African Journal of Agricultural and Resource Economics Volume 9 Number 3 pages 239-252

Legitimacy and ethics or deterrence factors: Which are more important for compliance with regulations among the artisanal fishers of Sudan?

Sanaa Abusin
Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, Room 2-6, Agricultural Annex, Hatfield, Pretoria 0002, South Africa. E-mail: sn_abusin@hotmail.com

Rashid Hassan*
Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, Room 2-6, Agricultural Annex, Hatfield, Pretoria 0002, South Africa. E-mail: Rashid.hassan@up.ac.za

* Corresponding author

Abstract

This study applied a modified deterrence model to evaluate the effectiveness of legitimacy and ethical factors compared to deterrence measures for compliance with mesh size regulation in the Jebel Aulia Reservoir of Sudan. The ordered probit and zero-truncated negative binomial models were employed to examine influences of determining factors on the choice between typologies of violators and non-violators, and then on frequency of violations (extent) respectively. Reported violation rates were high (87.5%), combined with weak enforcement and effective evasion used by almost all (97%) violators, leading to a low probability of detection, as only 28% of violators were caught. This is consistent with widely observed phenomena in developing countries, calling for increased efficacy of detection, monitoring and enforcement of regulations and higher penalties to fight non-compliance. The study also confirmed the high importance of legitimacy and ethical factors, suggesting that the involvement of stakeholders in the process of designing, monitoring and enforcing regulations is crucial as a process factor that may be more important than mere deterrence measures. This advocates for participatory co-management systems that are most likely to be more effective than top-down mechanisms in promoting compliance. The study also suggests that investments in the education of fishermen, the provision of alternative income and employment opportunities outside of fishing, access to credit to finance the acquisition of legal nets, and the effective regulation of importation of illegal nets will be necessary for enhancing compliance with mesh size regulation in Sudan.

Key words: fishery regulation; compliance; legitimacy; deterrence; Sudan

1. Introduction

Many African tropical freshwater lakes are believed to be fully exploited and over-fished. This presents a big threat to the capacity of these fishery ecosystems to continue providing for the livelihood of the many communities that are highly dependent on their harvest (MEA 2005). The practice of illegal fishing, particularly the use of small mesh sizes in an already over-fished resource, undoubtedly leads to stock collapse and fishery closure. Measures such as licensed harvest quotas and restrictions on the size of fishing nets have been introduced to rebuild fish stocks, but these have met with limited success. The actual catch from inland water is believed to be two to three times larger than is reported in official statistics due to illegal fishing, particularly in the

artisanal system of sub-Saharan Africa (FAO 2003; Welcomme 2010). Failure to account for illegal fishing contributes to inaccurate information about the status of fishery resources and consequently leads to misinformed fishery policy and management regimes (Atta-Mills *et al*. 2004). Achieving compliance with fishery regulations therefore is becoming an issue of serious concern to managers and policy makers worldwide, especially in the tropical freshwater fisheries of sub-Saharan Africa, given the high cost of enforcement and low probability of detection.

More research is needed to gain a better understanding of fishers' non-compliant behaviour in order to design effective control mechanisms. Illegal fishing, however, is a problem that is difficult to observe, as information about it cannot be obtained from government and fishery department statistics; instead, it is based mostly on self-reporting surveys and interviews (King & Sutinen 2010). Many empirical studies on non-compliance with fishery regulations have been conducted worldwide, generating results that differ across countries. Costly and weak enforcement and monitoring of compliance with laws and regulations, combined with tolerance of corruption, are believed to be behind the failure of fishery regulation (Charles *et al*. 1999; MEA 2005).

The high profits that fishers gain from violating national laws, estimated to amount to many fold the penalty paid, is considered to be the main incentive for non-compliance (Charles *et al.* 1999; Hatcher & Gordon 2005; Sumaila *et al.* 2006; King & Sutinen 2010). Other causes of illegal fishing include tolerance of corruption and cheating, given the lack of effective enforcement and monitoring mechanisms (MEA 2005; Akpalu 2011). The low probability of detection due to the high cost of enforcement and the violators' skill and practice in avoiding being caught (avoidance activities) have also been cited as among the main reasons for non-compliance (Furlong 1991; Charles *et al*. 1999; Sutinen & Kuperan 1999; Sumaila *et al.* 2006). Understanding avoidance behaviour has accordingly become important, as it has a direct influence on the probability of detection and the desire to violate.

