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Full Length Research Paper

Dynamic deterrence analysis of factors affecting the management of Sudan' fishery

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This paper adapted the modified dynamic deterrence model to investigate factors affecting compliance with mesh size regulation. the reduced form of this model is tested based on data from the Jebel Aulia Reservoir (JAR) in Khartoum State, Sudan. Factors that determine noncompliance with mesh size regulations were analysed, using the Tobit model. The results showed that the main determinants of noncompliance are poverty and weak and inefficient institutions. This has induced a sudden increase in violation that has led to desperate fishery situations. Young fishers are more likely to violate these regulations, and the study finds that deterrence and social variables are both important determinants of noncompliance with mesh-size regulation. A regime of self enforcement to manage this resource is not possible due to various factors, such as low levels of education, lack of proper knowledge about regulations, and the low skills and lack of ability of administration and of the funding needed to implement such a regime. The study therefore suggests a co-management regime given that co-management increases the awareness of fishing communities about the need for sustainable management of fishery resources and in this turn helps to reduce violation. More than half of the surveyed fishers believed that this regime is suitable for them to achieve sustainable fishery resource.

Keywords: fishery regulations, dynamic deterrence model, Sudan, Tobit, management

INTRODUCTION

Globally, the inland fish catch is registered at 10 million tons a year. In 2008, Africa contributes 25% of the total catch of inland fisheries (FAO, 2009; UNEP, 2010). The consumption of fish on regular basis is high and over 200 million African people are consuming fish as regular food (Heck et al, 2007). Despite the fact that inland fisheries sector in Africa are perceived to be very important, most countries on the continent lack accurate statistics about the potential role of their contributions to food security and livelihoods at both local and national levels (World fish centre, 2003).

Over-fishing and environmental degradation are threatening Africa's fisheries resulting in steady decreases in the fish stock and underestimating their contribution to human well-being. Another serious problem that the African fisheries sector faces is the use of destructive gear and the practice of illegal fishing. Illegal fishing is a very serious problem and a major source of loss of revenue, especially for the poorest countries, where there is a great dependency on fishing for food, livelihoods and employment (MEA, 2005).

It is believed that actual catch of inland water is 2-3 times larger than what is reported in official statistics due to illegal fishing and noncompliance with regulations especially in the artisanal systems predominant in sub-Saharan Africa (SSA) (FA0, 2003; Welcomme *et al*. 2010). Failure to account for illegal fishing therefore gives incorrect estimates of the resource and misleads fishery policy formulation and management decisions based on this information (Hatcher and Pascoe, 2006). Achieving compliance with fishery regulations is accordingly becoming an issue of serious concern to managers and policy makers worldwide and especially in the tropical freshwater fisheries of SSA.

Despite its major role in the failure of fishery management, illegal fishing has received little attention worldwide (Anderson, 1989, Sutinen & Hennessey 1986), particularly in the fields related to fishery economics and policy-making studies (Charles *et al*., 1999). However, illegal fishing has recently gained considerable attention in both fields, because of the increase in observed damage and losses associated with this problem (Sumaila *et al.,* 2006).

Recently, researchers and policy makers devote considerable attention to studies that investigate the determinants of illegal fishing and that suggest new methods to analyze the reasons for noncompliance with fishery regulations. Therefore, there is an urgent need to provide policies that reduce violation and propose a management regime that improves compliance with regulations. In Africa, where huge numbers of people depend on fishing, most of the fishery resources are managed as regulated open access, which means there is no constraint or limit on the catch besides various regulatory measures such as licenses and prescribed mesh sizes that have to be followed.

Generally, static and dynamic deterrence modeling is used in analyzing violation of regulations. Due to institutional factors that are related to human behavior and the enforcement situation, dynamic models are believed to be more accurate for investigating and explaining determinants of noncompliance with regulation (Akpalu 2008; Abusin et al). However, the Dynamic Deterrence Model is not common in literature, although it has recently gained some prominence (Leung, 1991). Davis, (1988) was the first to develop the dynamic deterrence model, in 1988. However, its empirical application in fisheries has only been investigated recently, by Akpalu (2008), who applied this model to artisanal fishery in Ghana.

