Aquaculture Vs. Wild Shrimp Fisheries: A Bio-Economic Analysis for West Bengal and Orissa

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Abstract*: The paper attempts to examine the impact of an increase in aquaculture shrimp production on wild shrimp fishery. In a major departure from the earlier works in this area, we have tried to establish the link between aquaculture industry and wild shrimp fishery. This has been done through a structure that analyzes the impact of an expansion of aquaculture shrimp industry, as reflected through an increase in the proportion of shrimp fry consumption. This issue has been captured by incorporating technological improvement of the shrimp industry via the increase in stocking density. On the basis of our structure we can thus conclude that technological change leads to an expansion of aquaculture industry and contraction of the wild fishery. This result is important from the point of view of policy makers and emphasizes on the need for defining more socially and ecologically responsible aquaculture industries that enhance traditional fishery and reduce current user conflicts that are in existence now.*

JEL Classification: Q51, Q56 and Q57

Key words: Aquaculture, Shrimp Farms, Shrimp Fry, Stocking Density, Wild Shrimp Fishery,, Technological Improvement, Effort.

Introduction

There is a growing per capita demand for fish products since the 1950s.The United Nations Food and Agricultural Organisation predicts that in this century, world consumption of aquatic proteins will increase to 150-160 million tons (FAO (2000)). Traditional Fisheries can provide no more than 100 million tons so the bulk of the increase will need to come from aquaculture. Over the past ten years, India has become the third largest shrimp producer in the world. Organizations like the World Bank and the Asian Development Bank have invested in shrimp aquaculture in developing countries[3] with the expectation that this industry will create jobs which will lead to new avenues of earnings. This would also help the policy makers to uplift the condition of the impoverished section of the society living mainly in village areas. However, the experience of developing countries is something different. Report published by National Environmental and Engineering Research Institute (NEERI) has concluded that resource destruction caused by shrimp aquaculture is actually greater than the amount of income generated from the exporting of shrimp in case of India. However, due to increased demand for shrimp by people in countries like United States and Japan shrimp aquaculture has become a very big business in India, since traditional fisheries (wild fisheries) can supply only a small portion of the total demand. Against such a backdrop, it is found that there is a rapid expansion of shrimp aquaculture in India.

As traditional fisheries i.e. wild fisheries and aquaculture both are used for meeting the increased food demand, the competition between both cannot be ignored. The rapid expansion of shrimp aquaculture industry in India creates ecological conflicts and hence this expansion must be accomplished by promoting an alternative aquaculture

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[3] See the website www.worldtrek.org

development model i.e. an "Ecological Aquaculture Model" (EAM). EAM considers not only the technical aspects of ecosystems design and ecological principles pertaining to aquaculture, but also incorporates comprehensive planning for the wider social, economic and environmental contexts of aquaculture.[4]

The expansion of the aquaculture industry is at the expense of growth of wild fishery since both these sectors are facing the same demand situations. Moreover, the expansion of aquaculture industry means a scarcity of wild shrimp fry. This is because the aquaculture industry uses wild shrimp fry as an input. This very issue raises the question of sustainability of shrimp farming. So the competition between aquaculture and fisheries should be so managed that they benefit both wild fishery and aquaculture operations as well as maintain ecological balance.

This tradeoff between aquaculture and wild shrimp fishery has only a small the literature in this regard. Some studies have considered the economic viability of aquaculture shrimp production vis-à-vis natural land uses (Srinath et al.(2000); Bhatta and Bhat (1998) Krishnan et al.(1995) etc).Some other studies have considered the adverse impact of commercial shrimp production on coastal environment(Sanathana-Krishnan (1995);Boyd (1997)). The aim of the present paper is different from the above. It attempts to examine the impact of an increase in aquaculture shrimp production (through an increase in the absorption of wild shrimp fry) on wild shrimp fishery. The issue is addressed in terms of an aquaculture shrimp farm/industry model. Such a structure is necessary for making policy making in determining the optimal allocation of shrimp fry between aquaculture and wild shrimp fishery.

The plan of the paper is as follows. Section 2 deals with structure of the theoretical model. Results and discussions are discussed in section 3. Finally, the concluding remarks are made in section 4.

2. The Theoretical Model

We assume that the aquaculture industry consists of 'n' identical farms[5] under a competitive set up. The aquaculture industry is actually competing with the wild fishery. In our model, we assume that the product of aquaculture and traditional fisheries are perfect substitutes. It implies that the prices are same for both the products. We also assume that the competing farms within the aquaculture industry are adopting the same technology. The producers of aquaculture farms use shrimp fry (SF) as an input along with other input effort (E). Producers buy their input, SF, from local fry collectors. Thus we ignore the role of hatcheries in shrimp production.[6] Though it is a simplifying assumption the introduction of hatchery will not bring any significant qualitative difference.