The influences of social and moral factors on compliance have also been analysed in theoretical and empirical applications, with mixed results, suggesting either positive (when fishers regard violation of regulations as a bad behaviour) or negative impacts on compliance (when fishers regard violation as normal). Social and moral variables have been measured in various ways, including: (1) fishers' perceptions of the number of violators, e.g. peer behaviour and pressure (Kuperan & Sutinen 1998; Sutinen & Kuperan 1999; Eggert & Lokina 2010); (2) fishers' social and moral standing in the community (Sumaila *et al.* 2006); and (3) how fishers perceive fairness in the way regulations are made. Some studies found that deterrence factors are more important than normative influences on compliance (Hatcher & Gordon 2005), while others found both factors to be equally important (Kupran & Sutinen 1998; Hatcher *et al*. 2000; Akpalu 2008; Eggert & Lokina 2010).

Related to normative factors is the view in the literature that the type of management system and the way it is designed and put into effect strongly influence compliance. Many authors argue that co-management systems encourage compliance, as they are perceived to be a democratic (fair) mechanism ensuring involvement of stakeholders in the process of making regulations, and hence ensure legitimacy (Jentoft 2000; Eggert & Ellegard 2003; Nielsen 2003). Legitimacy measured in terms of fishers' assessment of the extent to which they have been involved in designing and implementing the enforcement regulation (e.g. fairness) has accordingly become an important social and moral factor in compliance analyses (Nielsen 2003).

There is evidence that fishery resources in Sudan are under serious pressure from over-fishing, especially in the Jebel Aulia Reservoir (JAR), which extends over 629 km on the White Nile south of the Jebel Aulia Dam. The JAR is the main supplier of fish (fresh and processed), contributing more than 52% of the total inland fisheries production of Sudan. However, it is also infamous for

the practice of using small mesh sizes, which threatens the stock and leads to over-fishing (Fisheries Department 2004; FAO 2008). Over-exploitation and the use of destructive fishing gear by local inhabitants, who are highly dependent on fishing, are believed to be the main causes of the extreme over-fishing in the area (FAO 1999, 2008). The reasons for these practices, as well as possible solutions to the problem, remain poorly understood.

The present study represents a first attempt to provide an empirical analysis of the compliance behaviour of fishers in Sudan. The paper builds on the reduced form supply-of-offences function of the analytical fishery model, adapted by Abusin and Hassan (2012), to analyse the extent of violation of mesh size regulation and investigate the relative importance of various factors on effective compliance with fishery regulations in the JAR area. The results of the study will provide useful policy information on the number and attributes of violators in the JAR area, determine why fishers choose to comply with or violate the regulations, and identify the factors that influence the intensity (rate) of violation. The study intends to measure and test empirical relations, examining the influence of both deterrence factors (detection and fining) and normative factors (legitimacy and moral perceptions) on violation rates. The influence of other variables found to be highly important in the literature on developing countries, such as evasion activity and the uncertain probability of paying a fine due to corruption and bribery, will also be investigated.

Section 2 describes the case study area and the methods of data collection. Empirical models are specified in Section 3, and Section 4 describes variables included in the analysis and presents some of the descriptive results. The results of the empirical analysis are discussed in Section 5, while Section 6 draws conclusions and points out the implications of the study.

2. Study area and data

Although the fishery sector's contribution to national income in Sudan is small (viz. 0.4% of the gross domestic product, or GDP), fishing is the source of employment and livelihood for many communities (FAO 2008). It is estimated that the sector provides employment to more than 12 900 full-time fishers, in addition to 51 600 people supported by the secondary sector, supplying more than 64 550 thousand tonnes of fresh fish every year, of which 90% is from inland waters (FAO 2008). Fishers in the study area often use small mesh sizes of less than 10 cm, and even as small as 2 cm, resulting in the capture of small fish that are either sold fresh or dried for further processing for own subsistence use later. The inland waters of Sudan, in various localities in the country, are inhabited by over 126 fish species, and the main inland fisheries are lakes and reservoirs. Sudan's per capita fish consumption in 2008 was estimated at 1.6 kg per annum, which is considered low compared to other parts of the world (FAO 2008). However, with current population growth rates of 2.5% per annum (Census Bureau 2011) and high levels of urbanisation, especially the influx to the capital city region, it is predicted that the demand for fish will rapidly overtake current supplies, placing pressure on fishery ecosystems and increasing fish prices in the country. Prudent fisheries management therefore is of particular importance for fishing communities and for the potential of fish consumption as a source of high value animal protein in Sudan.