Despite its proved importance in analyzing the effects of deterrence, the DDM is limited to situations of constant "probability of detection" and "intensity of violation" as measures of violation rate. Both limitations have been addressed recently by Abusin *et al*. (2012) who developed the modified DDM. Therefore, this paper intends to adapt the modified dynamic deterrence model (DDM) and test empirically the forecasting from the modified model, based on data from Sudan's Jebel Aulia Reservoir.

Section 2 describes the case study area. Section 3 presents the development of the theoretical framework. Empirical models are specified in section 4, and section 5 describes the variables included in the analysis and presents some descriptive results. Results of the empirical analysis are discussed in section 6. Section 7 draws conclusions and outlines some of the implications of the study.

Jebel Aulia Reservoir (JAR) fisheries

The Jebel Aulia reservoir is the main supplier of fresh and processed fish in Sudan, contributing 52% of the total inland fish (FAO, 2008). The fact that Jebel Aulia is located near the capital city Khartoum gives it an economic advantage. Scientific research has confirmed that this reservoir is endowed with ecological factors that enable it to produce a high, sustainable yield of fish for the future (FAO, 1999).

After construction of the dam was completed in 1933, people began to settle in the area as farmers, officials and craftsmen. The JAR population tends to be artisanal, comprised of local fishermen living along the banks of the river. Small fish markets are held at a main site next to the dam, where transactions are made by middlemen and the fish is transported to consumption areas by ordinary trucks using ice for preservation.

The White Nile is known by its calmness which provides adequate environment for fish to generate and to be abundant in various types. This allows for the wide and intensive fishing activities along the Nile.

According to FAO (2006) statistics, the potential fish yield for the JAR is 15 000 tons a year. In recent years, the JAR has witnessed a remarkable increase in population in the settlement camps as a result of displacement of southern Sudan communities because of the civil war (International Organization for Migration, 2005). This has caused the emergence of major markets and triggered significant socio-economic changes related to food**.** For instance, the market for small-sized fish grew significantly and new types of products such as Mandasha is smoked fish, shaped into small balls and sun dried, then stored and used in farming camps. This is very popular in southern Sudan, were introduced. The demand for small-sized fish rose because it was the basic food for the displaced communities.

Most illegal catches of such small sizes are processed at home to produce food that is cheap, easy to prepare and easily stored and sold. The species used for home processing are *Hydrocynus forkhali, Alestes dentex, Alestes nurse,* and *Labeo niloticus.* These are the species currently facing the threat of over-fishing and their local names are *kass, kawara* and *dabis,* respectively. The fishing gear commonly used in the JAR are gillnets, trammel nets, beach seines, baited and unbaited long lines, cast nets and traps. Gillnets, however, are the dominant gear in this region. Over 25 fish species have been reported in the JAR from which *kass* and *kawara* are the most used in processed food as wet and salted fish.

Despite JAR fishing regulations, fishers are reported to violate regulations, especially by using a small mesh size (Aulia Regulation Office, 2004). A study conducted by fisheries research centre, (1985) in the northern part of JAR revealed that half of the fish catch was made up of undersize fish. The differences in length between fish caught illegally and prescribed length were significant. Since 1985, the situation has worsened and over-fishing has been cited as the main cause of the undersized catch. Many factors are reported to be the reason behind over-fishing of the JAR. In the north of the JAR these include increased use of illegal fishing gear, such as mesh below the prescribed size, poor law enforcement, loss of species diversity, heavy fishing pressure on the remaining breeding grounds and reduced natural regeneration (FAO, 1999).

However, the catch of immature fish is cited to be the main reason and cause of this threat. Unfortunately, with the exception of a few reports on the fish catch and its value, data on the state of inland fish stocks is lacking in Sudan, and little is known about illegal fishing (FAO, 1999). The northern part of JAR is under serious pressure from the practicing of illegal fishing and the use of non-prescribed size nets. To date we are not aware of any efforts at investigating or alleviating the problem. But it seems that poor enforcement of and consequent noncompliance with fishery regulations constitutes the key challenge to sustainable fishery management in the JAR.

