ECONOMIC STUDIES

DEPARTMENT OF ECONOMICS
SCHOOL OF BUSINESS, ECONOMICS AND LAW
UNIVERSITY OF GOTHENBURG
200

Essays on Natural Resource Economics

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UNIVERSITY OF GOTHENBURG

ISBN 978-91-85169-62-7
ISSN 1651-4289 print
ISSN 1651-4297 online

Printed in Sweden,
Geson Hylte Tryck 2011

To the memory of my dad, Wisdom Kwame Vondolia

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Preface

The journey for this thesis started a couple of years ago and has taken me far outside my immediate environment. Throughout this journey, I have been fortunate to meet dedicated individuals whose help and motivation have made such a difference. I am profoundly grateful to Dela and to my friend and dear wife, *Tee*. Your love, support and smile have been my bedrock. I am very grateful to my family for all the love, encouragement and support. As a kid, I was encouraged by Seth Akpah to look beyond my immediate environment; unfortunately, he departed too soon to celebrate the yellow book.

I am greatly indebted to my supervisors, Håkan Eggert and Jesper Stage. I will not even attempt to count the number of diagrams we have discussed over the last four years, yet those diagrams illustrate my journey in many ways. The prompt questions Håkan posed helped me rethink and redraw the diagrams. The constructive comments and deadlines helped to keep me focused. I am equally grateful to Jesper for his rare combination of intelligence and humility. I appreciate your comments and discussions on the thesis and on academic life in general. I commend both of you for your humility and dedication.

Several other individuals have inspired and helped me as well. I first met Wisdom Akpalu at the University of Cape Coast and since then we have been great friends. I learnt a lot from co-authoring two of the papers in the thesis with you. I have also benefitted enormously from comments by and interactions with Ståle Navrud. I am grateful to you for having me over and your abundant advice. Gunnar Köhlin and Måns Söderbom served as discussants at the higher seminar and provided many constructive comments. Fredrik Carlsson, Matthias Sutter and Katarina Nordblom have not only motivated me through their own research, but have also shared their knowledge with me. I would also like to thank Aart de Zeeuw for taking the time to look at some of the draft papers. Kerry Smith offered insightful comments during our sojourn at Camp Resources XVII**.**

Adjusting from one environment to another can pose significant challenges, but Elizabeth Földi was invaluable in helping me connect the two worlds. I will forever be touched by your dedication. I say *bra gjort* to Gunnar Köhlin and Thomas Sterner for their dedication to developing teaching, research and policy capacity in environmental economics. Theodora and I have truly enjoyed the genuine kindness and friendship of Ann Veiderpass.

The Department of Environmental and Natural Resource Economics, University of Rhode Island, hosted me for a semester, and I am very impressed with the cordial academic atmosphere there. The devotion and energy of Liz Smith is commendable. I will never forget your help and friendship during my stay at URI. Barbara Harrison guided me through the many formalities in connection with the visit. I also fondly remember and enjoyed my time with Hiroki, Emi and Hiro Uchida and Cathy Roheim, who showed me the best of Rhode Island. Samuel Aboh and my landlord, Armenio Costa, were also very helpful.

I have been blessed with a number of fine classmates and feel that I have benefitted enormously from interacting with them. I still remember the times we have spent together: Jerry, Clara, Haoran, Yonas, Nam, Måns, Andrea and Conny. I also enjoyed the coffees, lunches and discussions with Clara, Claudine, Jerry, Nam, Haoran and Weng Qian.

I greatly appreciate the help and support of my bigger family. Anatu not only welcomed me to Gothenburg and the US but also edited some of my papers in the thesis. Precious Zikhali has been infectious with her laughter, advice and friendship. Many thanks, Preh! Richard, Fafa and Abigail have been of tremendous help in introducing me to Gothenburg. Theo and I have also enjoyed the friendship of Ben Odjidja, George Adu, James Dzansi, Monica, Sarah Dobson, Godwin Armah and Gifty Klutse. Joel Ene and his family have been very generous, providing us with an open invitation to Oslo and sharing their home with *Tee* and me. The distance has not weakened the friendship I have with Julie Abimanyi and Threza Mtenga. Kodzotsey has also inspired me on my journey.