There is evidence that fishery resources in Sudan in general are under serious pressure due to over-fishing, especially in the Jebel Aulia Reservoir (JAR), which is the closest source and primary supplier of fresh and processed fish to the capital city Khartoum and nearby sub-urban areas, where there is a high level of demand for fish. Local inhabitants, who are highly dependent on fishing, use destructive gear, putting extreme pressure on the stock in the area (FAO 1999, 2000, 2003; Fisheries Department 2004). Important consequences of over-fishing include changes in fish biodiversity, as some species become rare or disappear. A decrease in the sizes of commercial species and in fish production has been observed in this area (Ali 2000). For example, a number of

studies show that the sizes of *Alests* spp. and *Hydrocyns* spp. have decreased from over 15 and 30 cm to 10 cm respectively. *Protopterus senegalus* appear only from time to time, and *Citharinus scitharus* have not been seen for a very long time (Rahman 1985; Ali 2000; FAO 2000).

Other problems associated with fish supplies from the JAR include highly scattered fish landings, a lack of efficient transport and proper storage facilities, and difficulty with the enforcement of regulations. This is aggravated by difficulties with the modernisation and mechanisation of the generally subsistence-oriented fishery, which still relies largely on traditional technology (fishing gear and preservation/curing methods) (FAO 1999). Fishing in the JAR and in Sudan in general is regulated by the issuing of access licences and the banning of destructive gear and small mesh sizes. Licensed fishers also receive subsidies to help them overcome poverty – a common practice in developing countries (Sterner 2003). However, it is believed that poor enforcement of fishery regulations in the JAR is a major constraint to the sustainable management of local fish resources (Fisheries Department 2004; FAO 2008).

Data for the analysis were collected through a survey of fishers from the JAR. The population included all skippers in Khartoum State who use small mesh nets. From this population, a random sample of 241 skippers, constituting approximately 30% of the total number of boats in the area, were interviewed from February to May 2010. Samples were selected from five survey sites, with adequate spatial spread across all landing sites on the White Nile between the city of Khartoum and the dam. Sampling fractions were allocated to the different survey sites proportional to the size of the population in the site, and then randomly selected from a prepared sampling frame showing lists (compiled by the site chief) of fishers who were willing to be interviewed.

A structured questionnaire was developed and pre-tested on the different populations before administering the main survey. The questionnaires were administered to the skippers by Master's degree students from the University of Juba and chief fishermen from the area who are highly trusted by all fishers. The fishers were asked about the previous years' violations to maximise accuracy and reduce the bias that might result from asking about their own current violation rates.

The questionnaire collected information on the demographic characteristics (e.g. education and experience) of fishing households, the types of fishing nets used and the number of fishing crew, the skippers' perceptions of the mesh size regulation, violation rates, and how frequently nets had been used in the previous year. Other questions covered fishers' opinions on current regulations, whether they had experienced any arrests, their interaction with the police and managers, and what evasion measures they had used to avoid being caught.

3. Specification of empirical models

The rate of violation (or compliance) has been measured in different ways in studies conducted in different countries. Some studies have analysed the extent of violation by looking at how frequently fishers violate (Furlong 1991; Sutinen & Kuperan 1999; Eggert & Lokina 2010). A study of fishers on Lake Victoria measured violation of the minimum mesh size regulation by looking at the number of violating fishing days in the previous year (Eggert & Lokina 2010). Furlong (1991) used the proportion of violation (proportion of regulatory regimes violated) on a typical fishing trip in a specific season as a measure of the frequency of violation. Hatcher and Gordon (2005) measured violation rate as the percentage of landings over quota in the previous year, whereas Kuperan and Sutinen (1998) measured the violation rate as the number of days a fisher had fished in a prohibited zone. All these studies, however, have used static model formulations, following Becker's (1968) deterrence model, which assumes that the violator faces a one-period decision problem of maximising expected utility.

In contrast, dynamic formulations based on the two-period dynamic deterrence model have so far used 'intensity' of violation, which is measured by the value of juvenile fish in an illegal catch per day, averaged over the past week's catch (Akpalu 2008). Although this measure may fit developed countries, it is highly unlikely to work well in developing countries, where property rights are not well defined and it is relatively easy for fishers to escape being caught. It is also difficult to estimate a total catch per day that includes violating harvests, implying a data problem. Second, by not employing frequency as a measure of the violation rate, one misses the opportunity of capturing the direct link between violation rates and opportune time periods for illegal fishing (seasonality). This is due to the fact that, during months of active breeding, the quantities of small fish are high, which encourages illegal fishing compared to months of no breeding. Thirdly, illegal catches are not sold on formal fishing markets, but are rather concealed and sold outside of formal channels, out of sight of monitors.

