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Natural resource modelling: accounting for gillnet size selectivity in dynamic deterrence model

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ABSTRACT

This paper applied the two times dynamic deterrence model (DDM) and relax the assumption of perfect size selectivity in gill-net in order to specify factors that determine violation rate. The method of comparative statics is employed to derive analytical results on the sensitivity of optimal violation to a number of key factors of high relevance to compliance with regulation designed to protect against over fishing. Analytical results obtained with this extended DDM confirm findings of earlier empirical studies. The study concludes that in developing country artisanal fisheries where probability of detection, enforcement and levels of fine are typically low, and poverty levels deriving high impatience about the future (discount rate) violation rates are bound to be high. The relative magnitude of the effects of each of these factors on compliance with regulation however, remains an important empirical question that requires further investigation for prioritization of policy actions.

Keywords: fishery regulation, dynamic deterrence model, gillnet size selectivity

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Introduction

Fishery renewable resource have been threatening worldwide by the practicing of illegal fishing which considered to be a theft from national revenues. It is the main driver of global over-fishing and marine ecosystem degradation. It threats food security and becoming associated with drugs, violation and even organized crime (AU-IBAR 2016).

Though it is difficult to estimate illegal and unreported fishing losses worldwide, some attempts have been done. For instance Agnew DJ, Pearce J, Pramod G, Peatman T, Watson R, et al. (2009) estimated illegal unreported fish to be between $10 bn and $23.5 bn annually, representing between 11 and 26 million tons. They found that developing countries are most vulnerable from illegal fishing, with total estimated catches in West Africa being 40% higher than reported catches. Pauly and Zeller's (2016) Refers this vulnerability for many reasons that are related to quality of governance such as corruption, ineffectiveness, rule of law, regulatory quality and accountability.

Illegal fishing drivers are found to be, the higher profits, rewards are high and the risks relatively low, debt relief, criminal involvement such as drugs, exchanging drugs for fish products, and poverty fuelled by limited livelihoods (AU-IBAR 2016)

Illegal fishing; particularly the practice of fishing with small mesh size using gillnets is very common in developing countries. "When a fisher uses gill net for catch, a fish swims into a net and passes only part way through the mesh. When it struggles to free itself, the twine slips behind the gill cover and prevents escape. Gillnets are so effective that their use is closely monitored and regulated by fisheries management and enforcement agencies. Gillnets have a high degree of size selectivity which means legal gillnet catches legal sizes while illegal gillnet or under-sized gillnets catches both legal and illegal catch"[1].

Violating mesh size regulation is driven by the selfish motive of maximizing private profits out of open access fishing waters and difficulties of implementing regulations. For example, Akpalu (2008 and 2009) and Eggert and Lokina (2009) found that the use of small mesh size seriously affected the fishery resources in Ghana and Tanzania, respectively. In India, where the prescribed minimum size is 35 mm, stake nets with mesh sizes less than 5 mm were used to catch juvenile fish (Srinivasa, 2005). Fishers in Sudan use mesh of 2 cm instead of the prescribed 4 cm size to catch species used for food processing (Hamid, 2000) putting serious pressure on the country's fish resources.

Many theoretical and empirical studies have been conducted to determine the reasons for non-compliance to fishery regulation. (Akpalu, 2008; Charles *et al*., 1999; Eggert & Lokina, 2009; Furlong 1991; Hatcher *et al.,* 2000 and Sumaila *et al.,* 2006). Sumaila *et al*., (2006) estimate gains from illegal fishing to amount to about 24 times the fine paid as a punishment compared to the 5 times the penalty estimated by King and Sutinen (2010).

The behaviour of violation of laws was first studied by Becker (1968). Many studies used Becker's model of the economics of crime and punishment under both static and dynamic formulations. Static deterrence models assume that violators face a one time period decision problem of maximizing expected utility from illegal fishing, i.e. choice of either to follow or not follow fishery regulation (Charles *et al*., 1999; Furlong, 1991; Hatcher & Gordon, 2005; Kuperan & Sutinen, 1998; Sutinen & Kuperan 1999 and Sumaila *et al.,* 2006). On the other hand in dynamic formulations the fisher will be optimizing his/her accumulative gains over time until he/she gets caught because the crime is committed repeatedly (Akpalu, 2008 and Leung,

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[1] for more information about gillnets, please refer to gillnet Wikipedia

1991). In addition the Dynamic Deterrence Model (DDM) also considers the change of the danger of getting caught over time and differences in fishers' time preference towards the future (discount rates) (Akpalu, 2008, Davis 1988 Lueng, 1991, Abusin and Hassan 2015).

The aim of this paper is therefore to explain mathematically the behaviour of the fisher who violate mesh size regulation and specify a DDM that relax the assumption of perfect selectivity used in previous literature. It also aim to analyse determinants of violating mesh size regulation.

