NON-CONVEXITY AND THE SUSTAINABILITY OF THE INDONESIAN LIFE REEF FISH FISHERY

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ABSTRACT

Fishing for the life reef fish has been an important source of economy both at macro level and micro level. At Macro level, life reef fish for food (LRFF) plays a greater role in increasing export revenue since most of the fish are sold in overseas markets such Hong Kong and China. At micro level, LRFF provides secured income and employment for people in coastal areas where poverty is persistent. The capacity of the fishery resource to supply the increasing demand, however, is limited due to the nature of non-convexity of the fishery system and the backward bending supply curve dictated by its yield function. This paper explores the consequences of such constraints by imposing the non-linear dynamic model developed previously by Rosser (2000). The study was empirically tested in one the Indonesian LRFF fishery in South Sulawesi and the results show that the non-convexity as seen from the backward bending supply curve will result in unsustainable management of the fishery which lead to poverty and ecosystem catastrophic in the coastal area if no serious actions are taken.

Keywords: non-convexity, life reef fish fishery, sustainability, backward bending

INTRODUCTION

Fishing for the life reef fish has been an important source of economy both at macro and micro levels. At Macro level, life reef fish for food fishery, or LRFF fishery for short, plays a greater role in increasing export revenue since most of the catches are sold in overseas markets such Hong Kong and China. At micro level, LRFF fishery provides secured income and employment for people in coastal areas where poverty is persistent.

The live reef fish fishery in Indonesia is predominantly practiced in the Eastern part of Indonesia with main target species is mostly grouper. Even though the fishery has been operating since 1975, it is only in 1990s that the fishery experienced a dramatic impact to local economy and ecosystem due to economic crisis experienced by the country in 1999. During this thirty years period that the fishery has evolved from mainly subsistence and small-scale fishery to more export oriented one triggered by continues increase in demand from international markets such as Hong Kong and China.

Rapid growing of demand in international markets has also raised concerns over the trade impact of this particular type of fish on the ecology as well as on the economic viability of the fishery in general. Various studies have voiced such a concern. On regional scale, for example, Peterson et al (2004) acknowledge the impact of trade of this fish on the sustainability of the supply side (i.e., resources). At national level, various studies have been conducted to analyze the exploitation of this fishery and its effect on the environment as well as on the socio-economic

aspects (Pet-Soede et al, 1999; Pet-Soede et al, 2004; Mouse et al, 2000 and Fauzi, 2007). The converging theme of most of these studies is that there is a growing concern about the sustainability and the future state of this fishery and its impact on the livelihood of the fishermen and the ecosystem.

One factor that determines the sustainability of the LRFF is the ability of resources to provide a long term supply of fish to the markets. It is on this issue that careful attention is needed. A number of peculiarities arise in the case of fisheries. First, since the work of Copes in 1970, it is now understood that, unlike regular commodities, the supply curve in fishery is rather "backward bending" just like the market for labor (Figure 1). In such a situation, when demand increases from D_0 to D_1 on the backward bending part of the supply curve, the equilibrium moves from point A to point B, and quantity supplied decreases from Q_0 to Q_1. This reversal impact of the backward bending part is not commonly found in neo-classical economic's perspective. It is attributed to the nature of biological resources which can not be harvested indefinitely.
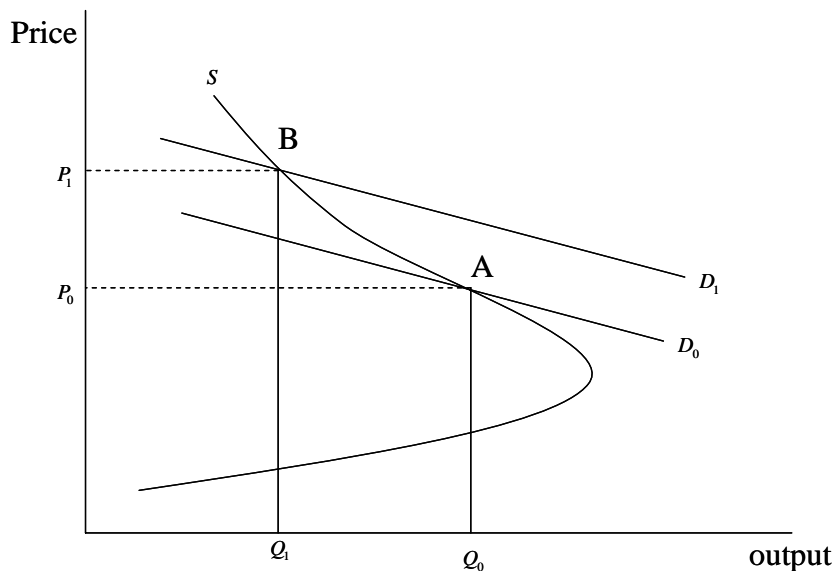