Specification of the analytical framework

We adapted the modified DDM of Abusin *et al,* (2012) which assumes that fishers enjoy incremental profit from violation in the first period until detected at time τ , which marks the end of the first period. The offender is then punished at the start of the second period and begins to behave legally thereafter. The more a fisher violates regulations, the more he/she accumulates profits, i.e. gains depend on the rate of violation. I'm very grateful to Prof Gregory Hertzler who contributes generously in the development of this new model.

Suppose that the goal of an individual fisher who violates mesh size regulations is to maximize his/her profit from two periods, i.e., before and after being caught. If the fisher violates specific regulations, this indicates a positive rate of violation (i.e. m > 0). The profit from fishing illegally in the first period is: π_m

Where, *m* is the frequency of violation which increases the gain from violation at a decreasing rate i.e. $\frac{d\pi_m}{dm} > 0$& $\frac{d^2\pi_m}{dm^2} < 0$.

Frequency of violation is measured by the number of times that fishers violate, which could be numbers of weeks, months or years. Assume that after being caught, the fisher will only fish legally (i.e. m=0) and his profit in the second period is (legal profit) π_n. Then n is the number of months of fishing legally in the second period.

Moreover, assume that in absolute terms, illegal fishing is more profitable than legal fishing.

$$\pi_m > \pi_n$$

Equation (1) states that, in the first period the violator will fish until getting caught at a random time τ in the future, given the fact that he has never been caught before. The second period starts from the random time τ when the fisher is caught and required to pay the fine (F). The fisher's inter-temporal expected profit is accordingly given by:

$$J(.) = max\, E\{\int_0^\tau e^{-\delta t}\, \pi_m(m, c, p_a, Q_m, E_m, s, x)dt + \int_\tau^\infty e^{-\delta t}\, \pi_n(n, b, p_n, Q_n, E_n, x)\, dt \; - e^{-\delta\tau}F \;\} \quad (1)$$

J(.) is the value function, E is the integral expectation, δ is the discount rate, *m* is the violation rate, τ is the random time when the second period starts i.e. The time that the fisher is caught and required to pay the fine F. Assume that the fisher is not a pure-maximising agent, but drives disutility (for example, feeling guilty of using illegal net) that incurs a psychological cost, from harvesting stocks, *s* and x with cost functions *k(s)* and *d(x)* respectively (i.e. illegal net catch both mature stock *x* and immature stock *s*) , following Akpalu, (2008). This will make the profit function to be re-specified as:

$$u(m, c, p_a, Q_m, E_m, s, x) = \pi_m(m, c, p_a\,, Q_m\,, E_m, s, x) - z(s) - d(x) \quad (2)$$

Where *z>0, d>0* and *d*(0*)=0,* and if the fisher doesn't violate his utility is $u(n, b, p_n, Q_n, E_n, x)$.Under the above assumptions, if the fisher is caught, he pays a fine *F*, which is a fixed amount of money plus the cost of the illegal catch which will be seized immediately. The expected present value of the fine is $\int_0^\infty Fg(t)\, e^{-\delta t}dt$

Substituting *u* for π_m , equation (1) can be rewritten as follow:

$$J(m, c, p_a, Q_m, E_m, s, x)$$

$$= max\,E\left\{\int_0^{\tau} e^{-\delta t}\ u(m,c,p_a,Q_m,E_m,s,x)dt + \int_{\tau}^{\infty} e^{-\delta t}\,u(n,b,p_n,Q_n,E_{n,}x)\,dt \quad - e^{-\delta\tau}F\ \right\} \quad (3)$$

Calculating the integration of equation (3) and rearranging terms (for details calculation see appendix A) gives:

$$J(.) = max\left\{\frac{u(m,c,p_a,Q_m,E_m,s,x)}{\delta} - \left[\frac{u(m,c,p_a,Q_m,E_m,s,x) - u(n,b,p_n,Q_n,E_{n,}x)}{\delta} + F\right]Ee^{-\delta\tau}\right\} \quad (4)$$

The interpretation of equation (4) is important. The first term is the discounted expected benefits of illegal fishing for an infinite time horizon, and the second part (between the brackets) is the penalty that the violator should pay when getting caught, including the illegal gain plus the fine. Then the goal of violator is to maximize equation (4), subject to the probability of detection. While the previous literature assumes a constant probability of detection, this study adds a new formula for the survival time that makes it inconstant, and this is explained in detail in the following section.