The next section of the paper develops the theoretical framework that adapts the DDM to explain fisher behaviour. Section three derives analytical results under dynamic formulations by applying comparative static method. Section four concludes with key implications of the results.

Dynamic deterrence with size selectivity measure

This study employed two- periods DDM of Akpalu (2008), Davis (1988) and Leung, (1991) which postulates that violators seek to maximize their expected discounted profit over two periods. In the first period, offenders gain from illegal activities until the time they get caught and pay a fine. Violators will then engage only in legal activities thereafter concluding the second period choice problem. The repeated nature of the crime and differences in fishers' time preference towards the future (discount rates) make them consider maximizing the sum of stream of net benefits over time using all skills and experiences to prolong the time to getting caught.

Assume that *m* is the frequency of illegal fishing measured as the number of sub-periods of fishing per unit time considered (i.e. it could be number of months/days or years of illegal fishing). If in any period the fisher uses a small (illegal) mesh size, he targets both mature and immature fish (perfect selectivity assumption is relaxed) (i.e. m> 0, his profit π_m from violation is:

$$\pi_m(m, c, p_a, Q_m, E_m) = p_a m.Q_m(E_m, s) - cm = m(p_a Q_m - c) \quad (1)$$

Where p_a refers to the average composite price of fish (mature and immature)[2], *c* is total cost of fishing illegally including the fixed (sunk) cost of the illegal net, and the variable efforts' cost per period m. Q_m is the quantity of fish caught using an illegal net (i.e. a mix of mature and immature fish) per period of violation, which is a function of the effort used to catch this quantity per period E_m and the stock *s* of fish (mature and immature) plus the legal catch which will be calculated next.

It is assumed that the time of the entire planning horizon is *T*; then the time of fishing illegally extends from *t*=1… *m*, where *m* as defined above (number of periods of illegal fishing till detection). After being caught at the end of the first period and the illegal net being seized, the fisher will be left with only one option which is to continue to maximise his profit from only legal catches thereafter (i.e. from *t*=*m*+1 …∞, second period of DDM)[3] earning profit π_n:

$$\pi_n(p_n, n, b, Q_n, E_n) = p_n n.Q_n(E_n, x) - bn = n(p_n Q_n - b) \quad (2)$$

[2] Average price is used because of the fact that the catch from illegal nets include both mature and immature catches and fishers usually sell their catch of mixed sizes to middlemen in weight units (kg) at a reduced price depending on the percentage of small fish.

[3] Though the planning horizon is infinite in the second period, n is used as number of times of legal fishing given the fact that non-violators can't live forever.

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Where *n* is the number of times of fishing legally, p_n is the price of normal (legal mature size) catch, *b* is total cost that include a fixed (sunk) cost of the legal net and the variable efforts' cost, and Q_n is the quantity of normal catch only in periods of no violation specified as a function of the effort E_n and the stock of only mature fish ***x*** per time period.

Here we have two important issues first, the assumption of perfect size selectivity that used in previous literature is relaxed. Previous literature that used DDM assumes perfect selectivity (Akpalu 2008); meaning illegal net catches only illegal catch while in this study illegal net catches mixed catches as explained before. The second issue is that most of the fishers in developing countries obtained both type of gillnets; legal and illegal (King and Sutinen 2010; Eggert & Lokina, 2009; Abusin and Hassan 2014). Accordingly, the profit of the fisher over the first period will be the sum of π_m & π_n (profits from both nets).

$$\pi_m + \pi_n = m(p_a Q_m(E_m, s) - c) + n(p_n Q_n(E_n, x) - b) \quad (3)$$

Given that the assumptions of the DDM holds, the violator lacks knowledge about the exact time of detection. However, he has some information about the distribution of the detection time (Davis, 1988). Thus, we assume a continuous distribution of time of detection t with the probability density function (pdf) given by $g(t)$ and the cumulative density function (cdf) given by $G(t)$ so that $g(t) = dG(t)/dt$. Then, the probability of being caught at time t is $G(t)$ and the probability of not being caught at time *t* is $1-G(t)$. If the fisher is caught, he pays a fine *F*, which is a fixed amount of money plus the cost of the seized net with illegal catch. According to Davis (1988), the expected probability of being fined is R^4 and the expected present value of the fine is:

$$R\int_0^{\infty} Fg(t)e^{-\delta t}dt \quad (4)$$

The following value function (equation 5) estates that the fisherman is maximising his expected discounted profit V (.) over an infinite time horizon (the two periods) and alternating between tow nets in the first period; legal and illegal. If the fisher caught, the illegal net will be sized and he will be forced to continue fishing legally in the second period.

$$V(.) = \int_0^{\infty} e^{-\delta t} \begin{Bmatrix} (p_a.m.Q_m(E_m, s) - cm + p_n.n.Q_n(E_n, x) - bn)(1 - G(t) + \\ (p_n.n.Q_n(E_n, x) - bn)G(t) - RFg(t) \end{Bmatrix} dt \quad (5)$$

Where V (.) is the value function, δ is the discount rate. Equation (5) states that the fisher's expected discounted net profit is equal to the expected discounted profit from illegal

[4] The use of expected fine is due to considerations such as corruption, as some fishers may escape paying a fine even if they are caught.

fishing (the first and second terms) plus the expected discounted profit from legal fishing (the third term) minus the expected fine from violation (last term).