The Swedish International Development Cooperation Agency (Sida) has funded the study and data collection through assistance to the Environmental Economics Unit, Department of Economics at the University of Gothenburg. The Microfinance Unit at the Department of Economics, University of Cape Coast, facilitated the data collection in Ghana and for that I am very grateful to the unit and to Peter Aglobitse. I am also grateful Sandie Fitchat and Debbie Axlid for the editorial assistance.

Godwin Kofi Vondolia, Gothenburg 20 April, 2011

Summary of the thesis

This thesis comprises the four self-contained papers summarised below.

Paper 1: *Enforcement of exogenous environmental regulation, social disapproval and bribery*

In Africa, natural resources have historically been managed by *external* central powers exerting social, political and economic control over citizens (Schroeder, 1999). This, as noted by Bromley (1991), has weakened the ability of local customary regimes to address resource degradation. The agents appointed by the central authorities to enforce the exogenous regulations have social ties to the resource users and may suffer social disapproval for enforcing the regulations strictly. This situation breeds corruption in natural resource management as the enforcement agents often accept bribes and overlook non-compliance. The paper presents a simple model that characterises this situation and derives results for situations where the officer is passively and actively involved in bribery. Specifically, we assume that an external authority mandates an enforcement agent who may have social ties to resource users to enforce resource use regulations. Since the agent incurs social disapproval (e.g. social exclusion) if he/she eagerly enforces the regulation, he/she may accept bribes and overlook non-compliance, a situation that could explain the lax enforcement of natural resource management regulations in developing countries.

Four results were derived from the model. First, the extent of the social disapproval determines the gap between the observed and the efficient levels of enforcement effort. Second, if the enforcement officer does not decide on a bribe amount but is offered a bribe voluntarily (i.e. is passively involved in bribery), the size of the bribe determines the level of effort that the officer will invest in enforcing the regulation. In addition, increased social disapproval, *ceteris paribus*, leads to an equilibrium situation where offenders pay bribes and enforcement effort is indeterminate (i.e. *only-bribery equilibrium*), and there is a complete collapse of the enforcement of the regulation. Furthermore, if the officer decides on a bribe price (i.e. is actively involved in the bribery), the violator may offer a bribe that is smaller than the fine and the officer will accept a bribe that is smaller than the fine. Some of these results are illustrated with data on fisheries law enforcement in Tanzania.

Published in *Journal of Socio-Economics*

Paper 2: *Bioeconomic model of spatial fishery management in developing countries*

Although fishers in developing countries use simple fishing technologies that restrict fishing inshore, fisheries still provide food, employment and foreign revenue to support the economies of coastal developing countries. For instance, developing countries' net exports of fishery commodities increased from US$ 4.0 billion in 1982 to $17.4 billion in 2002; and the values of net exports for fish exceed the sum of net exports of rice, cocoa, tobacco and tea (Vannuccini, 2004). The contribution of marine fisheries to the global economy is below full economic potential and comprehensive reform of marine fisheries governance can recover a substantial part of these sunken billions (World Bank, 2008). The ratification of United Nations Convention on the Law of the Sea in 1982 is the most important institutional reform in the governance of global marine resources. This document also requires coastal developing countries to sign fishing agreements with distant water fishing nations to fish offshore. Given that the offshore may serve as a natural marine reserve (i.e. a source) to the inshore (i.e. a sink), these partnership agreements could generate spatial externalities for migratory stocks. Although short-term rents from landing taxes on offshore catches are crucial for these coastal developing countries, the long-term stream of overall economic rents depends on sustainable fisheries management since most stocks are generally migratory and given that the offshore serves as a natural reserve.

This paper presents a bioeconomic model in which a social planner uses a landing tax to internalise this spatial externality and manages inshore and offshore fisheries with two goals: conservation and optimal social welfare. We found that the landing tax needed to achieve these goals must reflect the biological connectivity between inshore and offshore, the intrinsic growth rate, the price of fish, the cost per unit effort and the social discount rate. These results are calibrated with data on the exclusive economic zone of Ghana in the Gulf of Guinea Large Marine Ecosystem. The data indicates a unidirectional line of causality from offshore to inshore for the flat and round sardinela but a bidirectional line of causality for mackerel in both fisheries. This implies that the harvest of each of the species offshore could predict the harvest inshore. These results confirm both that the species are migratory and that policies addressing overfishing offshore could potentially affect the stock and harvest inshore.