The aquaculture industry uses a fixed proportion of total SF and the remaining amount of SF goes to wild fishery. Let ν proportion of SF goes to aquaculture industry and (1-ν) proportion goes to wild fishery.

Therefore;

$$SF = SF_A + SF_W \quad (1)$$

SF_A : Amount of shrimp fry which goes to aquaculture industry

SF_W : Amount of shrimp fry which goes to wild fishery

In this model, $SF_A = \nu SF$ and $SF_W = (1-\nu) SF$ (1a)

We next consider the production function of a representative aquaculture farm. We assume it to be a Cobb–

[4] See the works of Costa- Pierce (2002); Coasta-Pierce and Bridger (2002); etc.

[5] At first sight it seems to be a restrictive assumption. However, if we consider the technology of the farms then it seems very reasonable since all the farms in a region adopts more or less same technology. Moreover, from the point of view of the product (shrimp)which they are producing is essentially homogeneous in nature. Thus we can conclude that as they are adopting the same technology to produce a homogeneous product they are identical in nature.

[6] Our study area is mainly the Sundarbans, where the role of hatcheries in shrimp fry production is not at all significant. However, in Dhamara shrimp fries are supplied both by local fry collectors and hatcheries. So as a starting point exclusion of the role of hatcheries is quite a reasonable assumption when our purpose is to compare the role of aquaculture vs. wild fishery from the point of view of wild shrimp fry collection.

Douglas production function[7] and it is given by

$$Y_A = ASF_A^{b1} E^{b2} \quad (2)$$

where, Y_A = Total yield of a farm.

The cost equation of the farm is given by

$$C = F + P_f . SF_A + W.E \quad (3)$$

where,

P_f: Price of SF

W: Cost / unit of E

We have expressed effort 'E' in terms of labour days[8]. Hence we take the price of effort as wage given to per unit of labour days .We denote it by 'W'.

We now focus on the technology part of the production function. For the aquaculture farm owner, technology for shrimp production is a function of its stocking density, which we can specify as

$$A=A(SF_A/\Omega)=A(\nu SF/\Omega) \quad , A^{/} >0, A^{//}<0 \quad (4)$$

where Ω is the given pond area.

Under the assumption that pond area and total stock of shrimp fry are given (for a given time period),[9] we find that an increase in ν, i.e. increase in proportion of total SF that goes to aquaculture, leads to an increase in the level of the technology of the aquaculture farm through an improvement in its stocking density.[10]

We minimize cost, given by equation (3), subject to the production function, given by equation (2), and set up the Lagrangian to derive the input demand functions for 'SF' and 'E' by a particular farm.[11] They are derived as follows

$$E_d = (b_2 / b_1)^{b_1/(b_1+b_2)} (Y_A /A)^{1/(b_1+b_2)} (P_f / W)^{b_1/(b_1+b_2)} \quad (5)$$

$$SF_{A\ d} = (b_1 / b_2)^{b_2/(b_1+b_2)} (Y_A /A)^{1/(b_1+b_2)} (W / P_f)^{b_2/(b_1+b_2)} \quad (6)$$

where,

E_d : Effort demand

$(SF_A)_d$: Demand for shrimp fry for a particular farm

The total cost function of a particular farm can be expressed as

$$C = F+[\{P_f (b_1 .W / b_2 .P_f)^{b_2/(b_1+b_2)}\}+\{W. (b_2 .P_f / b_1 .W)^{b_1/(b_1+b_2)}\}]^{1/(b_1+b_2)} . (Y_A/A)^{1/(b_1+b_2)} \quad (7)$$

Hence marginal cost (MC) function of the farm is

[7] It is a common and a simplifying assumption.

[8] Effort is expressed in terms of labour days by using the equation E= (total variable cost of all inputs)/(average wage rate). For this we have converted variable cost of all inputs in terms of labour days by dividing it by the wage rate. In this way we have established the equivalence between variable cost of inputs other than labour in terms of labour days. For example, cost of chemicals is expressed in terms of labour days in terms of labour days by using the expression (cost of chemicals)/(average wage rate). It is to be noted that labour input is already expressed in terms of labour days.

[9] Pond area of a farm is given for a particular period (short run). The owner of the farm cannot change his pond area within that period. The decision to change its pond area is a planning decision, which can be implemented only in the long run. It is also true for stocking of shrimp fry. Moreover we are using cross sectional data. Hence we can assume that pond area and stocking of shrimp fry are given for a particular time period i.e. in short run.