The probability of detection is modelled as a hazard rate, which is the conditional probability of having a spell length of exactly t, conditional on survival up to time t (Jenkins, 2005). Following Davis (1988), the probability of detection is equated to the hazard rate and set to be independent of time. Used in this context, the hazard rate is the probability that a law-breaking fisher be caught at time *t*, given that he escaped the police until time *t*. This probability is given by[5]:

$$\Pr(E,m) = \frac{g(t)}{1-G(t)} \qquad (6)$$

Pr(.) is the probability of detection of a violator given that he/she has not been detected before; *E* is the constant enforcement effort of the regulator[6], *m*, as defined earlier is the rate of violation (e.g. number of months per year that the fisher fishes illegally). The survival function is (1-G (t)) and E and m are time-invariant. Then, we assume that the hazard rate increases with m at an increasing rate (i.e. $\frac{\partial \Pr}{\partial m} > 0$; $\frac{\partial^2 \Pr}{\partial m^2} \phi\ 0$). This assumption of a convex relationship between probability of detection and violation rate is made following the standard DDM of Davis (1988). Furthermore, we assume that no fisher will be falsely detected, that is:

Pr (0) =0

$$\Pr(m) = \frac{g(t)}{1-G(t)} = \frac{-d(1-G(t)/dt}{1-G(t)} \qquad (7)$$

$$\Pr(m) = \frac{-d\ln(1-G(t)/dt}{d(t)} \qquad (8)$$

Integrating both sides, we reach:

$$\int_0^t \Pr(m)d\tau = -\ln\{1-G(t)\} \qquad (9)$$

$$\ln\{1-G(t)\} = -\int_0^t \Pr(m)d\tau \text{; } \textit{Hence, } \{1-G(t)\} = \exp(-\int_0^t \Pr(m)d\tau) \qquad (10)$$

$$\{1-G(t)\} = e^{-\int_0^t \Pr(m)d\tau} \qquad (11)$$

In most developing countries, the fishery industry is managed as a “regulated open access” regime, which means there is no limit on catches. However, the model assumes that the rate of violation (m) is constant over time, then:

[5] The hazard rate is independent of time, implying an exponential distribution for the time of detection.

[6] Note that the enforcement is constant and independent of the individual. That is because if it is cross-section data, the perception of enforcement may differ among fishers. But this cannot influence directly the probability of detection, though an influence may occur indirectly through m. The fisher may decrease his rate of violation because of a perception of high level of enforcement. This situation will not be accounted for and hence E will be ignored in the rest of the paper.

$$\{1-G(t)\}=e^{-\Pr(m)t}\ ;\ \{G(t)\}=1-e^{-\Pr(m)t}\ ,\ and,\ g(t)=\Pr(m)e^{-\Pr(m)t} \quad (12)$$

Substituting the values of $g(t)$ and $G(t)$ in equation (5) and assuming that all other variables are constant over time, we get the value function of each violator (integrating and rearranging of terms that results in 13 is explained in Annex A):

$$V(.)=\frac{(p_a.m.Q_m(E_m,s)-cm)-(p_n.n.Q_n(E_n,x)-bn)-\mathrm{R\ FPr(m)}}{\mathrm{Pr(m)}+\delta}+\frac{(p_n.n.Q_n(E_n,x)-bn)}{\delta} \quad (13)$$

The first term is the discounted profit from illegal fishing, while the second term is the discounted profit from legal fishing. Since the study focuses on the discounted illegal profit that depends on the rate of violation (first term), the second term will is dropped. Thus, the objective of the fisher will be to maximise the discounted illegal profit given by:

$$V(.)=\frac{(p_a.m.Q_m(E_m,s)-cm)-(p_n.n.Q_n(E_n,x)-bn)-\mathrm{R\ FPr(m)}}{\mathrm{Pr(m)}+\delta} \quad (14)$$

Then, the optimal level of violation for each fisher is given by:

$$m^*=\arg\max\ \frac{m(p_a.Q_m(E_m,s)-c)-n(p_n.Q_n(E_n,x)-b)-\mathrm{R\ FPr(m)}}{\mathrm{Pr(m)}+\delta} \quad (15)$$