Resubmitted to *Environment and Development Economics*

Paper 3: *What do respondents bring into contingent valuation? A comparison of monetary and labour payment vehicles*

A recurrent finding from contingent valuation studies conducted in developing countries is that respondents are more likely to accept, i.e. state a positive willingness to pay (WTP), and also indicate a higher mean WTP under labour payment vehicle relative to monetary payment vehicle (see Swallow and Woudyalew, 1994; Echessah et al., 1997; Hung et al., 2007). The relatively higher acceptance rates for non-monetary payment numéraires have also been observed in revealed preferences (Lee et al., 1999) and in experimental settings (Ellingsen and Johannesson, 2009). These variations in responses to CV surveys hinder pooling of CV data (Layton and Lee, 2006), and according to Diamond and Hausman (1994), also question the credibility of the Contingent Valuation Method (CVM). Meanwhile, models from social psychology (e.g. Fishbein and Ajzen, 1975; Ajzen, 1991) and preference elicitations (e.g. Plott, 1996) postulate that these biases in decisions and choices decay in repeated and familiar choice environments.

The purpose of the present paper is to investigate the effects of experience with monetary and labour payment vehicles on the acceptance of contingent valuation scenarios and protest bids. Specifically, the paper conducts a split-sample survey among smallholders at the Afife Irrigation Project in Ghana to investigate the effects of experience with monetary and labour payment vehicles on the acceptance of a contingent valuation scenario and protest bids. Using convergent validity tests, we found that experience acquired from using both payment vehicles reduces the asymmetries in acceptances rates. These findings suggest that experience with payment vehicles acquired by using these payment vehicles to mobilise public goods reduces time-money response asymmetries in the CVM. The implications of these results for the conduct of CVM studies and devolution policies in developing countries are also explored. These results suggest that the payment vehicles we adopt in the CVM should not be of paramount concern. Specifically, if the respondents are familiar with the payment vehicles, both acceptance and total WTP could be comparable across different payment vehicles. Also, devolution policies do not need to adopt a particular payment vehicle to ensure participation.

Paper 4: *Nudging Boserup? The impact of fertilizer subsidies on investment in soil and water conservation*

The primary role of input subsidies in agricultural development should be to promote adoption of new technologies and accelerate agricultural production (Ellis, 1992). Despite the failure of past fertilizer subsidy programmes in Sub-Saharan Africa, there is renewed interest in fertilizer subsidies as a viable means to halt low agricultural production, malnutrition and poverty (e.g. Morris et al., 2007; Denning et al., 2009). The new fertilizer subsidies in Sub-Saharan Africa are intended to increase agricultural production and ensure fertilizer market development. Fertilizer adoption requires complementary inputs (e.g. investment in soil and water conservation) for efficient and optimal nutrient uptake. However, many fertilizer subsidy programmes implicitly assume that the fertilizer subsidies crowd in these investments.

The present study, therefore, evaluates the impact of fertilizer subsidies on the provision of soil and water conservation effort in Ghana. The results indicate that beneficiaries of the studied fertilizer subsidy programme do not invest significantly more in soil and water conservation, which advises against excessive reliance on farmers to respond to fertilizer subsidies with substantial investment in soil and water conservation. These results are consistent with the theoretical model and empirical findings of Duflo et al. (2010) that farmers may not undertake profitable investments. Thus, more comprehensive measures such as an integrated soil fertility management programme could be considered to promote fertilizer adoptions and investment in soil and water conservation for sustainable agricultural development. Investments in soil and water conservation have also been noted to protect agricultural production in Sub-Saharan Africa against climate change since the soil and water conservation investments will mitigate the growing water shortages, the worsening soil conditions, as well as drought and desertification (IPCC, 2001; Kurukulasuriya and Rosenthal, 2003).