[10] As pond area is given in short run, which is mentioned in footnote 8, we can say that improvement in the stocking of shrimp fry implies improvement in the stocking density, which ultimately reflects the technology of a representative farm. Since producers generally operate in the economic zone of production function i.e second zone of production function, increase in stocking density will definitely increase the yield of a particular farm which will ultimately increase the total supply of the aquaculture industry.

[11] Since profit maximization and cost minimization, are dual to each other in this case we have adopted the technique of cost minimization. See Sathirathai(1998) in this context.

$$MC = 1/(b_1 + b_2).\ (1/A)^{1/(b1+b2)} \left[\{P_f\ (b_1 .W / b_2 .P_f)^{b2/(b1+b2)}\} + \{W.\ (b_2 .P_f / b_1 .W)^{b1/(b1+b2)}\}\right]^{1/(b1+b2)} .(Y_A)^{\{1-(b_1+b_2)\}/(b_1+b_2)} \qquad (8)$$

i.e. $MC > 0$ as long as $(b_1 + b_2) \leq 1$

Hence, under the conditions of CRS / DRS the supply curve is positively sloped. The possibility of IRS does not arise since it is not compatible with the assumption of perfect competition.

As all the farms are price takers the demand curve of a particular farm for the final product must be a horizontal straight line having an intercept. Let the price of shrimp be 'P'. Thus, from the equilibrium condition P = MC we can derive the equilibrium output of a particular farm and we denote it as Y^*.

The supply curve of the aquaculture industry can be derived by simple horizontal summation of individual supply curves of all the farms.

The supply curve of the aquaculture industry is nothing but $SS_A = \sum MC_i$. (9)

Let the supply curve for the wild fishery be given by; SS_W.

The total supply of the fishery sector is SS_F.

Hence,

$$SS_F = SS_A + SS_W \qquad (10)$$

The equilibrium output of the fishery sector can be determined by the intersection of SS_F and the demand curve (DD) for the fishery sector.

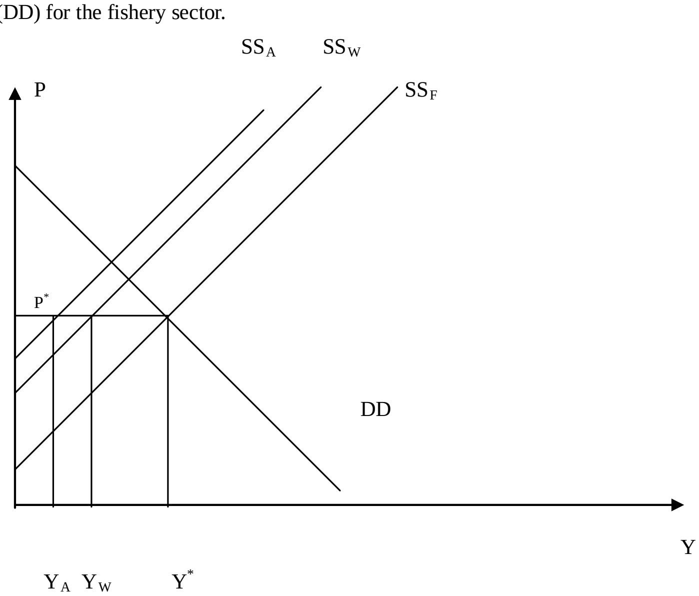

Figure 1: **Allocation of total supply between aquaculture and wild fishery**

The equilibrium values of price (P) and output (Y) are P^* and Y^* respectively. In this situation the aquaculture industry supplies Y_A whereas the wild sector fishery supplies Y_W. Thus though our theoretical model, we can establish the allocation of total supply between aquaculture industry and wild fishery.

Next, we now want to analyse the case when aquaculture industry expands for given total supply of shrimp fry in the region for both aquaculture sector and wild shrimp fishery sector.

With the expansion of aquaculture industry, requirement of 'SF' increases which means 'ν' increases and with this increment SS_A also increases and hence 'SS_A' curve shifts parallely rightwards as $SS_{A\,1}$. It is to be noted that increase in ν actually implies an expansion of aquaculture farm and hence of aquaculture industry through technological upgradation (see equation (4)). This technological upgradation leads to a rightward shift of 'SS_A' curve. However, with the increase in 'ν', '(1 -ν)' falls. As a result SS_W shifts to the left and becomes $SS_{W\,1}$. Thus supply from wild fishery decreases and that of aquaculture increases. This is true for given supply of total shrimp fry.[12]

In the following diagram (Figure 2) we can see that aquaculture supply increases to Y_{A1} whereas supply of wild fishery decreases to Y_{W1}.