Assuming an interior solution, the first order condition is given by:

$$\frac{\partial V}{\partial m}=\frac{(p_a.Q_m(E_m,s)-c-RF\Pr_m)(\delta+\Pr(m))-\Pr_m(m(p_a.Q_m(E_m,s)-c)-n(p_n.Q_n(E_n,x)-b)-\mathrm{R\ FPr(m)})}{(\delta+\Pr)^2}=0 \quad (16)$$

Where $\Pr_m$ is the differential of Pr with respect to *m*. Condition (17) suggests that illegal fishing will be attractive up to the point where:

$$p_a.Q_m(E_m,s)-c-RF\Pr_m=\frac{(\Pr_m(m(p_a.Q_m(E_m,s)-c)-n(p_n.Q_n(E_n,x)-b)-\mathrm{R\ FPr(m)})}{\delta+\Pr} \quad (17)$$

Which is the point where the optimal level of illegal fishing is reached and beyond which net expected marginal benefits (left hand side) will be less than the discounted net marginal cost (right hand side) of illegal fishing. Note that in expression (17) the fisher takes into account the cost advantage of illegal fishing (c-b) and the marginal expected fine *R, F,* and Pr_m. The fisher will never fish illegally (i.e. *m*=0) if:

$$p_a.Q_m(E_m,s)-c-RF\Pr_m<0 \quad (18)$$

This condition is fulfilled for those who never violate (NV). This equation could only be positive if *m* becomes positive, i.e. the fisher starts to violate and thereby earns more money. The question becomes: why are fishers not willing to violate? There are two justifications for making such an inquiry. Firstly; it can be attributed to the influence of some other important non-monetary reasons preventing fishers from violating regulations (i.e. normative factors) such as moral beliefs. Secondly, fishing is not likely to be the main source of income for this group.

However, in a poor institutional environment with weak enforcement, condition (18) is highly likely to be positive. For instance, in a community of chronic violators, we can deduct from equation (18) that violators will totally switch to illegal fishing if:

$$p_a.Q_m(E_m,s)-c-RF\ \mathrm{Pr}_m \geq \frac{(\mathrm{Pr}_m(m.(p_a.Q_m(E_m,s)-c)-n.(p_n.Q_n(E_n,x)-b)-\mathrm{R\ FPr(m)}}{\delta+\mathrm{Pr}} \qquad (19)$$

This condition is fulfilled for those who are full-time violators (CV). Note that the condition in equation (18) is independent of the discount rate, but depends on the expected marginal fine.

The effect of key determining factors on the optimal violation rate

This section employs the method of comparative statics to explore direction of the effect of each factor on the rate of violation. The first order equilibrium condition is calculated to derive comparative static results on the effects of various factors on the frequency of violation using the implicit differential rules in equilibrium (Chiang, 1984). These results will help us understand the nature of determining effects of some factors of policy relevance on the optimum value of violation, i.e. frequency of violation.

Let the first order conditions of equation (16) be denoted by K and use it to derive the comparative statics of the model with respect to its parameters (See detailed derivation of results in Annex -B).

(1) Effect of probability of fining R (enforcement)

$$\frac{\partial K}{\partial R}=\frac{-F\,\mathrm{Pr}_m\,\delta}{(\delta+\mathrm{Pr})^2}<0 \qquad (20)$$

There is no doubt that equation (20) has a negative value, given the fact that Pr_m, F and δ are all positive. This result implies that violation rate/ (*m**) decreases with an increase in the expected probability of paying the fine R.

(2) Effect of level of fine F

$$\frac{\partial K}{\partial F}=\frac{-R\,\mathrm{Pr}_m\,\delta}{(\delta+\mathrm{Pr})^2}<0 \qquad (21)$$

The same argument used in equation (20) applies to equation (21) suggesting that Violation rate (*m**) decreases with an increase in the amount of fine (F).

(3) Effect of probability of detection Pr(m)

$$\frac{\partial K}{\partial \Pr(m)} = \frac{RF\,\Pr_m.(\partial + \Pr) - 2.(\Pr_m RF\,\Pr(m))}{(\delta + \Pr)^3} = \frac{RF\,\Pr_m.(\partial - \Pr(m))}{(\delta + \Pr)^3} \leq 0 \qquad (22)$$

For condition (22) to give the expected negative sign (negative impact of probability of detection on violation rate), probability of detection Pr (m) has to be greater than δ. This will hold true for larger values of Pr (m), implying that the higher the probability of detection, the lower is the violation rate.

(4) Effect of discounting the future δ

$$\frac{\partial K}{\partial \delta} = \frac{-(p_a.Q_m(E_m,s) - c - RF\,\Pr_m).(\partial + \Pr(m)) + 2.(\Pr_m.(m.Pa.Qm - c.m) - RF\,\Pr(m)))}{(\delta + \Pr)^3} \geq 0 \qquad (23)$$

The positive result of the specification in (23) is implied by the condition of optimality derived in equation (18) for violating fishers, e.g. for $m > 0$. Accordingly, this result suggests that violation rate increases with higher discount rates. That means the less important the future is for violators (who prefer a given amount of money today than to having the same amount in the future) the higher is the rate of violation.