This study builds on the work of Abusin and Hassan (2012), who modified the Davis (1988) fishery dynamic deterrence model to allow for an inconstant probability of detection and a frequency measure of violation intensity. The solution to the optimisation problem of their modified model produced the following "supply-of-offences" function, representing the optimal rate (frequency) of violation (m*):

$$m^* = m(F, \delta, n, v, D) \quad (1)$$

Equation 1 provides the reduced form of the empirical relationship between the degree of violation of, or non-compliance with, fishery regulations and their determinants, which will be specified and tested in this study. In addition to the social discount rate δ, two important variables have been introduced in the supply-of-offences function, namely evasion activity (v) and enforcement efforts (n). Moreover, the D vector of determinants includes the perception variables that affect the disutility from violation and the socioeconomic characteristics of the fisher, such as years of experience, as well as effort factors such as the number of crew members per boat, which directly affects the profits and costs of harvest. Other factors in D include normative elements, such as peer pressure (e.g. measured by the perception of the number of violators in the community), which is found to motivate fishers to increase violation in studies analysing the importance of normative factors for the enforcement of regulations (Hatcher & Gordon 2005; Sumaila *et al*. 2006; Akpalu 2008; Eggert & Lokina 2010; King & Sutinen 2010). The influences of other factors, such as prices, are incorporated into the constant term of the regression model, since they are common to all skippers.

As said above, this study intends to achieve two objectives: (1) to study factors that influence the choice between violation and compliance, and (2) to analyse the determinants of the rate of violation (degree) among violators. Various models have been used to pursue such objectives. Binary logit and probit models have been employed to study the determinants of the decision to violate or not. Binary specifications have been criticised in the literature as giving limited information about violators (King & Sutinen 2010). Ordered choice models are more suitable when the dependent variable is measured with data of an ordered nature. The dependent variable in our study is a positive, discrete number ranging from zero to 12 months of violation. Although we expected the skippers to give information about violation rates in continuous time, they argued that it was easier for them to answer in discrete time (number of months of violation).

However, ordered models are not relevant when estimating the extent/degree of violation among violators. To analyse the extent of violation, we chose count data models, which measure the number of times an event occurs within an interval of time, as the most relevant for this study. Since in this case we are interested in violators only, the zero-truncated Poisson distribution was chosen as

the most suitable among commonly used count models. Nevertheless, this model is known to violate the over-dispersion assumption that characterises count data (the variance of occurrences exceeds their mean). We therefore employed the general version of this model: the zero-truncated negative binomial model (ZTNB), which was developed to overcome this problem and is known to give more accurate results than the famous Poisson model (Long 1997; Kennedy 2003; Wooldridge 2000).

3.1 Determinants of the choice to violate or comply

A frequency-of-violation index was employed to classify fishers into three categories or typologies. To implement this we followed the behavioural choice variable of type of fishing equipment owned/used in the previous year, as suggested by Eggert and Lokina (2010). Fishers are accordingly classified, based on information provided on the numbers of months of using legal and illegal nets, into non-violators (NV), occasional violators (OV) and chronic violators (CV).

The dependent variable, Y^*, is the latent variable measuring the degree of violation. It has an ordered nature that justifies the use of ordered maximum likelihood for the estimation of model parameters, and hence our choice of the ordered probit model (OPM) for analysing the determinants of the choice to belong to one of the three fishers' typologies. We assume that the latent variable Y^* can be described by a normal distribution, such that:

$$\Pr(Y = A) = \Phi(-\beta' X) \quad (2)$$

A = 0 if the fisher owns only legal nets (NV)
= 1 if the fisher owns both legal and illegal nets (OV)
= 2 if the fisher owns only illegal nets (CV)

The latent variable is related to the observed variable as follows:

$$\begin{aligned} Y \quad &= 0 \text{ if } Y^* \leq 1 \\ &= 1 \text{ if } 1 < Y^* < 11 \\ &= 2 \text{ if } Y^* \geq 11. \end{aligned} \quad (3)$$

To interpret the model results, marginal effects are calculated as:

$$\frac{\mathrm{dPr}(Y=A|x)}{dX_k} \quad (4)$$

The marginal effect of factor k is then the slope of the curve relating X_k to $\Pr(Y = A|x)$, holding all other variables constant. In other words, for a unit increase in explanatory variables, the probability of the dependent variable can increase or decrease according to the sign of the coefficient β (Kennedy 2003).