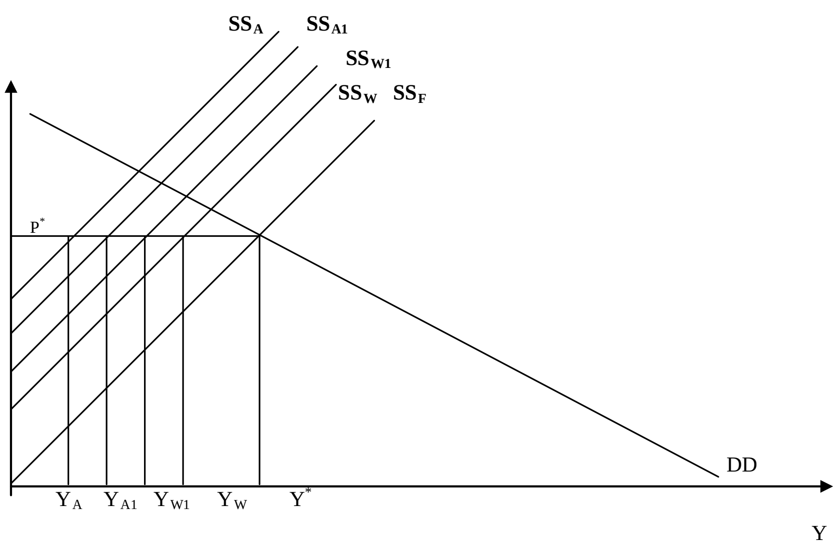

Figure 2

In the next part of our theoretical structure we will discuss the distributional effects of the above problem.

3. Results and Discussion

In this section, our attempt is to estimate our theoretical structure empirically. For this purpose, we first estimate the marginal cost (MC) function to derive the supply function of an individual farm. Since, we have dealt with cross section data we do not have marginal cost data. So we have considered price (P) of shrimp in place of MC.[13]The level of price varies from farm to farm due to spatial differences. They vary around the equilibrium market price so that the average of all prices can be assumed to be the equilibrium market price. To derive the supply function we equate MC with various levels of P as we find from our data and regress P on Y_A. We take natural logarithm of equation (8) of the theoretical model and find that ln MC is a function of $\ln Y_A$. Finally we equate lnMC with lnP and find that lnP can be expressed in terms of $\ln Y_A$.

For our estimation field surveys are conducted in various blocks of Sundarban (in West Bengal) and Dhamara (in Orissa). The following supply function has been estimated for two types of data sets, viz. Sundarban region and

[12] See footnote 16 for an explanation.

[13] Under the assumption of perfect competition P = MC condition holds in equilibrium. So we can take P instead of MC.

Dhamara region.[14]

$Z = \alpha + \beta X$

where, $Z = \ln(P)$, $X = \ln(Y_A)$

$$\alpha = [1/(b_1 + b_2)] \left[\ln 1/(b_1 + b_2).(1/A)^{1/(b1+b2)} [\{P_f (b_1 .W / b_2 .P_f)^{b2/(b1+b2)}\} + \{W.(b_2 .P_f / b_1 .W)^{b1/(b1+b2)}\}] \right]$$

and $\beta = \{1/(b_1 + b_2)\} - 1$

The results are given in the following table.

Table 1: Regression Results

	No.of observations(n)	R^2	$\bar{R}^2$	$\hat{\alpha}$	t values (intercept)	$\hat{\beta}$	t values (slope)
Dhamara	14	.53	.49	4.67	26.12	.2	3.68
Sundarban	81	.73	.72	4.49	62.2	.17	14.52

Comment [mr1]:

From the above table, on the basis of the values of R^2, we find that the regression fit of Z on X is quite good; given the fact we have considered cross section data for our analysis. This is true for both Dhamara and Sundarban. Moreover, all the estimated values of parameters are significant along with expected signs.

Using the average estimated value of Z, we can find the average value of X for all the data series. Taking the antilog of X, we can find the average yield i.e. $\bar{Y}_A$. This $\bar{Y}_A$ can be considered as the equilibrium output of a representative aquaculture shrimp farm. Multiplying this with the number of farms[15] (given by the number of observations), we can find the total yield of aquaculture industry for each of the above mentioned two data series. The equilibrium price is obtained by taking the average of Z, i.e. $\ln \bar{P}$, and then taking the antilog of $\ln \bar{P}$. As aquaculture industry supplies only 33% of total requirements, we can conclude that wild fisheries supply the rest 67% of total requirements that is not supplied by aquaculture industry.[16] So we can calculate the supply of wild shrimp fishery and hence the total supply of shrimps.[17] The following table provides all such details.