(5) Effect of price of / returns to illegal catch P_a [7]

$$\frac{\partial V}{\partial p_a} = \frac{Q_m(E_m,s).(\delta + \Pr - \Pr_m)}{(\delta + \Pr)^2} \geq 0 \qquad (24)$$

For equation (24) to be optimal the following condition must be hold:

$$\delta + \Pr > \Pr_m \qquad (25)$$

This implies non-negativity of result (25) suggesting that frequency of violation increases with higher prices of (returns from) illegal (mixed) catch. This confirms that equation (25) has a positive sign.

(6) Effect of fixed cost of the illegal net c

$$\frac{\partial V}{\partial c} = \frac{-\delta - \Pr + \Pr_m.m}{(\delta + \Pr)^2} = ? \qquad (26)$$

Result (26) is indeterminate and would give the expected negative effect of a rise in the cost of acquiring the illegal net if the following holds:

$$\Pr_m \,\pi\, (\partial + \Pr(m))/m \qquad (27)$$

[7] Average price could be specified as $P_m\alpha + P_n(1-\alpha)$ where α is the proportion of small fish and 1-α is the proportion of normal fish. a P is used for simplicity. The positive sign of equation 24 implies that the illegal proportion outweighs the legal one and hence increases the price of the illegal net per kg.

Condition (27) simply requires that the incremental risk of being caught (marginal chance of detection) should be less than the average expected gains from not violating (opportunity cost of waiting for next period plus probability/opportunity of being caught) per violation attempt.

The analytical results of this extended DDM that account for size selectivity are compared with the results of earlier empirical studies in Table 1. It is clear that dynamic formulations have important advantages over static models as they could control for the effects of key factors such as discounting the future, costs and prices. Analytical results derived with the extended DDM, with size selectivity measures, confirm the findings of the empirical DDM assume perfect selectivity for the effects of key factors. These factors are probability of fining (enforcement), level of fine and discount rate. However, accounting for size selectivity instead of perfect selectivity could sign the indeterminate effects of price of and income from illegal fishing in addition to the change in probability of detection.

Table (1): Summary of the comparative statics' analyses

Determinants of compliance/violation rates	**Dynamic models with size selectivity**
Probability of fining (R)	Negative
Level of fine (F)	Negative
Probability of detection	Must be higher than the discount rate to deter violation
Discount rate (δ)	Positive
Price of / income from illegal catch	Positive
Fixed cost of illegal fishing	Undetermined

Dynamic formulation with size selectivity also revealed interesting economic meaning in the effects of and relationship between probability of detection and the social discount rate. The conclusion from the static model of Becker (1968) and other studies that used static formulations is that a penalty (fine) should be high to deter violation. On the other hand, studies that applied the dynamic deterrence model suggest that crime is more likely to be deterred by increasing the hazard of being caught than by raising the fine (Akpalu, 2008; Davis, 1988; Lueng, 1991).

Summary

This paper presented the DDM analytical framework adapted in the study to investigate the importance factors that determine violation rates. It also adapted DDM that accounting for size selectivity instead of perfect selectivity used in literature. This give interesting results sign the indeterminate effects of price of and income from illegal fishing in addition to the change in probability of detection.

The extended model helps to classify fishers into categories of chronic violators and non-violators. These categories will help policy makers and managers design policy measures and instruments suited for each group. In spite of these apparent advantages gillnet size selectivity hasn't been used in static deterrence models and studies that employed DDM have so far only used perfect selectivity to analyse noncompliance with fishery regulation.

The method of comparative statics is employed to derive analytical results on the sensitivity of optimal violation to a number of key factors of high relevance to compliance with regulations designed to protect against over-fishing. Analytical results obtained with this extended DDM confirm the findings of earlier empirical studies employing alternative static and dynamic formulations and reveal more interesting economic meaning of modelled relations. The study shows that in the artisanal fishery industry in developing countries, violation rates are bound to be high. This is the case, given that probability of detection, enforcement and levels of fine are typically low and poverty levels lead to high impatience about the future (social discounting). Nevertheless, the relative magnitude of the effects of each of these factors on compliance with regulations remains an important empirical question that requires further investigation for prioritisation of policy actions. The paper however, provides a general theoretical model that could be valid and potentially applicable to developing countries with similar fishing circumstances of regulated open access such as the one modelled her.