Figure 1. The supply and demand curve for a typical fishery (Copes, 1970)

Second, fishing is subject to various economic and ecosystem constraints which constitutes non-convexity in nature. Lewis and Schmalensee (1979), for example, recognizes that the existence of non-convexity in fishery in the form of increasing return in harvesting and re-entry costs can radically alter the optimal strategy for fish harvesting. They show that when non-convexities are considered, the conventional continues harvesting strategy can not be reassured and it calls for cyclical policy of harvesting which may lead to unsustainable fishing. Similarly Dasgupta and Maler (2004) show that the existence of non-convexity in fishery may lead to a qualitative break in the dynamical property of the fishery due to the presence of bifurcation point resulting from the non-convexity.

In the case of equilibrium supply and demand, the existence of non-convexity results in a unique dynamic behavioral supply and demand interaction. Hommes and Rosser (1998), for example, note that the non-convex nature of the fishery supply curve is the most obvious example of a dynamic behavior which will lead to chaotic dynamic and self-fulfilling mistake. They also note that combined with open access nature of the fishery (high discount rate) and relatively inelastic demand curve, the chaotic dynamic nature of the fishery may lead to the collapse of fishery. This finding reinforces what had initially been analyzed by Copes (1970) who argued that increasing demand in the fishery faced with backward bending supply curve could lead to collapse of a fishery, as the equilibrium jumps discontinuously from one point to the other.

Studies on the behavior of chaotic dynamic in fishery due to the nature of the non-convexity of the supply curve have been exposed theoretically by Rosser (2000), Hommes and Rosser (2000), and Faroni et al (2003). Empirical applications of such an analysis however are few. Perhaps, this paper is the first to test empirically of such a theory in real fishery. Given the importance of the LRFF fishery to national and local economy and its critical impact on ecosystem, it is interesting therefore, to know how the property of non-convexity will affect the sustainability of the live reef fish fishery.

THE MODELS

To analyze how the existence of non-convexity of the fishery in the form of non-linear supply curve will affect the dynamic behavior of supply and demand in the live reef fish trade, this paper draws heavily from classic model of Clark (1985) and Clark (1990) and latest development of non-linear model developed by Rosser (2000).

Let the dynamic of fish population is given by a function of the form

$$\frac{dx}{dt} = f(x) = rx(1 - x/K)$$

(Eq. 1)

where x represents population or stock in terms of biomass unit, r is the intrinsic growth rate of population, and K is environmental carrying capacity. Following Clark (1990), let assumes that society's objective is to maximize discounted net revenue in the form

$$\max \int_0^\infty e^{-\delta t}(p - c(x_t))h_t dt$$

(Eq. 2)

Subject to

$$\frac{dx}{dt} = f(x_t) - h_t$$

$$x_t \geq 0, h_t \geq 0$$

3

where $f(x)$ is the growth function as defined by (Eq.1) and h_t is harvest level which is assumed to be in the form of Cobb-Douglass production function i.e, $h = qxE$ where q is catchability coefficient and E is the level of effort exerted to the fishery.