3.2 Determinants of the extent of violation among violators

Assuming their dependent variable (number of months a fisher has violated) is continuous and normally distributed, Eggert and Lokina (2010) employed the two-stages Heckman selection model. Our response variable is measured in the same way, but we considered it to represent count data, which, according to Wooldridge (2000), cannot take a normal distribution, hence estimating such data with standard linear regression implies a critical bias. Therefore, the ZTNB model is estimated where the dependent variable Y assumes a range of values from one to 12 months of violation, which means that the model is truncated at zero. Then the conditional probability of observing Y

events, given that Y > *0*, i.e. the probability that a fisher violates given that NV fishers are not part of the sample, is computed with the law of conditional probability as:

$$\Pr(Y_i \,|Y_i > 0\,, x) = \frac{\exp(-u_i)u_i^{Y_i}}{Y_i\,[1-\exp(-u_i)]}\,, \qquad Y = 1, 2, \ldots, 12 \tag{5}$$

Since zero counts are excluded (NV), the value is increased by the inverse of the probability of a positive count for both OV and CV, which forces the pdf to sum to 1 (Long 1997):

$$\mathrm{E}(Y_i \,|Y_i > 0\,, x) = \frac{u_i}{[1-\exp(-u_i)]} \tag{6}$$

u_i (u_i=1, 2..., 12) is the predicted number of months the fisher violates, conditional on explanatory variables (covariates) X_i. A truncated negative binomial model is estimated by modifying the likelihood function (i.e. adding $\propto$ to adjust for over-dispersion) for the Poisson regression model as follows (Long 1997):

$$\mathrm{L}(\beta\,, \propto |\mathrm{Y_i}\,, x) = \prod_{i=1}^{N} \Pr(Y_i \,|Y_i > 0\,, x_i) \tag{7}$$

The model is estimated by the discrete effect method, holding variables at their mean level. This model estimates the influence of determining factors on the extent of violation within violators.

4. Variables included and results of the descriptive analysis

The survey gathered information on four categories of non-compliance determinants (Table 1). Information on socioeconomic attributes, such as education level, experience, source of income and number of skippers per boat, represented one category of explanatory variables. There is strong evidence in the literature for the significance of socioeconomic factors in non-compliance. Information was also collected on a second category of explanatory variables associated with enforcement efficacy and deterrence measures, viz. whether violators met regulatory enforcing agents when landing (Agent). To estimate the probability of being fined when caught, fishers were asked about the action taken against them when caught. If the answer was only net seizure (Action), then paying a fine is bypassed. This category also included information on incentives to violate, such as whether or not a fisher used some evasion mechanism to avoid the seizure of his or her net or paying a fine (Evasion). Fishers were also asked if they believed a small mesh net is more profitable than nets of the prescribed size (e.g. advantage in terms of profit from violation), and if they could buy illegal nets through credit or only on a cash basis (Credit). This variable is believed to reflect the fishers' poverty level and hence their discount rates, as those who could afford to pay in cash or have access to credit finance for their nets were considered to be relatively well off and hence to have a lower discount rate, i.e. to be less concerned about the present.

Table 1: Descriptive statistics of variables included in the estimations

Name	Variable description	Mean (%)
Violation rate		
NV	Non-violators (zero frequency)	12.5
OV	Occasional violators (1-10 months)	50.5
CV	Chronic violators (11-12 months)	37.0
Education	Level of education in years of schooling	2.82
Experience	Years of fishing experience	27.63
Crew	Number of crew members per boat	3.14
Income	Fishing is the main source of income	77.5
Advantage	Perception that small net is more profitable	77.6
Agent	Regulation-enforcing agent seen when landing illegal catch	15.1
Action	Net seized	70
Credit	Lack of cash or credit to pay for new net	72.9
Evasion	Used net-sinking evasion measure	97
Ethical	Peer violation is not wrong	56.4
Unjust	Fishers' views not considered in regulation design	75.1
Adequate	Enforcement in fishing area is adequate	70.1

The third category of explanatory variables included influences of social (ethical) factors on non-compliant behaviour. Information on one such factor was sought by asking fishers whether they perceived their peers' attitudes towards violation as wrong or not (Ethical). A fourth category represented fishers' perceptions of the legitimacy and efficacy of the regulation. Information was collected on four legitimacy variables: if fishers' views were not considered in formulating the regulation (Unjust), if small mesh prohibition was fair (Fair), if the enforcement in JAR was adequate (Adequate), and if a violator could skip detection even if they violate (Ineffective). Previous studies have revealed that such factors are important determinants of non-compliance (Sutinen & Kuperan 1999; Eggert & Lokina 2010; King & Sutinen 2010). Some of these variables had to be dropped (Unfairness and Ineffective) from subsequent analyses due to statistical insignificance and suspected high correlation with other explanatory variables. Correlation between the remaining explanatory variables (multicollinearity) was estimated to be less than 0.50.

