumption may lead to increased consumption of staple food such as grains, which contain lower-quality protein than fish. Therefore, greater catches and income do not necessarily translate into improved food security. Kawarazuka and Béné (2010) highlight the risk that food-insecure households may opt to sell a larger proportion of their fish catch to secure minimum quantities of basic goods, often perceived as a priority. In such cases, food consumption may come at the cost of nutritional security.

Table 7 Effect of selected policies on key model variables. Direct effect refers to the effect without considering changes in stock. Values are expressed in percentages.

Variable	**Increase 1% in fish prices**		**Improved 1% fishing technology**		**1% fishing costs subsidy**		**1% increase in transfers**		**Alternative activities, 1% increase wage**	
	Direct effect	After Stock reduction	Direct effect	After Stock reduction	Direct effect	After Stock reduction	Direct effect	After Stock reduction	Direct effect	After Stock reduction
L_Y	2.73	-0.07	2.00	-0.78	0.73	-2.02	0	-2.73	-2.00	-4.68
L_{Off}	-2.63	-0.07	-1.93	0.65	-0.70	1.91	0	1.63	1.93	4.61
Y	1.36	-1.03	2.00	-0.41	0.36	-2.01	0	1.36	-1.00	-3.34
γ	-1.47	-0.02	-1.34	0.10	-0.12	1.34	0.07	1.53	1.34	2.83
γY	-0.10	-1.00	0.66	-0.25	0.24	-0.66	0.07	-0.83	0.34	-0.56
F	0.90	-0.01	0.66	-0.25	0.24	-0.66	0.07	-0.83	0.34	-0.56
U	0.76	-0.15%	0.66	-0.25	0.24	-0.66	‘.07	-0.83	0.34	-0.56
Change needed to overcome 1% stock reduction	1.20%		1.38%		3.77%		13.85%		2.66%	

However, if fish stock is affected by over exploitation, the effectiveness of this policy may quickly diminish. As shown in Table 7, (column *After stock reduction*), a 1% increase in fish prices is not enough to restore catch levels to those observed before the stock declined.

We estimate that a 1.20% increase in fish prices is required to restore household wellbeing to the level observed before a 1% reduction in stock. That is, the compensating variation for each 1% decline in stock corresponds to a 1.20% rise in fish prices.

A second policy would involve improvements in ***fishing technology*** (φ), which, in turn, would improve catch productivity and would increase the fishing effort. As for model construction, this parameter also includes capital assets such as vessels, gear, and fishing arts. The simulation shows that the catch of those fishers who improve their technology increases more than proportionally, negatively affecting 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 or more effective fishing gear. The additional catch will be reflected in increased income. While the proportion of the catch allocated to self-consumption is reduced, its absolute amount increases, improving households' intake of nutritional food.

Once the stock is affected, the impact of this policy may also be undermined: a 1% decrease in stock reduces the policy's effect, resulting in a 0.41% decline in fishing. The overall impact on wellbeing is similarly affected—what was initially a 0.66% increase turns into a negative outcome of -0.25% for each 1% reduction is stock.

The compensating variation to overcome the decrease in the stock and its effects on wellbeing would require an increase of 1.38% in the technology to compensate each 1% reduction is stock.

The third intervention would be to reduce ***fishing costs*** (θ) through subsidies or lower prices of variable inputs. In the simulation, this policy produces effects similar to those of technological improvements, though the magnitude of its impact across all analyzed variables is notably smaller. As a result, once the stock effect is included, fishing declines by more than 2% for each 1% reduction in stock, while consumption of fish and other goods falls by 0.66%, along with overall wellbeing. To offset the impact of each 1% decrease in stock on wellbeing, fishing costs would need to be reduced by 3.77%.

A fourth possible policy is to increase ***direct transfers*** (*T*), whether conditional or unconditional lump-sum transfers to households. These transfers do not affect catch levels or the allocation of time to fishing or other activities. They do affect consumption decisions, but given the low value of current transfers, a 1% increase has only a modest impact. According to the model, compensating for the reduction in stock would require an increase in direct transfers of approximately 14%.

The fifth possible policy is to strengthen ***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 positively impact household wellbeing, improve income and consumption, reduce harvest, and, therefore, the pressure on the fishing resource. It would also serve to increase household self-consumption of fish. Although income from fishing significantly reduces, income from alternative activities increases more than proportionally, ensuring that total income does not decline, and therefore, wellbeing increases.