Using Euler equation and dropping time notation for convenience, the solution to the equation (Eq.2) will yield the following equation:

$$f'(x) - \frac{c'(x)f(x)}{p - c(x)} = \delta$$

(Eq. 3)

(Eq.3) is known as the Modified Golden Rule (MGR) of the fisheries management (Clark and Munro, 1975) and will yield implicit solution for optimal equilibrium level of biomass x^*. (Eq. 3) can also be used to derive the discounted supply curve for the fishery. Using $c(x) = \frac{c}{qx}$ and (Eq. 1), we obtain

$$c'(x) = \frac{-c}{qx^2}$$

(Eq. 4)

$$f'(x) = r - \frac{2rx}{K}$$

(Eq. 5)

If we substitute (Eq.4) and (Eq. 5) into (Eq.1), one can obtain solution for optimal level of biomass and the corresponding level of harvest as described in Clark (1990). Doing this way one can obtain usual standard dynamic bioeconomic solution of optimality condition. Since our objective is to determine how the fishery will behave under non-linear supply curve condition, we should solve the modified golden rule in terms of price. Following technique developed by Rosser (2000), the solution for the modified golden rule is the following.

$$p = c\left\{\left[\left(\frac{1}{qx}\right) + r\left(\frac{1}{qx} - \frac{1}{qK}\right)\right] \middle/ \left[\delta - \frac{2rx}{K}\right]\right\}$$

(Eq. 6)

As can be seen from (Eq.6), even though the growth function (Eq.1) is concave (therefore has convex set), the resulting price equation will have non-convex set for some positive values of δ. (Eq. 6) is actually a non-linear supply curve in terms of biomass. In economic theory, however, it is more convenient to write the supply curve in terms of output, i.e harvest level. To accomplish such a transformation we use equilibrium condition of harvest level i.e $h = f(x) = rx(1 - x/K)$ and use this quadratic equation of x to solve x in terms of h. The result can then be substituted back into (Eq.6) and obtain the following non-linear supply curve in terms of output.

$$p = c\left\{\left[\left(1\!\!\!/_\phi + r\phi\right) - \frac{1}{qK}\right]\middle/\left[\delta - 2\left(rh\!\!\!/_K\right)^{1/2}\right]\right\}$$

(Eq. 7)

where

$$\phi = q\left[K\!\!\!/_2 + \left(Kh/r\right)^{1/2}\right]$$

This supply curve will be backward bending at various levels of discount rates (δ). As $\lim \delta \to \infty$, the supply curve will converge to the open access supply curve since at $\delta = \infty$, fishermen become "myopic" which corresponds to open access equilibrium of Gordon (1954) and associated with over fishing behavior.

APPLICATION TO THE LRFF FISHERY IN INDONESIA

Empirical observation of the life reef fish fishery in Indonesia, especially in South Sulawesi, reveals that the fishery has been experiencing a cyclical production which leads to discontinuity in supply during the last five years. This indicates that the LRFF fishery is facing non-convexity of the supply curve. To derive the supply function of the Indonesian LRFF fishery, a field study had been conducted in two islands of South Sulawesi, i.e; Barrang Lompo and Barrang Caddi islands. These two islands have been well known as the main supplier of live reef fish among 120 islands in Spermonde Island of South Sulawesi. A cross section survey involving 114 LRFF fishermen was conducted to determine the economic parameters of the model, while time series data of catch and effort of LRFF from these areas were used to derive the biological parameters. Fauzi (2007) has estimated biological parameters for the LRFF fishery as the following, $r = 0.53$, $K = 8307.22$, and $q = 7.10^{-7}$. Combining these parameters with economic parameters derived from field survey which are p=40 (Rp million/ton), c=0.08854 (Rp million/trip) and varying the value of discount rates δ, we have all parameters required to run the model. Due to complexity of mathematical formulation, MAPLE algorithms as well as Excell algorithms were used to run the model.

To assess dynamic equilibrium of supply and demand of the fishery, the model requires demand function. The derivation of demand function was carried out by following technique used by Rosser (2000), Hommes and Rosser (2000) and Foroni et al (2003) in which the demand curve is linear in the form of

$$D(p) = A - Bp$$

(Eq. 8)

The coefficient of marginal demand (B) in (Eq. 8) has been chosen to allow the possibility of multiple equilibria, while parameter A has been chosen such that at the minimum price $P_{\min} = \dfrac{c}{qK}$ consumer demand will be equal to the maximum sustainable yield. The value of these parameters were proxied from current demand of the live reef fish in Indonesia.