References

1 Abusin S ; R hassan, (2014): Legitimacy and ethics or deterrence factors: Which are more important for compliance with regulations among the artisanal fishers of Sudan? African Journal of Agricultural and Resource Economics Volume 9 Number 3 pages 239-252

2 David J. Agnew1 *, John Pearce2 , Ganapathiraju Pramod3 , Tom Peatman2 , Reg Watson3 , John R. Beddington1,4, Tony J. Pitcher3(2016): Estimating the Worldwide Extent of Illegal Fishing. PLoS ONE 4(2): e4570. doi:10.1371/ journal.pone.0004570

3 Akpalu, W. (2008). Individual Discount Rate and Regulatory Compliance in a Developing Country Fishery. *Journal of Environment and Development Economics*: 13: 591-606.

4 Akpalu, W. (2009). A Dynamic Model of Mesh Size Regulatory Compliance in Fisheries. *Working Paper Number 123*. Farmingdale state college.

5 Andrew Bene, C, Hall.S and Ratner, B (2007) “Diagnosis and management of small-scale fisheries in developing countries: *Fish and fisheries*, 8, 227–240

6 AU-IBAR 2016. Economic, Social and Environmental impact of Illegal, Unreported and Unregulated Fishing in Africa. AU-IBAR Reports Prepared by: Bergh M O, Sowman M, Rampartab C, Leach K and P Lallemand

7 Becker, G. (1968). Crime and Punishment: An Economic Approach. *Journal of Political Economy,* 76(2):169-217.

8 Boyd, H. J. (1966). Optimization and Sub optimization in Fishery Regulation: Comment. *American Economic Review,* 56(3):511-517.

9 Charles, A.T, Mazany, R.L and Cross, M.L,(1999) .The Economic of illegal fishing a Behavioral mode. *Marine Resource Economics*, 14: 95-110.

10 Chiang, Alpha C.,(1984). *Fundamental methods of mathematical economics*. Third edition. Mc Graw-Hill, Inc. Page 208.

11 Davis, M.L. (1988). Time and Punishment: an Intertemporal Model of Crime. *Journal of Political Economy*, 96(2):383-390.

12 Eggert .H and Lokina.2009 Regulatory compliance in Lake Victoria fisheries. *Environment and Development Economics:* page 1 of 21 C_ Cambridge University Press 2009

13 Furlong, W.J. (1991). The Deterrent Effect of regulatory Enforcement in the fishery. *Land Economics*, 67(1):116-129.

14 Hamid Um. Y 2000. Environmental impacts of surge industry waste water on White Nile area-Khartoum. *Unpublished results. Master thesis.*

15 Hatcher, A.,Jaffry, S. Thebaud, O and Bennett, E. (2000). Normative and Social Influences Affecting Compliance with Fishery Regulations. *Land Economics*, 76(3):448-461.

16 Hatcher, A. and D, Gordon. (2005). Future investigation into the factors affecting compliance with U.K. fishing Quota, *land economics*, 81(1):71-86.

17 Jenkins, S.P. (2004). Survival Analysis. Unpublished manuscript, Institute for Social and Economic Research, University of Essex, Colchester, UK. [Online]. Available : http://www.iser.essex.ac.uk/teaching/degree/stephenj/ec968/pdfs/ec968lnotesv6.pdf

18 King, D.M and Sutinen, J.G. (2010). Rational noncompliance and the liquidation of Northeast ground fish resources. *Marine Policy* 34(1), 7-21.

19 Kuperan, K & Sutinen, J. (1998). Blue Water Crime: Deterrence, Legitimacy, And Compliance, In Fisheries. *Law & society review,* 32(2): 309-338.

20 Kuperan, K. and J.G.Sutinen. (1994), Compliance with Zoning Regulations in Malaysian Fisheries, *paper presented to the 7th Conference of the International institute of Fisheries Economics and Trade, Taipei, Taiwan, 18-21 July 1994.*

21 Leung, S.F. (1991). How to make the fine fit the corporate crime? : An analysis of static and dynamic optimal punishment theories. *Journal of Public Economics*, 45: 243 56.

22 Millennium Ecosystem Assessment (MEA) (2005). *Ecosystems and Human Well-Being: Current State and Trends Volume 1*. Global Assessment Reports. Island Press: Washington.

23 Pauly, D., and D. Zeller.(2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nature Communications 7:9

24 Pauly, D. (1996). ITQ: the assumptions behind a meme. *Review in Fish Biology and Fisheries,* 6:109-12.

25 Srinivasa, J. T., 2005. State Regulation versus Co-management: Evidence from the Cochin Estuarine Fisheries in India. *Environment and Development Economics* 10, 97-117

26 Sterner, T.(2003).Policy *instrument for environmental and natural resource management*. RRF Press and the World Bank

27 Sumaila.R. U ; Alder. J. and Keith.H,(2006). Global scope and economics of illegal fishing. *Marine policy,* 30: 696-703.