Specification of probability of detection function

According to Abusin *et al,* (2012) modified model, Probability of detection is modeled as Cox's proportional hazard model. This model is perhaps most often used in survival analysis (Cox, 1972; Jenkins, 2005**).** Survival analysis commonly uses methods for analyzing data in different fields of science such as medicine, environmental health, criminology, and marketing (Lee & Go 1997).

In this study, the proportional hazard model is employed and linked to the Cox model or probability of detection function (as in equation 4) in order to calculate the density function that multiplies all terms in the deterrence model (see Appendix B). The proportional hazard model's general expression is given as follows:

$$\mathrm{H}(\mathcal{T},m,v,n) = \mathcal{B}(m,v,n)h(\mathcal{T})$$
$$\Pr(\mathcal{T},m,v,n) = \mathcal{B}(m,v,n)h(\mathcal{T}) \qquad 0 \le \mathcal{B} \le 1 \ \ \textit{and} \ \ \frac{d\beta}{dm} > 0 \quad (5)$$

Where *m*, is the violation rate; the right-hand side includes two hazard functions: the first $\beta(.)$ is the individual-specific hazard function which does not depend on τ , whereas the second $h(\tau)$, which depends on time but not on β factors, is the baseline hazard function. The latter function is the one which is determined if the hazard rate is constant, decreasing or increasing (if we use Weibull distribution for example) as will be explained more in the following sections. The individual hazard function $\beta(.)$ is linearly related to the probability of detection; it increases with the crime rate (*m*) and decreases with enforcement (*N*) and evasion activities (*v*) as cited in the literature (Charles *et al*., 1999). An especially important implication associated with the Cox proportional hazard is that the baseline hazard function can accommodate constant and inconstant time, while the individual hazard function is linearly related to probability of detection.

For information on how to get the value of the density function in equation (6), see (Annexure B):

$$g(\tau,m,n,v) = \mathcal{B}(m,v,n)h(\mathcal{T})\mathrm{e}^{-\mathcal{B}(m,v,n)h(\mathcal{T})} \quad (6)$$

The introduction of the time of detection distribution in equation (6) into the value function, gives the violator's maximization problem, which depends on time, as follows:

$$J = max_m\ \left[\frac{u(m,c,p_a,Q_m,E_m,s,x)}{\delta}\right] - \left[\frac{u(m,c,p_a,Q_m,E_m,s,x) - u(n,b,p_n,Q_n,E_n,x)}{\delta} + F\right]\int_0^{\infty} g(\mathcal{T},m,v,n)\ e^{-\delta\mathcal{T}}\,dt$$

The net gain from violation is the expected discounted illegal fishing minus the discounted expected penalty. The last term represents the discounted density of time of detection, which is the function of explanatory variables (*m, v, N*) that determine the hazard rate and rate of violation.

For simplicity, the last term of equation (7) will be replaced by the following formula throughout the text:

$$D(\tau,m,n,v) = \int_0^{\infty} g(\mathcal{T},m,v,n)\ e^{-\delta\mathcal{T}}\,dt \quad (8)$$

D is the discounted density of the detection time. The discounted density function that is used as the probability of detection in this model can take different distribution functions that give the flexibility of addressing the three possibilities of constant, increasing and decreasing probability of detection by using a Weibull distribution.

The following are assumed:

$$\frac{dD}{dm} > 0;\ \ \frac{dD}{dv} < 0;\ \ \frac{dD}{dn} > 0;\ \ \frac{dD}{d\delta} < 0 \quad (9)$$

Substituting equation (7) into the value function, gives the final specification as follows:

$$J = max_m \left[\frac{u(m,c,p_a,Q_m,E_m,s,x)}{\delta}\right] - \left[\frac{u(m,c,p_a,Q_m,E_m,s,x) - u(n,b,p_n,Q_n,E_n,x)}{\delta} + F\right] \int_0^\infty D(\mathcal{T},m,v,n) \quad (10)$$

The optimal level of violation is obtained from the first order conditions by differentiating the objective function with respect to *m* to decide on the optimal amount of *m* that maximizes the profit through the optimal path. Then the supply of offences function is given by:

$$m^* = m(F,\delta,n.v,B) \quad (11)$$

F is the fine, *n* stands for enforcement, delta is the discount rate, *v* is evasion activity and B is a vector that represents socioeconomic and normative factors believed to be very important in analyzing violation with fishery regulations. The next section explains the empirical testing of the reduced from using cross section data from JAR.