Figure 2 shows supply and demand curves with high level of discount rates which mimic open access condition. The intersection of the supply curve with the demand curve yields multiple price equilibria at p= 20 (Rp thousand/kg) , p=47 (Rp thousand/kg) and p=745, (Rp thousand/kg), respectively.

As explained in Clark (1990), the multiple equilibria will result in an instability of economic of fishing which will tend to lead to overfishing situation. Consider equilibrium level at p=47 thousand rupiah per kg, this level of equilibrium is an unstable one since any slight movement of catch below this equilibrium level, the demand curve is always higher than the supply curve, leading to increase in price, while at the harvest level above the equilibrium, the demand curve is below the supply curve leading to drop in price. The instability of the price level at this point is indicated by movement in arrows which are opposite of each other.
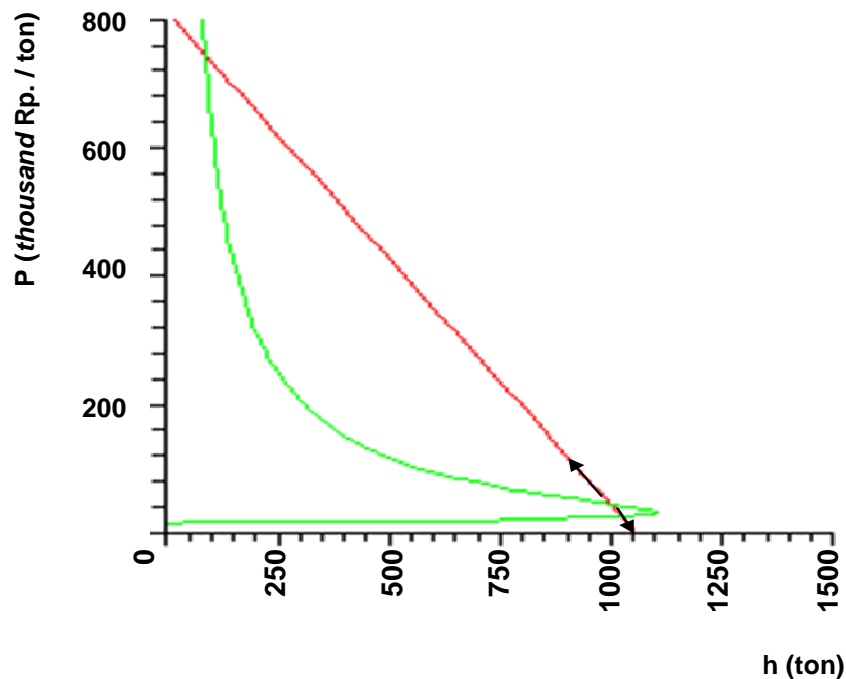

Figure 2. Dynamic Equilibrium of supply and demand LRFF under open access

Figure 3 shows the discounted supply curve under various values of δ with the highest level of discount rate resembles open access situation. Figure 3 also reveals that the supply curve is rather sensitive to variation in discount rates. Change in the value of δ from 5% to 9%, for example, has created a sharp bending in the supply curve. This might indicate high opportunity cots of fishing in the LRFF fishery. Leaving valuable resources to be harvested in a later period mind end up in huge economic lost for fishermen due to high value of the fish in the market. The