28 Sutinen, J.G and Kuperan, K. (1999). A socio-economic theory of Regulatory Compliance. *International journal of Social Economics*, 26(1, 2, 3):174-93.

Annexures

Annexure A: **The dynamic deterrence with gillnet size selectivity specification**

By taking into consideration the definitions of illegal profits $\pi_m\big(m, c, p_{a,}Q_{m,}E_{m,}s\big) = m\big(p_{a.}Q_m\left(E_{m,}s\right) - c(s)\big) = m\big(p_{a.}Q_m - c(s)\big)$ in the first period and the legal profit $\pi_n\big(n, b, p_{n,}Q_{n,}E_n\,, x\big) = n\big(p_{n.}Q_n\left(E_{n,}x\right) - b(x)\big) = n(p_{n.}Q_n - b(x)$ in the second period: Let us denote the illegal profits by π_m and the legal profit, by π_n and also $v\big(p_{a.}Q_m\,, E_{m,}, s, c, m, n, b, x, Q_n\,, E_n\,, p_{n,}\big)$ by v (.) and Pr(m value function for each violator is:

$$v(.) = \int_0^\infty e^{-\delta t}(\pi_m + \pi_n)\;(1 - G(t)) + \pi_n G(t) - RFg(t)dt \qquad (A.1)$$

$$v(.) = \int_0^\infty e^{-\delta t}\big(\pi_m + \pi_n - \pi_m G(t)\big) - RFg(t)dt \qquad \text{(A.2)}$$

By developing further the hazard rate equation$\Pr(E, m) = \frac{g(t)}{1-G(t)}$, we manage to get the values of G(t) = 1-e^{-Bt} and g(t) = B e^{Bt} and B=Pr(m) then A4.2 to becomes:

$$v(.) = \int_0^\infty e^{-\delta t}(\pi_m + \pi_n - \pi_m(1 - e^{-Bt})) - RFBe^{-Bt})\,dt \qquad (\,A.3)$$

$$v(.) = \int_0^\infty e^{-\delta t}(\pi_n + \pi_m e^{-Bt}) - RFBe^{-Bt})\,dt \qquad (A.4)$$

$$v(.) = \int_0^\infty e^{-\delta t}(\pi_n + (\pi_m - RFB)e^{-Bt})\,dt \qquad (A.5)$$

$$v(.) = \frac{\pi_n}{\delta} + \frac{\pi_m}{B+\delta} \qquad (A.6)$$

Which is in the expanded form (substituting for *Pr(m)*) is:

$$v(.) = \frac{(m\,p_{a.}Q_m\left(E_{m,}s\right) - m\,c(s) - (n\,p_{n.}Q_n\left(E_{n,}x\right) - n\,b(x) - RFPr(m)}{\delta + \Pr(m)} + \frac{n\,p_{n.}Q_n\left(E_{n,}x\right) - n\,b(x)}{\delta} \qquad (A.7$$

This will give the value function for each violator as:

$$v(.) = \frac{(m\,p_{a.}Q_m\left(E_{m,}s\right) - m\,c(s) - (n\,p_{n.}Q_n\left(E_{n,}x\right) - n\,b(x) - RFPr(m)}{\delta + \Pr(m)} \qquad (A.8)$$

The second term in equation A47 is excluded since doesn't include (m)

Annexure B: **Derivation of comparative statics' properties**

Employing the first-order conditions' equation 14, which determine the optimal frequency of violation (i.e. m*) implicit in equation B1, we can derive the comparative static' (CS) properties of m* with respect to its parameters $p_{a.}, F, R, C, b, Pr, \delta$. Let K be

$$K = \frac{dV}{dm} = \frac{(\,p_{a.}Q_m\,(.) - c(s) - RFPr_m\,)(\delta + \Pr(m)) - Pr_m(m\,p_{a.}Q_m\,(.) - mc(s) - (n\,p_{n.}Q_n\,(.) - n\,b(x) - RFPr}{(\delta + \Pr)^2}$$

(B.1)

We simplify 4B1 using above definitions of π_m and π_n to:

$$K = \frac{dv}{dm} = \frac{(\pi_{mm} - RFPr_m)\,(\delta + \Pr(m)) - (Pr_m(\ \pi_n - RFPr(m))}{(\delta + \Pr)^2} = 0$$

(B.2)

Where, $(Pr_m\ is\ \frac{dPr}{dm}$ is and π_{mm} is $\frac{d\pi}{dm}$

Invoking the Implicit Function Theorem for function K (m*(α), α), where α is a vector of the set of arguments in the model and *m* is at its optimal level *m** (hence omitting the * for simplicity), the following holds for each argument α_j at the optimum (Chiang, 1984):

$$\frac{dk}{d\alpha} = \frac{dk}{dm} * \frac{dm}{d\alpha} + \frac{dk}{d\alpha} = 0\ such\ that\ \frac{dm}{d\alpha} = -\frac{\frac{dk}{d\alpha}}{\frac{dk}{dm}} \qquad (B.3)$$