Empirical model estimation

The Tobit model

The dependent variable is a continuous variable measuring the number of times a fisher uses a small mesh size net in the last year (NoTim). This follows Furlong (1991), Kuperan and Sutinen (1998) and Akpalu (2008), who use Tobit models to estimate the supply of violation function. The Tobit model is used because the dependant variables are censored taking values from zero upwards. That is, some observations of the dependent variable take a zero value. Estimating the relationships for the dependent variable (NoTim) using ordinary least squares in this case would result in biased estimates of the coefficients (Cameron and Trivedi, 2009).

Tobit models are often used to avoid the problem caused by censored data. The data is believed to be censored because fishers might be non-violators for some other reasons (such as lack of access to illegal nets due to high costs) rather than their moral standing.

The Tobit model is employed to specify factors that determine noncompliance with mesh size regulation and the dependent variable is a continuous variable measuring the number of times a fisher violated in the previous year. The dependant variable is censored at zero for non-violators, with the upper limit of 12 months for those who violate all the year round. The fishers' responses were in both number of months and weeks. However, all the data is converted to months only. The regression of interest is specified as unobserved latent variable Y* given by:

$Y^* = X'\beta + \varepsilon_i$ Where i=1, …, N

WhereY^*, measures the noncompliance rate with mesh size regulation. The X' is a vector of conditions reflecting the individual's perceived potential illegal gains and risk of detection and arrest, and measures of moral, social and legitimate influences.

The unobserved variable with the latent variable is related, as follows (Cameron and Trivedi, 2009):

$$Y = Y^* if\ Y^* > \tau$$
$$= \tau_y\ if\ Y^* \leq \tau \quad (11)$$

Where, τ is the censoring point and in the case of this study is equal to zero, the probability of a case being censored for is:

$$pr(Y^* < \tau) = pr(X'\beta + \varepsilon_i \leq \tau) = \emptyset\left[\frac{(\tau - X'\beta)}{\sigma}\right]\emptyset(.) \quad (12)$$

Which, is the standard normal cumulative function and ε_i is distributed$N(0,\sigma^2)\varepsilon/\sigma_i$, is distributed N(0,1)

Marginal effect is calculated to predict the effect of change in the explanatory variable on violation rate.

Data and variable description

This study used data that was collected in 2010 at the Jebel Aulia Reservoir in Khartoum state. The survey gathered information on four groups of noncompliance determinants (Table 1). These are information on socioeconomic attributes such as the age of the skipper (Age) and ownership of the nets (OWN), source of income (Income) and number of fishermen on the boat (Crew). Information was also collected on a second group of explanatory variables associated with incentives for violation, such as if the fisher perceives that the number of detections chances have decreased (Chances). The fishers were given options to select which evasion activities they use to avoid being caught such as using mobile phones and sinking the illegal nets (Sink). Fishers were also asked if they believe a small mesh net is more profitable than prescribed size nets (Advantage) and if they could buy illegal nets on a credit or cash basis (Credit). This variable is believed to reflect violators' time preferences and hence, their discount rates, as those who could afford to pay in cash for their nets were considered to

Table1. Descriptive statistics of variables included in the estimations

Name	Variable description	Mean/ %
NoTim	Number of times fishers violated in the past year	7.5
Violators	Numbers of violators	88 %
Non-violators	Numbers of non-violators	12 %
OWN	If the fisher own the net	90 %
Education	Number of years in school	2.82
Age	Skipper's age	47.2
Crew	Number of crew per boat	3.14
Income	If fishing is the main source of income (Yes = 1 and No = 0)	77.5 %
Chances	Chances of getting caught has decreased (0/1)	96 %
Escape	Violator can avoid paying the fine (No=0, Yes=1)	75.5 %
Credit	Paid in credit or installment (Yes = 1, No = 0)	72.9 %
Sink	Net sinking 1/0	80.1 %
Advantage	Small net profitable (Yes=1, No=0)	77.6 %
Not viol	Peer fishers are not violators (Yes=1, No=0)	80%
Fair	Mesh size regulation is fair (No = 1, Yes = 0)	75 %
Adequate	Enforcement in fishing area is adequate (Yes = 1, No = 0)	70.1 %

be relatively well off, having a lower discount rate. To estimate the probability of being fined when caught, fishers were queried on their perception about whether violators can escape paying the fine (Escape).