equilibria of dynamic price adjustment under various levels of discount rates as well as their stability conditions are listed in Table 1.
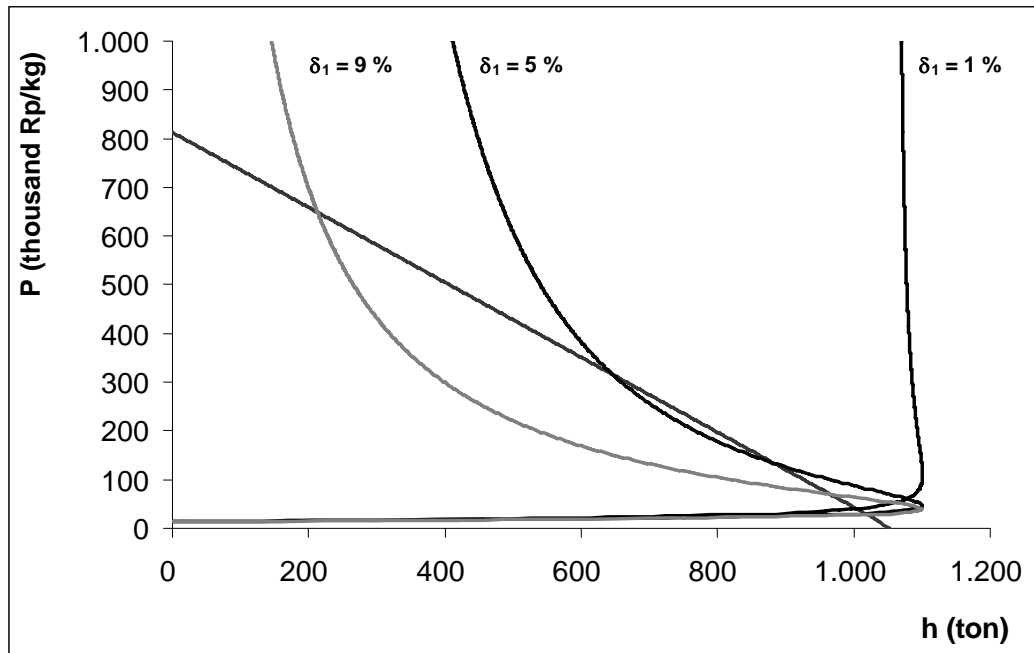

Figure 3. Various equilibria of LRFF under different value of discount rate

Table 1. Price equilibria and their stability condition under different level of discount rates

δ	Price equlibria (Rp thousand /kg)	Stability
0.1	41.3	Unstable
0.5	31.5	Stable
	136	Unstable
	315	Stable
0.9	30	Stable
	70	Unstable
	650	Stable

As can be seen from the Table 1, price level ranges from Rp 40 thousand to Rp 136 thousand rupiah indicates unstable price levels. These price levels are, to some extent, mimic current price fluctuation in the Indonesian LRFF. This implies that current price level will result in instability of fishing for live reef fish. Clark (1990) refers this situation as "catastrophic jumps" since a relatively minor shift in the demand curve will engender a serious degree of

7

overfishing. Clark (1985) provides a comprehensive list of fisheries that collapsed around the world due to similar instability behavior as described here.

Rosser (2000) found similar behavior in fishery characterized by backward bending supply curve. He refers this situation as "self-fulfilling chaotic mistakes" where economic agents cannot distinguish between randomness and determinism. In such a situation, agents may be unable to distinguish the true dynamic of the system in which they involved. Faced with this situation, agents may adopt simple, boundedly rational rule of thumbs based on some sort of backward looking adaptation. Agents do not realize the catastrophic effect of their fishing behavior and continue fishing only based on their adaptive expectation in the past.