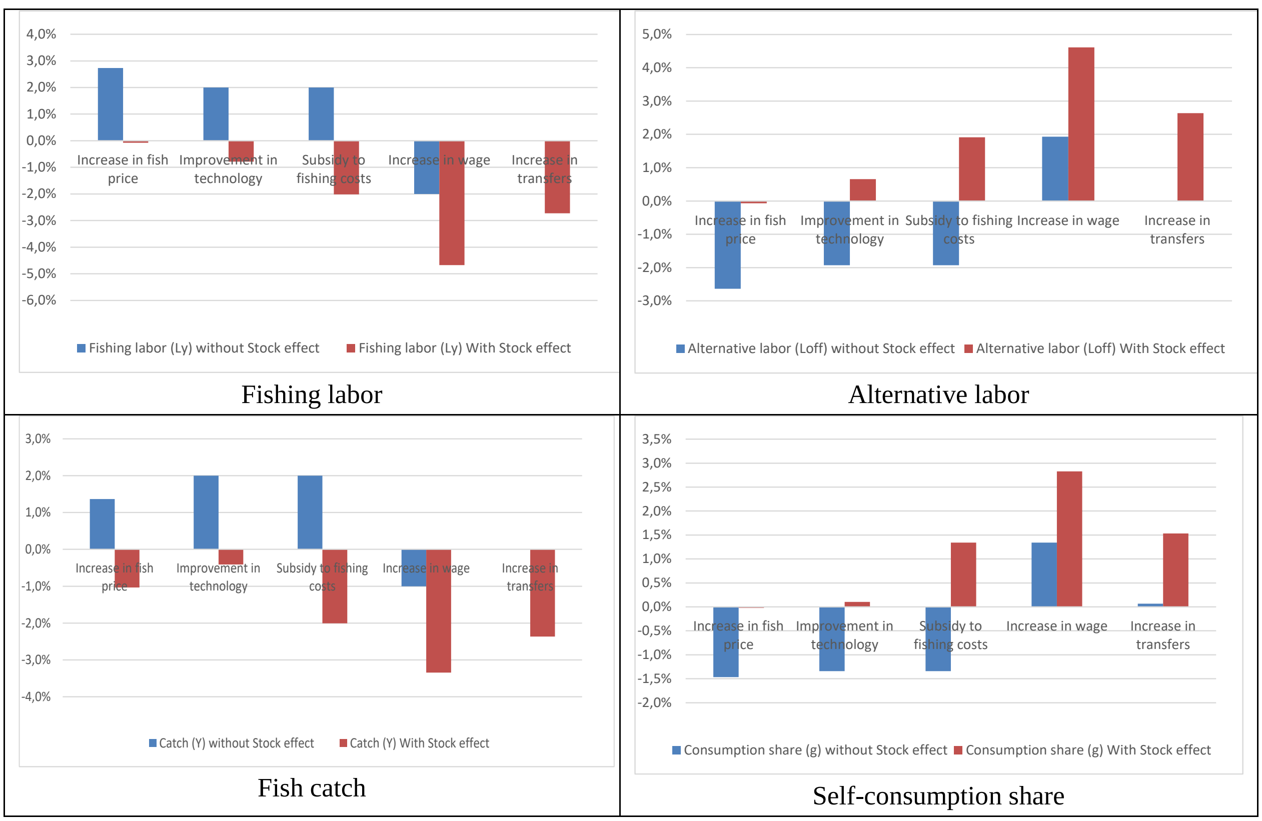
When the fish stock reduces, the observed effects of the wage increase are reinforced: fishing decreases even more, as does the allocation of time to fishing. However, now consumption is negatively affected, as is wellbeing. It is estimated that a compensating variation of 2.66% in wage rate allows households to recover the original levels of wellbeing.

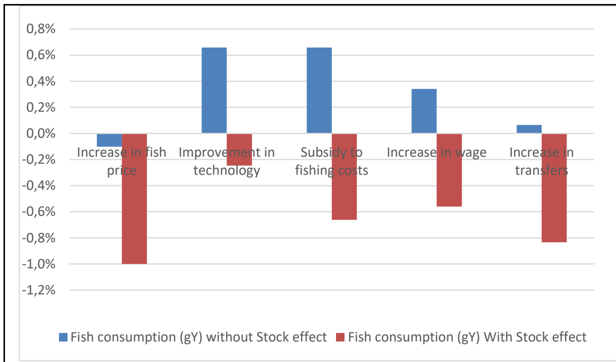
When comparing this policy to fish price, technology, or fishing costs, ***alternative activities*** is the only policy that reduces pressure on fish stocks. In this sense, this last policy seems to fit better if the objective is to improve living conditions while reducing pressure on natural resources.

Examples of this type of intervention include a wide range of options, such as the creation of alternative formal jobs in activities related to ecosystem conservation, restoration, and monitoring, as well as ecotourism. Promoting and supporting sustainable productive activities could serve as a further alternative.