The third group of explanatory variables included is the influence of social factors on noncompliant behavior. Information on such factors were sought through asking fishers whether they perceive peers as violators (Not viol) and asking skippers if they perceive that poverty justifies violation (Pover). The last group of noncompliance factors represents fishers' perception of the legitimacy and efficacy of the regulations. Information was collected on two legitimacy variables: first, whether the enforcement in JAR is adequate (adequate) and the second entails whether a violator believes that small mesh prohibition is fair (Fair).

The data shows that only 12 % of the total fishers are non-violators and this is aggravated by the fact that 77 % of the fishers depend totally on fishing. This justifies the higher percentage of those who own nets (90 %) rather than renting. If the fisher owns the net his willingness to violate is high, so that the probability of maximizing his profit from violation is higher than those who rent a net and just get a small income. The mean of the skippers' age is 47 years, with a minimum of 17 years and maximum of 80 years.

More than half of the population prefers that the governance of the fishery sector be in cooperation between both fishers and the government. The fishers see it as rational for them to have a mixed regime that can satisfy their needs as well as allow them to participate in the management.

Although violation rate is found to be high, 75 % of the fishers believed that violators can avoid paying a fine. It was not clear from the data if this is because those enforcing the regulations accept bribes or ignore violations and fail to apply proper enforcement given the poverty among fishers. This is also confirmed by the fact that 96 % of fishers believed that the chances of getting caught are decreasing. All variables used in the model and their descriptive statistics are presented in Table1.

RESULTS AND DISCUSSION

All socio-economic variables are found to be highly significant. Generally, demographic factors have two different influences on the violation rate. These influences are encouragement and/or discouragement. For instance, for fishers that fish as the sole source of income and fishers owning the nets, violation increases. The higher the level of education and fisher's age the more violation decreases. The age variable is divided into four categories, according to respondents' ages, and the results show that younger fishers are more likely to violate regulations. This might be due to the hard work associated with using a small mesh size, while older fishers are less likely to violate. This finding agrees with the finding of Akpalu, (2008) and Furlong, (1991).

Table2. Estimation results of the Tobit model of the determinants of noncompliance

Variable	Coefficient	Standard error
Socioeconomic variables		
Cons	*- 4.3987**	*2.2780*
Age	-.0356***	0.0110
Education	- 0.2640* *	0.1341
Crew	- 0.1836*	0.1086
Source	2.29 69***	0.5479
own	0.8642*	0.5200
Incentive variables		
Chances	1.9237	1.2919
Credit	0.7498*	0.3878
Escape	0.6748*	0.3731
Sink	6.8006***	0.6632
Advantage	2.4490***	0.5018
Social variables		
Pover	0 .9546**	0.4326
Not violate	-0.2961*	.0 1776
Enforcement variables		
Fair	0.5147	.3764
Adequate	-0.6677*	.3717

* Significant at 10% ; ** Significant at 5% ; *** Significant at 1%.
Prob > Chi^2 = 0.0000 ; Log likelihood = -496.871
No. of observations = 241 ; Pseudo R^2 = .2238

Incentives for noncompliance in the JAR are explained by the second group. For instance, the skipper's perception that the chances of getting caught are decreasing steadily over time encourages him in more violation. This variable measures probability of detection and gives information about the weak enforcement. The violation problem is exacerbated by the fact that fishers in the JAR, who cannot afford to buy illegal nets, can get access to credit. This behavior is found to be rational for them, since the higher gain from violation will compensate the extra cost of buying on credit. The perception of the skipper that the fine can be escaped is also a very important encourager for violation. Fishers usually use two methods to escape penalty, either bribe the police or use effective evasion activity that make it difficult for the police to recognize violation.