The survey indicates very high violation rates among the studied population of fishers, as only 12.5% of the respondents reported that they had never violated the mesh size regulation, with 42% of the violators using illegal small nets all year round (CV), and the remaining 58% alternating between small sized and prescribed nets during the year (OV). While the percentage of violation is quite high (87.5%), only 28% of the violators had encountered arrests. It is clear that fishers in the study area have a high probability of avoiding being caught. The main evasion measure practised by 97% of the violating fishers is to tie the illegal net to a big stone and let it sink deep when caught, and then try to recover it later. In spite of this strategy, the loss of the illegal net remains the biggest cost to violators, as about 70% of those arrested suffered seizure of nets. Only 3.7% of those caught using illegal nets admitted to bribing enforcement agents, while 8.5% had to pay a fine and the remaining 17% managed to get away with a warning.

5. Discussion of empirical estimation results

The OPM specified above was fitted to the data described in Table 1, and the estimation results are presented in Table 2. As mentioned earlier, our dependent variable is an ordered variable classifying fishers into three typologies: NV, OV and CV. Error statistics indicate a good statistical fit of the model, the majority of the variables have the expected signs, and their influences have high statistical significance. To measure the effects of influencing factors on the probability of belonging to any of the ordered fisher categories, we derived measures of marginal effects of a one unit change (increase/decrease) in explanatory variables, holding all other variables at their mean levels (Table 3). A negative sign indicates the willingness of a fisher to leave the group (i.e. discouraging

factors), and the reverse holds for a positive sign (i.e. incentive to remain in the same group or increase association with the current position/choice).

The effect of deterrence variables on non-violators is irrelevant, since they do not interact with regulators and have not experienced arrests before. However, the only variable of significance that appeared to be highly correlated with the probability of compliance was the fact that members of this category of fishers do not use illegal nets and hence do not need to use evasion measures (large negative effect of 47% of odds). Another interpretation may be that the possibility of using evasion measures encourages NV to violate and hence reduces their probability of staying in this group.

Among the socioeconomic factors, better education and more years of experience tend to encourage moving to lower violation categories (OV and NV), i.e. they discourage chronic violation. High reliance on fishing income has the opposite effect. This indicates that, with better education and more experience, fishers are able to diversify their income and hence be less dependent on fishing for a living.

Table 2: Estimation results of the ordered probit model of the violation probability

Variable	Coefficient	Standard error
Socioeconomic variables		
Education	-0.220*	0.127
Experience	-0.038***	0.011
Crew	-0.298***	0.115
Income	1.43 7**	0.577
Advantage	2.167***	0.601
Deterrence variables		
Agent	-0.807*	0.473
Credit	0.734**	0.376
Action	0.982**	0.411
Evasion	5.836***	1.162
Ethical variables		
Ethical	0.239	0.327
Legitimacy variables		
Unjust	0.239*	0.327
Adequate	-0.791**	0.360
* Significant at 10%; ** Significant at 5%; *** Significant at 1%		
Prob > Chi^2 = 0.0000; Log likelihood = 133.27 No. of observations = 241; Pseudo R^2 = 0.431		

Table 3: Marginal effects of determinants of decision to violate

	Non-violators		Occasional violators		Chronic violators	
Variable	dy/dx	*t stat*	dy/dx	*T stat*	dy/dx	*t stat*
Socioeconomic						
Education	0.0019	0.94	0.321*	1.67	-0.0341*	-1.68
Experience	0.0003	1.08	0.0052***	3.32	-0.0055 ***	-3.38
Crew	0.0028	1.07	0.04670***	2.72	-0.0496***	-2.77
Income	-0.0309	-1.01	-0.1427***	-4.34	0.7136***	3.65
Advantage	-0.0556	-1.37	-0.1925***	-4.71	0.2482***	5.63
Deterrence						
Agent	0.0049	0.98	-0.1395	1.48	-0.1445	-1.50
Credit	-0.0093	-0.96	-0.9940**	-2.24	0.1088**	2.18
Action	-0.0061	-1.01	-0.1757**	-2.11	0.1818**	2.15
Evasion	-0.4701***	-3.48	0.1329	1.02	0.3372***	8.53
Ethical variables						
Ethical	0.0025	0.65	0.038	0.80	0.0412	0.80
Legitimacy						
Unjust	-0.0084	-0.91	-0.0922**	-2.08	0.1007* *	2.01
Adequate	0.0059	0.99	0.2155*	1.93	-0.1314*	-1.95
* Significant at 10%; ** Significant at 5%; *** Significant at 1%.						