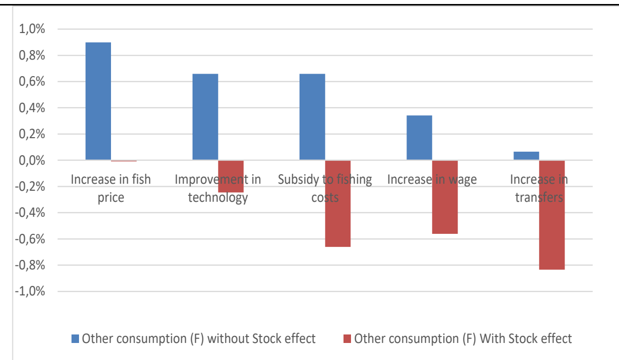
The panels in Figure 1 compare the effects of the policies both with and without considering the effect of changes in stock. Stock reductions resulting from overfishing end up in more attenuated effects or even opposite effects for most of the variables. Again, it is important to note that none of the policies restore fish catch and consumption to their previous values.

Figure 1 Comparison of policy effects with (red bars) and without considering stock effects (blue bars) for model variables





Fish consumption



Consumption of other goods

6. DISCUSSION

The main purpose of this study was to shed light on the livelihoods of small-scale fishing communities in coastal areas. Specifically, it addresses two questions: (i) how do key economic parameters influence fishing households' livelihood decisions, given their dependence on stocks that functions as a common-pool resource (CPR), and (ii) what policies can be implemented to promote the sustainable use of marine resources while improving the living standards of local communities, considering the implications of managing these stocks as a CPR.

The model reveals that the productive variables (total fishing, Y, time spent fishing, L_Y, and time spent on other activities, L_{Off}) are elastic to 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 in income generation within the household. Consumption variables (food acquisition, F, and self-consumption of fish, 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.

The share of fish allocated to self-consumption, γ, is an elastic variable with respect to almost all parameters (except fishing costs, transfers, and the price of other goods). This variable plays an essential role in balancing 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, selling another share 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 gamma variable appears to play a key role in adjusting household consumption decisions.

Our results confirm the presence of the profit effect, as described by Singh et al. (1986b), 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.

Overall, the estimated elasticities align with the theoretical predictions in terms of the signs. For those elasticities with theoretically ambiguous signs, the following empirical results are particularly noteworthy. 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 rise 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 a reduced catch should lead to reduced consumption of caught fish and 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 an increase in both the consumption of other goods and in the amount of fish the household keeps. That is, despite the reduced catch, wage increases lead 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, five policies were analyzed that affect the key model variables: changes in fish prices, changes in fishing technology, changes in the costs associated with fishing activities, changes in transfers, 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 only one that simultaneously showed benefits in terms of food intake and household wellbeing, and a reduction in the pressure on natural resources. In the other options analyzed, there is always a trade-off between conservation and fishing communities' economic development.

In a dynamic setting, the existence of a production input that is non-excludable but rival—the fish stock—leads to further consideration. If a policy, for instance, increases fish extraction, the stock might be affected in the long run, and changes in the fish stock will induce changes in household decisions. We found that a drop in the fish stock might reduce the impact of policies up to the point that they are not even relevant, when compared to the conditions in period 0. Therefore, depending on the context of the CPR, households might need to adjust their decisions when the aggregate impact of extraction determines the stock size. To maintain the fish stock at its initial levels, fishing must be reduced at a rate that depends on the fleet size and the resource's growth function. Alternatively, if we treat the proposed policies as compensatory tools, the model suggests that, to restore household wellbeing after a 1% stock reduction, we would need to increase fish prices by 1.2%, improve technology by 1.38%, raise subsidies by 3.77%, increase wage rates by 2.66% and boost direct transfers by 13.85%. These figures offer a useful benchmark for estimating the value of the lost fish stock.

These effects are not captured in previous household production models. Notably, higher wages outside the fisheries sector can have a dual positive impact—enhancing both sustainability and fishing households' wellbeing. Meanwhile, direct transfers may influence consumption without altering fishing-related decisions.

For a community like Barú—where there is no access to land, limited access to credit, and few alternative income-generating activities—strategies should be developed to address these constraints as part of broader conservation and development planning. As shown in this study, a significant proportion of the community's fishing households are above the poverty line and therefore do not qualify for direct state support, such as cash transfers. Imposing restrictions on fishing would increase poverty and vulnerability, posing a threat to food security. This, in turn, would demand targeted attention from the state to expand social protection programs and help mitigate the negative effects of income and food security. Unfortunately, these conditions are not unique to Barú and apply to many other communities across the developing world.

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