Fishers in the JAR are very poor, and struggle to find catches for survival. They are convinced that poverty justifies violation. For instance, when a fisher is asked if his peers are violators, he responds by asking another question: "What can he do, given his hunger and need?" Having a sense of a fellow fishers' well-being, the skippers refuse to call themselves or their peer violators.

Due to low enforcement and high evasion activity, the influence of the factor "probability of detection" is not observed. This is reflected by the insignificance of the variable measuring this probability. The insignificance of this variable is expected and justified by literature to be associated with the fact that fishers sometimes don't understand the concept of probability, thus resulting in wrong estimations (Kuperan & Sutinen, 1998).

Although the skippers believed that enforcement in the JAR is adequate, most of them argued that the mesh size regulation is not fair. They refer the unfairness of this regulation to the fact that normal size fish are not available during all seasons.

Both deterrence and social variables are important determinants of violation and have to be taken into consideration in JAR fishery.

CONCLUSIONS AND POLICY IMPLICATIONS

This paper adapted the Modified Dynamic Deterrence Model (MDDM) to explain theoretically motives for noncompliance with mesh size regulation in order to help suggesting a new management regime that helps sustainability of the fishery resource.

The reduced form of the new modified model is tested, based on data that was collected in 2010 from the Jebel Aulia Reservoir in Khartoum state. The survey gathered information on four groups of noncompliance determinants. These are socio-economics, incentives for violation, social and legitimacy factors.

The Tobit model is employed to estimate factors that determine noncompliance with mesh size regulation in the JAR. Results showed that poverty, coupled with weak and inefficient institutions are the main drivers of illegal fishing in the JAR. The rate at which violation is increasing has led to a desperate fishery situation. The current level of noncompliance expresses the story of the "tragedy of the commons".

The perception of fishers about regulations is found to be very important in fishery management. They perceive that the probability of detection is decreasing, that fines can be bypassed and that the mesh restriction is not fair, which encourages them to persist in violations.

The model shows the importance of incorporating both deterrence and social variables in compliance analyses because of their direct influences on violation rate in the JAR.

In fishery resource management, collective actions and self enforcement are preferred when the social influence within a community is strong. Unfortunately, the cost of enforcement is always high and is not expected to be low given the inefficient institutions. However, a self enforcement regime is not possible due to factors such as low levels of education, lack of proper knowledge about regulations, and the low skills and ability of administration and funding needed for implementing the regime. All these factors are supported by the fact the younger fishers are found to violate more. Therefore, the study suggests a co-management regime for managing the JAR fishery, especially so that the younger violators will be forced to become regulators in cooperation with the government, leading to a reduction in violation. This might work well, because half of the fishers support a co-management regime. Co-management increases the awareness of fishing communities about the need for sustainable management of fish resources and in turn helps to reduce violation.

Jentoft (2000) attributed perfect compliance under this regime to the improvement of the legitimacy of fisheries management system such as sharing decisions, a feeling of fairness and justice and greater understanding of regulations. Nilsen, (2003) ascribes the success of compliance to the fact that managers and decision makers lack knowledge about the factors that affect compliance and legitimacy within the fishers' communities. The management approaches that are currently applied in most developing countries are based on centralized government intervention and have proven inadequate to deal with the issue of compliance with fishery regulation.

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Annexure A

Calculation of the modified model

Annexure A shows all the steps for the integration to calculate the expected net present value of illegal gain using the modified two time dynamic deterrence model.
As noted in the text
For simplicity $u(m, c, p_a, Q_m, E_m, s, x)$, will be replaced by $u(m)$
$u(n, b, p_n, Q_n, E_n, x)$, will be replaced by $u(n)$

$u(m) = \pi(m) - z(s) - d(x)$, $u(n) = \pi(n)$, substituting for $u(m)$; $u(n)$ in the value function and integrating gives the followings:

$$J(m) = E\int_0^{\mathcal{T}} e^{-\delta t}\, u(m) dt + E\int_{\mathcal{T}}^{\infty} e^{-\delta t}\, u(n)\ dt - e^{-\delta\mathcal{T}}\, F \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots A.1$$

$$= E\left[u(m)\left(\frac{-e^{-\delta\tau}}{\delta} + \frac{1}{\delta}\right) + u(n)\frac{e^{-\delta\tau}}{\delta} - e^{-\delta\tau}F\right]$$