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Paper 1

The Journal of Socio-Economics 38 (2009) 940–945

Contents lists available at ScienceDirect

The Journal of Socio-Economics

journal homepage: www.elsevier.com/locate/soceco

Enforcement of exogenous environmental regulation, social disapproval and bribery☆

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A R T I C L E I N F O

Article history:
Received 21 December 2008
Received in revised form 4 June 2009
Accepted 17 June 2009

JEL classification:
Q20
Q28
Z13

Keywords:
Natural resource management
Bribery
Law enforcement
Social exclusion

A B S T R A C T

Many resource users are not directly involved in the formulation and enforcement of resource management rules and regulations in developing countries. As a result, resource users do not generally accept such rules. An enforcement officer who has social ties with the resource users may encounter social disapproval and possible social exclusion from the resource users if he/she enforces the regulation zealously. The officer, however, may avoid this social disapproval by accepting bribes. In this paper, we present a simple model that characterizes this situation and derive results for situations where the officer is passively and actively involved in the bribery.

1. Introduction

Public policies, say an environmental policy, seek to promote efficiencies in resource allocation. As a result, regulations are implemented to realign individual incentives with optimum social welfare. However, in spite of the implementation of a plethora of environmental management policies, the state of many environmental resources in many countries is in danger of extinction and irreversible regime shift (see FAO, 2004; Pauly et al., 1998 for an illustration with fisheries resources). In developing countries, these regulations are hardly enforced due to the weakness of the institutions responsible for making and enforcing regulations. Consequently, the natural resource abundance in these countries has failed to reverse their economic problems.

Notably, weak institutional quality breeds corruption and non-compliance with resource appropriation rules and these have remain a dominant explanation of inefficient use of natural resources (Mehlum et al., 2006; Akpalu, 2008; Eggert and Lokina, 2008). The lax regulatory environment for the enforcement of environmental regulations creates an environment in which the regulations are not optimally enforced and resource users do not comply with the regulations. Jentoft (1989) highlights factors that are required for successful compliance with regulations. These include the content of the regulations; distributional impact of its effects; and design and implementation of the regulations. In the absence of any of these factors, the resource users may consider the regulation illegitimate. For example, among 310 skippers who were interviewed in a fishing community where the stock is overharvested, only 11% of the respondents agreed that mesh size regulation imposed by the government is a *right thing* (Akpalu, 2008).

Recent research findings have established that resource users' perceived legitimacy of resource appropriation rules matters for compliance (see e.g. Kuperan and Sutinen, 1994; Akpalu, 2008; Eggert and Lokina, 2008). As a result, regulation imposed by an external authority suffers from higher rates of violation relative to rules formulated and enforced by resource users in many developing countries (see e.g. Gebremedhin et al., 2003). For example, in Africa, state regulation of natural resources has little success (Moorehead, 1989; Shepherd, 1991; Brinkerhoff, 1995; Williams, 1998). On the other hand, devolving resource management rights to local communities coupled with effective internal governance usually improves legitimacy and consequently increases compliance (see e.g. Tyler, 1990; Swallow and Bromley, 1995; Turner et al.,

☆ The authors are very grateful to Aart de Zeeuw, Jesper Stage and Jorge Garcia and two anonymous referees for their invaluable comments. Financial support from the Environmental Economics Research and Consultancy, Inc (EERAC), Sida and the Environment for Development (EfD) initiative is gratefully acknowledged.
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doi:10.1016/j.socec.2009.06.002

1994; Gebremedhin et al., 2003). According to Tyler (1990), acceptance of the legitimacy of an authority encourages compliance with its laws even where those laws conflict with an individual's own self-interest.

Bromley (1991) noted that the introduction of state property regimes to address resource degradation in developing countries has weakened local customary regimes. This is because resource users are often divorced from the conservation policies in the state formation. With state institutions in charge of managing natural resources, the regulatory environments are weak, causing harvests to exceed sustainable levels (FAO, 2004; Pauly et al., 1998). In Brazil, it has been observed that during elections, mayors do not enforce logging regulations around the Amazon region. Moreover, the weak monitoring and enforcement of rules is mostly caused by institutional problems in the civil service. One reason is the inadequate pay, education, and equipment of forest guards and the fact that single unarmed guards often live in villages they are supposed to control (Heltberg, 2001). While in some cases, local authorities are reluctant to enforce regulations for fear of losing elections as noted by Nkonya et al. (2008), the most common experience is that the agents appointed to enforce such exogenous regulations have social ties with the resource users and may suffer social disapproval for zealously enforcing the regulations. Social ties contribute to building social capital, which lubricates all kinds of informal contracts in developing countries (see Woolcock and Narayan, 2000 for a synthesis of the literature on social capital). As a result, people care about shame-based sanctions, such as social ostracism (Ostrom et al., 1992; Barr, 2004). Granovetter (1985) observes that even strict economic transactions are embedded in social structures that influence the decisions and behavior of economic agents. This situation breeds corruption in natural resource management as the enforcement agent very often accepts bribes and overlooks violations.