This situation occurs in the fishery, especially LRFF in Indonesia. Empirical observation reveals that unsustainability in supply side which leads unstable movement in price levels has led to downsizing and closures of midlleman business. This can be observed from the declining of fish exporters in the area from around 26 exporters in the mid 1990s to only four exporters left lately. The inability of live reef fish fishers to cope with non-convexity also results in destructive behavior of fishing. Bombing and poisoning have occurred more frequently since catch is no longer reassured. These findings are in line with those theoretically developed by Lewis and Schmalensee (1979 where non-convexity due to high cost of re-entry lead to dramatic impact on harvesting. This kind of situation has happened in Indonesia's LRFF fishery. The declining in supply makes it very expensive for fishermen to re-entry. High start up cost has led them to engage in myopic decision leading to destructive behavior. Bombing and poisoning are cheaper ways to re-entry into business. This has caused ecosystem destruction in the area leading to downward spiral of economic-ecological twist. Prasetiamartati (2006), for example, shows that 75% of coral reefs in study area are damaged. The damage is attributed to the fact that most reef fish live in coral reef, so getting fish quickly and easily in fisher's perception is by bombing the reef. She also shows that half of fishermen in Barang Caddi use poison fishing, and the number does not decrease even in the presence of external assistance that developed marine sanctuaries in the area since 2004. Using index of poison and bomb fishing, Prasetiamartati (2006) shows that Barang Caddi where the LRFF fishery mostly takes place is among the highest incident of bomb and poison fishing in the region (Figure 4).
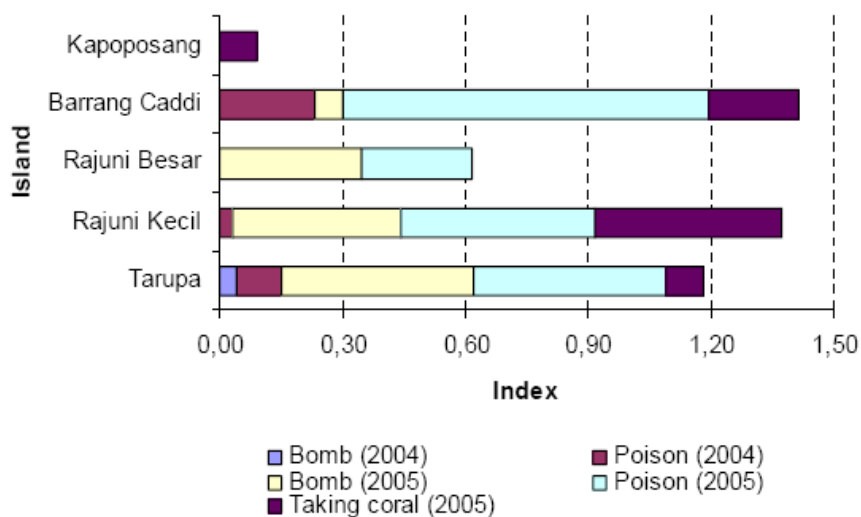

Figure 4. Index of bomb and poison fishing in LRFF fishery in South Sulawesi (From Prasetiamartati, 2006)

High index of bomb and poison fishing is very obvious indicator how non-convexity affects decision making behavior of the fishers which in turn have severe impact on ecosystem and economic livelihood of the fishermen.

CONCLUDING REMARKS

Understanding the peculiarity of the fishery, in particular the nature of the non-convexity of the supply curve of the fishery, and analyzing it in a more comprehensive way will undoubtedly benefit us in understanding the impact of economic activities on fishing as a whole. Continuing increase in demand for live reef fish food and the constrained imposed by natural productivity might lead to a catastrophic impact if no actions are being taken. This "would be chaotic", however, could be avoided if we understand the dynamic behavior of the fishery and inform the economic agents on what to do to avoid it. With regard to the dynamic of the fishery being studied, it is worth noting that this modeling effort reinforces much that has already been known in the theory of fisheries economics as well as in theory of mathematical dynamics that chaotic or instability might arise due to myopic decision by agents (as in the case of LRFF fishery), or as a result of lack of control over access to the fishery resources. This suggests that markets and fishers should take a longer perspective when fishing for LRFF and a system to control over access to the resources should be encouraged. Homes and Rosser (2000) note that the fishery could be prevented from collapsing if fishers are able to follow an underlying truly chaotic dynamic, even by doing so through a self-fulfilling chaotic mistake.

With regard to the Indonesian LRFF fishery in place, several policies recommendation could be offered. First, current licensing system for LRFF fishery must be reevaluated. The licensing system should be issued on species basis instead of flee capacity basis as currently used. With species basis it is much easier for the authority to prevent the collapse of the fishery by, for example, revoking the license. The current establishment of marine reserve in the area must be reinforced by involving community so that it will minimize free riders in the community. Finally it worth considering of fighting poverty outside fisheries so it will ease the pressure on marine resources and the economic livelihood could be secured in the long run.

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