More crew members on the same boat seem to discourage chronic violation. This could be due to the relatively higher risk of being caught and fined with a large number of crew members, and the fact that they can pool resources to afford alternating between legal and illegal nets. Violation also tends to increase (move from NV and OV to CV) if the perception of fishers is that illegal nets are more profitable than legal ones (Advantage).

The comparative statics analysis of Abusin and Hassan (2012), employing the same model, advanced the following hypotheses on the direction of the relationships between frequency of violation and its key determinants (deterrence, legitimacy and time impatience or discounting the future):

1. Increase in enforcement (deterrence) discourages violation (negative effect)
2. Need for higher evasion efforts reduces frequency of violation (negative effect)
3. Higher social discount rates (impatience) increase frequency of violation

The results of the OPM analyses of the effects of deterrence and legitimacy/ethical factors do not provide clear-cut conclusions on these hypotheses. While some deterrence factors, such as the prevalence of regulation agents, have the expected sign (discouraging violation) for all violating categories, the effects of others vary between OV and CV. For example, while the seizing of illegal nets discourages OV, it unexpectedly seems to encourage CV. The positive effect on CV may be due to the fact that CV are more likely to have their nets confiscated. The ethical factor (i.e. believing that peer violation is not wrong) encourages violation in both categories of violators, whereas the belief that enforcement is adequate provides an incentive for the cautious flexible strategy of being an occasional rather than a chronic violator. Not considering fishers' views in designing regulations encourages higher violation (from NV and OV to CV). Lack of access to cash or credit to buy new nets (as a proxy for high discount rates) seems to encourage CV and discourages compliance. The OPM results also show that using evasion activity to hide illegal nets discourages OV but encourages CV.

A zero-truncated negative binomial (ZTNB) model was employed to achieve the second objective, of determining the factors that influence the frequency of violation within violators only (both OV and CV), and to allow better assessment of the extent to which the data support or refute these hypotheses. The results of the model estimation are presented in Table 3 and are compared to those

from the OPM. Most variables (high reliance on fishery – *Income*; high discount rates – *Credit*; profitability of violation – *Advantage*; and not considering fishers' views – *Unjust*) share high statistical significance in both models, and their signs confirm our OPM results, namely that they all encourage moving from OV to CV, i.e. increase the frequency of violation (positive sign in the ZTNB model). The statistical significance of the legitimacy factor *Adequate* decreased the significance, whereas the ethical factor (*Ethical*) effect increased the significance, but the deterrence factor *Agent* remained statistically insignificant in the ZTNB estimation.

The fact that both models show low statistical significance of the effect of an *Agent* factor (measuring the probability of detection) is not surprising if one notes that only 15% of the fishers reported seeing an enforcement agent when landing an illegal catch (Table 1). The result is also consistent with other studies, confirming the problem of having a low probability of detection in developing countries due to the high cost of enforcement and monitoring. In addition, the effectiveness of this measure is also a function of other factors, such as evasion activities.

Table 4: Determinants of extent of violation within violators

Variable	Coefficient	T stat
Socioeconomic variables		
Education	0.023	1.30
Experience	0.005	0.40
Crew	-0.001	-0.12
Income	0.43 7***	4.50
Advantage	0.1231***	2.89
Deterrence variables		
Agent	-0.075	1.00
Credit	0.167***	2.85
Action	0.118**	2.04
Evasion	1.78***	7.56
Ethical variables		
Ethical	0.087*	1.79
Legitimacy variables		
Unjust	0.149***	2.61
Adequate	-0.050	-0.94
* Significant at 10%; ** Significant at 5%; *** Significant at 1%		
Prob > Chi^2 = 0.0000; Log likelihood = -514.38423 No. of observations = 211; Wald $Chi^2(12)$ = 9443.51		

The results of the ZTNB model for effects of deterrence (*Agent*) and high discount rate/impatience (*Credit*) factors seem to support the hypotheses that Abusin and Hassan (2012) advanced above, consistent with most of the relevant literature. However the positive effect of evasion on frequency of violation rejects the above hypothesis on the influence of evasion activities. It is important to note that the above hypothesis is based on the assumption that increased investment in evasion efforts increases costs and reduces profits from illegal fishing, and hence reduces the demand for more frequent violation (Charles *et al*. 1999).