As noted by Robbins (2000), corruption in natural resource management entails the use or overuse of community natural resources with the consent of a state agent, an enforcement officer for instance. Corruption depends on trust among the parties involved and on social expectations that rules will be enforced in particular, ways and that none of the agents will inform higher authorities. As a result, relationship between individuals involved in corruption extends beyond monetary exchange (Robbins, 2000). In addition, natural resource corruption is common in situations where officials have monopoly over environmental goods; control of externalities such as control a bulk of forestland or have exclusive rights to issue waste dumping permits (Goudie and Stasavage, 1998; Ostrom et al., 1993).

A number of theoretical models have been developed to explain corruption in natural resource management. These models essentially consider how corrupt policymakers are bribed by resource users to influence the resource appropriation policymaking processes (see e.g. Aidt, 1998; Fredriksson, 1997, 2003; Schleich, 1999) and the various political and administrative branches within which the design of environmental policy can be corrupted (Wilson and Damania, 2005). While these models have helped to enrich our understanding of corruption in the policymaking process, theoretical research on corruption in enforcement, especially when enforcement officers have social ties with resource users, is very scarce. As noted by Nyborg (2003), if behavior is guided mainly by the desire for social acceptance, economic incentives have much weaker effects than predicted by the traditional economic model. In this paper, we extend the existing theoretical model of crime to fill the gap. We assume that an external authority mandates an enforcement agent who may have social ties with resource users to enforce resource use regulations. Since the agent incurs social disapproval (e.g. social exclusion) if he/she eagerly enforces the regulation, he/she may accept bribes and overlook non-compliance, a likely situation that may explain the far from complete enforcement of natural resource management laws in developing countries.

In this paper, we have found that, first; the extent of the social disapproval determines the gap between the observed and efficient enforcement levels of effort. Second, if the enforcement officer does not decide on a bribe amount but is offered a bribe voluntarily (i.e. passively involved in the bribery) the size of the bribe would determine the level of effort that the officer will invest in enforcing the regulation. In addition, increased social disapproval, *ceteris paribus*, would lead to an equilibrium situation where offenders pay bribes and enforcement effort is indeterminate (i.e. *only-bribery equilibrium*), and complete collapse of the enforcement of the regulation. Furthermore, if the officer decides on a bribe price or is actively involved in the bribery, the violator may offer a bribe that is less than the fine and the officer will accept a bribe that would be less than the fine. The rest of paper is organized as follows: Section 2 presents the models, propositions and proofs; Section 3 concludes the paper.

2. The model

In this section, we first present a simple utility maximization problem for which utility depends on leisure, consumption of composite good and social disapproval from rule enforcement. Second, we extend the problem to include the possibility of a violator bribing the enforcement officer. Two bribing situations are considered: first, if the enforcer does not decide on a bribe amount (i.e. the bribe is exogenous since he is only passively involved in the bribery) and second, if he/she decides on a bribe price (i.e. the bribe is endogenous since he decides on the bribe). Moreover, given that the officer decides on the bribe amount, we derive a condition under which the violator may pay a bribe and the officer may accept such a bribe.