From 4B.1 –4B3 we get the following CS results:

(1) Probability of fining R (enforcement)

$$\frac{dK}{dR} = \frac{(-FPr_m)(\delta + \Pr(m)) + Pr_m\ FPr(m)}{(\delta + \Pr)^2} = \frac{FPr_{m(-\delta - Pr + Pr)}}{(\delta + \Pr)^2}$$

$$= \frac{-FPr_m\ \delta}{(\delta + \Pr)^2} < 0 \qquad (B.4)$$

B4 has to yield a negative value since the denominator is +ve and F, Pr_m(m) and δ are all +ve values (Pr_m(m) is +ve by the assumption of concavity of Pr(m) function, e.g. hazard rate is increasing in frequency of violation m). This result $\frac{dK}{dR} < 0$ together with the satisfaction of the second order conditions of value function $v(.)$,

$$\frac{dK}{dR} < 0 \text{ which implies that, } \frac{dm}{dR} = \frac{dk}{dr} / \frac{dk}{dm} < 0 \qquad \text{(B.5)}$$

Result B45 implies that violation rate – frequency (optimal m) decreases with an increase in the probability of paying a fine (R) if detected.

(2) Level of fine

$$\frac{dK}{dF} = \frac{(-RPr_m)(\delta + \Pr(m)) + Pr_m\ RPr(m)}{(\delta + \Pr)^2} = \frac{RPr_{m(-\delta - Pr + Pr)}}{(\delta + \Pr)^2}$$

$$= \frac{-RPr_m\ \delta}{(\delta + \Pr)^2} < 0 \qquad (B.6)$$

Following the same argument as above (denominator is +ve and R, Pr_m(m) and δ are all +ve values) it is clear that $\frac{dK}{dF} < 0$. Again, together with value function's conditionality (that $\frac{dK}{dm} < 0$) results 4B.5 implies that frequency of violation (optimal m) decreases with an increase in the amount of the fine (F).

(3) Probability of detection Pr(m)

$$\frac{dK}{dPr(m)} = \frac{RFPr_m\,(\delta + \Pr(m) - 2(Pr_m RFPr(m)}{(\delta + \Pr)^3} = \frac{RFPr_m\,(\delta - \Pr(m))}{(\delta + \Pr)^3} \quad \leq 0 \qquad (B.7)$$

For Result B7 to yield the expected negative sign (negative impact of probability of detection on violation rate) Pr(m) has to be greater than δ. This will hold true for larger values of Pr(m) implying that the higher the probability of detection, the lower is frequency of violation.

(4) Discount rate

$$\frac{dK}{d\delta} = $$

$$= \frac{-(\,p_{a.}Q_m\,(.) - c(s) - RFPr_m)(\delta + \ (\Pr(m)) + 2\Big(Pr_m(m(\,p_{a.}Q_m\, - mc(s) - RFPr(m))\Big)}{(\delta + \Pr)^3} = \geq$$

$$0 \qquad (B.8)$$

The non-negativity of Result B7 is implied by the condition of optimality derived in Equation 18 for violating fishers (e.g. for m > 0). Result C8 accordingly suggests that violation rate increases with higher discount rates, i.e. less important is the future.

(5) Return from violation (price of illegal catch)

$$\frac{dK}{dP_a} = \frac{Q_m\left(E_{m,}s\right)(\delta + \ \ (\Pr(m)) - mPr_m Q_m\left(E_{m,}s\right)}{(\delta + \Pr)^2} = \frac{Q_m\left(E_{m,}s\right)(\delta + \Pr - \Pr_m)}{(\delta + \Pr)^2} \geq 0$$

(B.9)

Concavity of Pr(m) implies that the value function Pr(m) ≥ its marginal value $Pr_m(m)$ at optimal levels of m, which implies non-negativity of Result B9, which suggests that frequency of violation increases with higher prices of (returns from) illegal (mixed) catch

(6) Fixed cost of illegal net - c

$$\frac{dK}{dc} = \frac{-\delta - \Pr + \mathrm{m}\Pr_\mathrm{m}}{(\delta + \Pr)^2} = ? \qquad (B.10)$$

Result B.10 is indeterminate.

For this to yield the expected negative effect of cost of acquiring the illegal net the following must hold:

$$\Pr_\mathrm{m} > \frac{\delta + \Pr(\mathrm{m})}{\mathrm{m}} \qquad (B.11)$$

Condition B.11 simply requires that the incremental risk of being caught (marginal chance of detection) should be less than the average expected gains from not violating (opportunity cost of waiting for next period plus probability/opportunity of being caught) per violation attempt.