The fact that our study measured evasion as a binary index of whether evasion is used or not, and that 87.5% of fishers violate and almost all of them (97%) use evasion (Table 1), is the main reason for the failure to capture the hypothesised negative effect on the frequency of violation (e.g. evasion practices are highly correlated with violation). The hypothesised negative effect would most likely have been captured if evasion was measured on a continuous scale of degree (how much evasion effort) and correlated with corresponding levels (frequency or intensity) of violation, which would reflect the trade-off between the need for more evasion efforts versus more frequent violation. Abusin and Hassan (2012) suggested the reformulation of the deterrence model to optimise over two control variables, namely evasion efforts and frequency of violation, as key determinants of

profits from non-compliance to reflect such a trade-off and to determine optimal combinations of the two that maximise returns from illegal fishing.

Similarly, the variable deterrence *Action* (seizure of net) seems to motivate higher violation rates (increase frequency), which is also contrary to expectations. Again, this may be attributed to the low rates of detection, as only 28% reported arrests in spite of the very high violation rates (87.5%); and to the effectiveness of the evasion measure used by almost all (97% in Table 1), i.e. the probability of detection and seizure of a net is highly unlikely.

While not showing statistical significance in affecting the decision to belong to violator categories, ethical belief had a significant negative effect on the frequency of violation. This means that the community's ethical beliefs have important influences on violation rates. It also suggests that a communal self-regulatory mechanism, such as co-management schemes, would improve compliance and assist in ensuring some equity among the fishing population, especially where poverty is high and violation is common. The study confirms the significant influence of both legitimacy and ethical factors as being no less, if not more, important than deterrence factors in explaining non-compliance with regulations among the artisanal fishers of JAR of Sudan. While having significant influences on the decision to belong to violator groups, social factors such as education and experience do not seem to be of significance for how intensive violation is.

6. Conclusions and policy implications

This study applied a modified deterrence model, using frequency measures of violation, to analyse the determinants of the problem of non-compliance with mesh size regulation in the Jebel Aulia Reservoir, Sudan. The studied determinants included both deterrence (detecting and fining) and normative (ethical) factors. High violation rates were observed (87.5%), with 58% of the violators being occasional violators (OV) and 42% being chronic violators (CV). However, weak enforcement (15% incidence of presence of enforcement agent) and effective evasion used by almost all (97%) violators contributed to the low probability of detection, as only 28% of violators were caught. Two models were employed in the analysis: the ordered probit model (OPM), to examine the effects of factors influencing the choice of what fisher typology to belong to (NV, OV or CV), and the zero-truncated negative binomial (ZTNB) model, to analyse the determinants of how frequently violations occur (extent).

Deterrence factors have proven important, with fining (seizure of net) showing higher statistical significance than the presence of an enforcement agent. This is mainly due to weak enforcement and to effective evasion activities by all fishers, which is consistent with widely observed phenomena in developing countries. Policy alternatives to fight non-compliance include efforts to increase the efficacy of detection, monitoring and enforcement of regulations, and higher penalties.

The study also confirmed the importance of legitimacy and ethical factors, suggesting they are equally important in explaining non-compliance with regulations. The results suggest that the involvement of stakeholders in the process of designing, monitoring and enforcing regulations would be crucial process factors that may be more important than mere deterrence measures. This basically advocates for bottom-up and participatory co-management systems, which are most likely to be more effective than top-down mechanisms in promoting compliance.

The study also suggests that investments in the education of fishermen, the provision of alternative income and employment opportunities outside of fishing, access to credit to finance the acquisition of legal nets, and effective regulation of the importation of illegal nets will be necessary to enhance compliance with mesh size regulation in Sudan. It would also be necessary to promote community-

level organisation and awareness campaigns among fishers concerning the damage to future fish stocks caused by the erosion of small fish stocks through the use of illegal nets – a practice that is jeopardising the social welfare of all.

Given the complexity of managing trade-offs between demand for increased evasion efforts and/or higher frequency of violation, the study suggests extending the deterrence model to determine the optimal combination of the two control variables (levels of evasion and violation) that maximises profits from illegal fishing. Implementing such analyses empirically will require improved measures of evasion efforts and intensity of violation, particularly on continuous scales, including implications for the cost of illegal fishing (costs of legal and illegal nets, bribing and other evasion activities).

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