2.1. Resource management rule enforcement officer's problem

Suppose a natural resource management law enforcement officer (i) derives utility from consuming a composite good (c) and leisure (l) but derives disutility from social disapproval for enforcing the law (i.e., $S(E)$), which depends on enforcement effort, say number of inspections or time spent on inspections (E), within a period of time. In addition, suppose the number of inspections or time spent on inspection is directly related to the number of arrests. The total time endowment of the officer is L, so that $l = L - E$. Assume that the utility is of a Cobb–Douglas form, i.e., consumption, leisure and enforcement effort are all essential to utility and appear in positive amounts for any utility larger than zero. In order to make it more analytically tractable we use the specific functional form of the logarithmic transformation of the Cobb–Douglas utility function.

$$u^i(c, l, s(E)) = \alpha \ln c + \beta \ln(L - E) - \theta \ln E \quad (1)$$

where $\theta \le \alpha$, β. Suppose that the officer can choose the level of enforcement effort (e.g. work full time or on part time basis). For tractability, let E be a continuous variable and $g(E)$ be a function that defines the benefit received by the officer for the effort he/she invests in enforcing the regulation. The benefit function may not necessarily be linear because the officer could be rewarded for the quantity as well as efficient use of his effort. However, for simplicity, but without losing generality, let w denotes a constant marginal private benefit of increased effort (hereafter denoted a wage rate) and p_c be fixed price of the composite good so that the officer's budget constraint is $wE \ge p_c c$. His objective will be to maximize the utility function (i.e., Eq. (1)) with respect to E and c subject to the budget constraint. The corresponding Lagrangian function is

$$\ell = \alpha \ \ln c + \beta \ \ln(L - E) - \theta \ \ln E + \lambda(wE - p_c c), \quad (2)$$

where λ is the Lagrangian multiplier. The first-order conditions are

$$\frac{\partial \ell}{\partial E} = -\beta(L-E)^{-1} - \theta E^{-1} + \lambda w = 0 \qquad (3)$$

$$\frac{\partial \ell}{\partial c} = \alpha c^{-1} - \lambda p_c = 0 \qquad (4)$$

$$\frac{\partial \ell}{\partial \lambda} = wE - p_c c = 0 \qquad (5)$$

From Eq. (3), in equilibrium, the marginal benefit from increased enforcement effort (i.e. λw) should equate the marginal cost of the increased effort (i.e. $\beta(L-E)^{-1}+\theta E^{-1}$). The marginal cost is the sum of the disutility from decreased leisure (i.e. $\beta(L-E)^{-1}$) and the disutility from social disapproval (i.e., θE^{-1}). Second, from Eq. (4), the marginal utility from the consumption of the composite good (αc^{-1}) must reflect the utility of the price of the good (i.e., λp_c). Solving for the equilibrium enforcement effort (E^*) from Eqs. (3) to (5) gives

$$E^* = L(\alpha-\theta)(\alpha+\beta-\theta)^{-1} \qquad (6)$$

Proposition 1. *The divergence between equilibrium enforcement efforts, with and without the possibility of social disapproval, increases with the degree of social exclusion but decreases in the proportional change in utility with respect to the composite good (i.e. α).*

Proof. In the absence of social disapproval (i.e., $\theta = 0$), the optimum effort level is given by $E^\circ = L\alpha(\alpha+\beta)^{-1}$. Therefore, the difference in the two effort levels is

$$\Delta E = E^\circ - E^* = \frac{\beta\theta L}{(\alpha+\beta)(\alpha+\beta-\theta)} \qquad (7)$$

Taking the first-order derivative of Eq. (7) with respect to θ and α, we obtain the following signs: $\partial(\Delta E)/\partial\theta > 0$ and $\partial(\Delta E)/\partial\alpha < 0$ (the partial derivatives are in Appendix A). The first (i.e., $\partial(\Delta E)/\partial\theta > 0$) indicates that the more social disapproval the officer encounters from the resource users, the less effort he/she will devote to enforcing the rules. Perhaps a more surprising finding is that the officer will increase enforcement effort if the proportional change in the utility of consumption of the composite good (i.e., α) increases. The intuition is that if the officer receives increased utility from consuming the composite good, the officer will need increased income to finance the consumption of the composite good. As a result, he/she has to increase enforcement effort to obtain an increase in income. Furthermore, without the possibility of bribery, if the officer encounters social disapproval for enforcing the rules, increased wages or incentives will not impact on enforcement effort (i.e., $\partial(\Delta E)/\partial w = 0$).