Table 2: Showing the Average of P, Y and Total Supply of Different Sectors for Different Region

	$\bar{P}$ **(Rs)**	$\bar{Y}_A$ **(Kg)**	Y_A **(Kg)**	Y_W **(Kg)**	Y^* **(Kg)**
Dhamara	202.35	2405	33670	68360.3	102030.30
Sundarban	254.68	428.38	34698.78	70449.04	105147.82

From the above table, we can see that though average yield of an aquaculture farm in Dhamara is greater than the average yield in Sundarban, total supply of aquaculture and wild sector fishery and hence the composite fishery sector in Sundarban is quite greater than Dhamara region, since the total number of surveyed farms in Sundarban is quite large compared to Dhamara region. Next we will examine the impact of changes in technology on wild fishery

[14] For estimation purposes we have used E. VIEWS package.

[15] Here we assume that the total number of farms forming the aquaculture industry is equivalent to the number of surveyed farms in a particular region.

[16] We have obtained this proportion from the literature. See Costa –Pierce (2002) in this context.

[17] As we assume that the aquaculture industry is nothing but the sum of total surveyed farms we can say that total supply of aquaculture industry is nothing but the requirements that is not supplied by wild shrimp fishery. This is true for the total population of matured shrimps. Here , however, we have considered a representative sample of aquaculture shrimp farms. Naturally we have focused only on a representative part of total population of matured wild shrimp. It has been implicitly assumed here that the ratio between the supply of aquaculture industry and wild sector remains the same, whether it is population ratio or sample ratio.

and aquaculture sectors.

In our model, changes in technology can be captured by changes in stocking density. As pond area is given to an owner for a particular time period, changes in stocking density is nothing but changes in the stocking of shrimp fry for a farm. Moreover, we have ignored the role of hatcheries in our model. Thus changes in the stocking of shrimp fry of an aquaculture farm will definitely affect the availability of shrimp fry for the wild fisheries.[18]

We now consider the case of increase in the stocking density of an aquaculture farm i.e an increase in the proportion of shrimp fry that goes to aquaculture industry. This means an increase in the value of 'ν' will definitely increase the value of 'A', since $A^{/} > 0$. An increase in the value of $A^{/}$ means an improvement of technology which ultimately reduces the value of '$\hat{\alpha}$'. For the time being, we will consider the case of reduction in the value of '$\hat{\alpha}$' by 1%. The impact of a reduction in the value of '$\hat{\alpha}$' on aquaculture industry and wild fishery has been summarized in the following table.

Table 3: Showing the Impact of Changes in the Technology on Y_A and Y_W

	% changes (increase) in Y_A	**% changes (decrease) in Y_W**
Dhamara	30.98	15.26
Sundarban	41.91	20.64

From the above table, we can say that an improvement of technology of the aquaculture farm will cause a reduction in the supply of wild fishery and an increment in the supply of aquaculture industry for both the regions.

4. Concluding Remarks

In India shrimp industry plays an important role not only in earning foreign exchange but also catering to domestic needs. This industry consists of two parts: wild fishery and aquaculture industry. Aquaculture industry has expanded due to the fact that wild shrimp fishery alone cannot meet the increased demand for shrimp in the world market. However, there exists a tradeoff between wild fishery and aquaculture shrimp industry and they should be better managed for the benefit of both traditional fishing and aquaculture farming communities. In a major departure from the earlier works in this area, we have tried to establish the link between aquaculture industry and wild shrimp fishery. This has been done through a structure that analyzes the impact of an expansion of aquaculture shrimp industry, as reflected through an increase in the proportion of shrimp fry consumption. This issue has been captured by incorporating technological improvement of the shrimp industry via the increase in stocking density.

On the basis of our structure we can thus conclude that technological change leads to an expansion of aquaculture industry and contraction of the wild fishery. This result is important from the point of view of policy makers and emphasizes on the need for defining more socially and ecologically responsible aquaculture industries that enhance traditional fishery and reduce current user conflicts that are in existence now. Resarchers can explore this area for getting more insights on shrimp aquaculture management practices.

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[18] For a given time period total amount of shrimp fry is given for a region, since changes in shrimp fry will only occur when there is a new recruit of shrimp fry or there is a migration of shrimp fry from other regions which is not possible in case of a shorter time period.

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