$$= E\left\{\frac{u(m)}{\delta} - \left(\frac{u(m)-u(n)}{\delta}\right)e^{-\delta\mathcal{T}} - e^{-\delta\mathcal{T}}\, F\right\}$$

$$= E\left\{\frac{u(m)}{\delta} - \left(\frac{u(m)-u(n)}{\delta} + \mathrm{F}\right)\, e^{-\delta\mathcal{T}}\right\}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots A.2$$

$$= \left\{\frac{u(m)}{\delta} - \left(\frac{u(m)-u(n)}{\delta} + \mathrm{F}\right)\int_0^{\infty} g(\tau, m, N, v)e^{-\delta\mathcal{T}}\right\}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots A.3$$

Equation (A.1) is the discounted net present value of a fisher who violates the first period (first term) plus the gain from the second period (second term). After in between calculation and integration, we reached equation (A.2), which give us the exact expected discount profit from violation, the first term is the gain from violation (discounted expected profit from violation) and the second term is the amount of penalty that the fisher gets after being caught (immature catch plus fine) the outcome will be the pure gain from violation. In equations (A.3), we insert the value of the expectation parameter, which is the net present value of the time of detection.

Annexure B Calculating the Probability Density (the relation between the density function and proportional hazard rate)

This is straightforward calculation to get the proportional density function g(.) from the hazard formula and inserts the final results in the maximization equation.

$$\Pr(\mathcal{T}, m, v, N) = \mathcal{B}(m, v, N)h(\mathcal{T}) \qquad \mathrm{B.1}$$

With the survival function given by:

$$h(\tau) = \frac{g(\tau, m, N, v)}{1 - G(\tau, m, N, v)} \qquad \mathrm{B.2}$$

$$= \frac{\frac{dG(\tau, m, N, v)}{d\tau}}{1 - G(\tau, m, N, v)} \qquad B.3$$

$$= \frac{-d(1 - G(\tau, m, N, v))/d\tau}{1 - G(\tau, m, N, v)} \qquad B.4$$

$$= \frac{-dln(1 - G(\tau, m, N, v))/d\tau}{d\tau} \qquad B.5$$

Integrating both sides we get

$$\int_0^{\mathcal{T}} \mathrm{h}(\tau, m, N, v)\, d\tau = -ln\{1 - G(\tau, m, N, v)\} \qquad B.6$$

$$-\int_0^{\mathcal{T}} \mathrm{h}(\tau, m, N, v)\, d\tau = ln\{1 - G(\tau, m, N, v)\} \qquad B.7$$

Hence

$$1 - G(\tau, m, N, v) = \exp\left(-\int_0^t h(\tau, m, N, v)\, d\tau\right) \qquad B.8a$$

Which can written as

$$1 - G(\tau, m, N, v) = \mathrm{e}^{\left(-\int_0^t \mathrm{h}(\tau,m,N,v) d\tau\right)} \qquad B.8b$$

If the periodic harvest in this model is assumed to be constant overtime then

$$1 - G(\tau, m, N, v) = \mathrm{e}^{(-\int_0^t \mathrm{h}(\tau,m,N,v) d\tau)} \qquad \mathrm{B.9}$$

$$1 - G(\tau, m, N, v) = \mathrm{e}^{-\mathcal{B}(m,v,N)h(\mathcal{T})} \qquad \mathrm{B.10}$$

$$G(\tau, m, N, v) = 1 - \mathrm{e}^{-\mathcal{B}(m,v,N)h(\mathcal{T})} \qquad \mathrm{B.11}$$

And,

$$g(\tau, m, N, v) = \mathcal{B}(m, v, N)h(\mathcal{T})\mathrm{e}^{-\mathcal{B}(m,v,N)h(\mathcal{T})} \qquad \mathrm{B.12}$$

Substituting fro $g(\tau, m, n, v)$ in the value function we obtain:

$$\left\{\frac{u(m)}{\delta} - \left(\frac{u(m) - u(n)}{\delta} + \mathrm{F}\right)\int_0^{\infty} g(\tau, m, N, v) e^{-\delta\mathcal{T}}\right\} \qquad \mathrm{B.13}$$