2.2. Bribing the enforcement officer

2.2.1. Accepting the bribe

Suppose that the law enforcement officer can accept bribe (B) to avoid social disapproval from enforcing the law but derives disutility from the shame associated with accepting bribe. Let the shame or psychic disutility function be $v(B) = -\kappa B$, where $\kappa < \theta$. Note that the officer does not decide on the bribe price so we assume that B *is exogenous* in his optimization program. If the bribery is detected, the officer loses his job and income. The subjective probability of getting away with the bribery is $q(B) \in (0,1)$ with $q_B(B) < 0$ and $q(\infty) \to 0$ (i.e. the officer is more likely to get away with a lower amount of bribe than a higher amount). The objective of the agent is to maximize the following expected utility function

$$\underset{c,l,E}{\text{Max}} \; E\{u^j(c,l,s(E),v(B))\} = \alpha \ln c + \beta \ln(L-E) - \theta \ln E - \kappa B, \qquad (8)$$

subject to

$$q(B)wE + B \geq p_c c. \qquad (9)$$

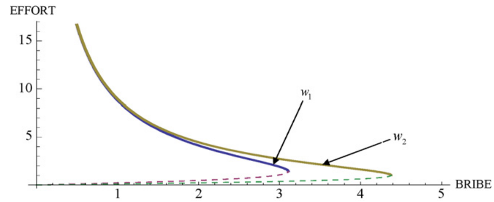

Fig. 1. Equilibrium relationship between bribe and effort: higher wages (i.e., $w_2 > w_1$) increases the turning point of the graph.

The left hand side of Eq. (9) is the expected benefit that the officer obtains if he/she gets away with the bribe. Since he/she does not decide on the bribe price, B is not a choice variable in his objective function. The Lagrangian function is

$$\ell = \alpha \ln c + \beta \ln(L-E) - \theta \ln E - \kappa B + \mu(B + q(B)wE - p_c c) \qquad (10)$$

The first-order conditions are

$$\frac{\partial \ell}{\partial E} = -\beta(L-E)^{-1} - \theta E^{-1} + \mu q(B)w = 0 \qquad (11)$$

$$\frac{\partial \ell}{\partial c} = \alpha c^{-1} - \mu p_c = 0 \qquad (12)$$

$$\frac{\partial \ell}{\partial \mu} = B + q(B)wE - p_c c = 0 \qquad (13)$$

From Eq. (11), the expected marginal benefit of increased enforcement effort (i.e., $\mu q(B)w$) depends on the probability of getting away with the bribe. Assuming that $q(B) = e^{-\phi B}$ and solving the first-order conditions (i.e., Eqs. (14)–(16)) gives a quadratic solution of

$$E^* = \frac{Be^{\phi B}(B-\theta) + wL(\theta-\alpha)}{(2w(\theta-\alpha-\beta))} \pm \frac{(\alpha wL - w\theta L + \theta Be^{\phi B} - B^2 e^{\phi B})^2 - 4Be^{\phi B}L\theta w(\theta-\alpha-\beta)^{0.5}}{(2w(\theta-\alpha-\beta))} \qquad (14)$$

where $E^* = E_1, E_2$ of which one is admissible.

Proposition 2. *An increase in the wage rate increases the bribe necessary to plunge the system into only-bribery equilibrium.*

Proof. Note that the *only-bribery equilibrium* refers to a situation where the enforcer accepts bribe and invest unpredictable amount of effort in enforcing the regulation. The proof for Proposition 2 requires solving for B at the bifurcation point of the only-bribery equilibrium from Eq. (14) and then solving and signing the expression $\partial B/\partial w$. As shown in Appendix (i.e., Eqs. (2A)–(2C)), equating the two arms of the Eq. (14) (i.e., equating E_1 and E_2), solving for B and taking the derivative gives $\partial B/\partial w > 0$. This implies that if the officer's wage increases, a higher bribe price is necessary to collapse of enforcement of the regulation.

To illustrate these relationships, we plotted the solution for B (i.e. Eq. (2C) in Appendix) using the following parameters values assumed for convenience: $\alpha = 0.3$, $\phi = 0.1$, $\beta = 0.2$, $\theta = 0.2$, $\nu = 20$, $w = 10$ and $L = 100$. Fig. 1 shows the equilibrium relationship between the bribe amount and effort based on some chosen parameter values. The curve (i.e., the inner curve) shows that the equilibrium relationship between the optimal effort and the bribe price has a flipping point beyond which the system falls into only-bribery equilibrium. An increase in the wage rate to $w = 20$ implies that the bribe amount could plunge the system into the only-bribery equilibrium is much higher than before. This is shown by the second curve (i.e., the outer curve).

Table 1
Ordinary least square estimation of the relationship between rate of violation and bribery.

Variable	Coefficient	t-stat
Bribery	2.92137	(1.76)*
MARA[a]	19.35052	(1.95)*
KAGERA[a]	−3.92292	(−0.57)
Constant	20.75432	(3.83)***
Observations	21	
R-squared	0.31	

Note: Robust *t*-stats in brackets.
[a] MWANZA is the reference region.
[*] Significant at 10%.
[***] Significant at 1%.

Thus, if the bribe is large enough, the enforcement officer will exert unpredictably low levels of effort in enforcing the regulation. This would invariably intensify non-compliance with the regulation. Note that we have just presented the dashed segments of the curves to show that the curves have flipping points but not to indicate a positive relationship between optimum effort and bribery, which is not admissible. From the foregoing analyses, it is therefore not very surprising that in many developing countries a significant correlation exists between the bribery and violation rates of resource appropriation rules. In the following subsection, we present some basic empirical results to substantiate this claim. However, as can be seen from Fig. 1, by increasing the wage rate, the bifurcation point increases. This means that as the wages increase or if compensation packages increase, enforcement increases and it takes a relatively larger amount of bribe to plunge the system into only-bribery equilibrium. Furthermore, if it is possible for the officer to be bribed voluntarily, then for any given level of the probability of detection of the bribery, it is possible to determine the size of incentive (e.g. wage increases) that could mitigate the impact of the social disapproval.

2.2.2. *A numerical illustration of the relationship between bribery and rate of violation*

To illustrate the positive relationship between bribery and the rate of violation of a resource appropriation law, we use data from Eggert and Lokina (2008) which was collected on violation of mesh size regulation in artisanal fishery in Tanzania. The data was collected at 21 beaches in three regions: Kagera, Mwanza, and Mara, along the Tanzania part of Lake Victoria in April–June 2003 where 459 skippers were interviewed using a questionnaire. In response to the declining catch per unit effort, some gill-net fishers who target Nile perch, tilapia or dagaa use nets with illegal mesh sizes to increase their landings. The rate of violation is computed as the proportion of the fishers at each beach who indicated that they violate the regulation. The *bribery* variable is the proportion of violators who ever bribed the enforcement officer. From the Ordinary Least Square (OLS) results presented in Table 1, the rate of violation is regressed on bribery and regional dummy variables. The rate of violation and bribery are positively related, after controlling for regional difference. An approximately 3% increase in bribery will increase the rate of violation by 1%. This relationship conversely lends support to our theoretical prediction that increased bribery will lead to an increase in violation rate through lower enforcement effort.

2.2.3. *Demand for bribe (the enforcement officer deciding a bribe price)*

Suppose that the law enforcement officer decides on a bribe if the illegal activity is detected. Let the indirect utility function of the officer be $V^i(w, p_c, I_0)$ if he does not accept the bribe offered by the offender (where I_0 is a vector of all other constants in the utility function), and the corresponding indirect utility function be $V^j(w, p_c, I_0, B_d)$, if he accepts the bribe. Where $V^j > V^i$ and B_d is the bribe taken. Furthermore, the bribe amount that the officer will ask for will depend on the fine (i.e., F) as well as the giver's psychic cost of guilt (z) for offering the bribe. Thus, e.g. if the psychic cost is perceived to be relatively high the officer would accept a relatively low amount of bribe. Suppose the officer does not know the exact psychic cost of guilt but only the range (i.e., $z \in [\underline{z}, \bar{z}]$) and its probability distribution. Assume the distribution is uniform. Define the probability that the violator will offer a given amount of bribe requested by the officer as

$$\Phi(z < F - B_d) = \frac{F - B_d - \underline{z}}{\bar{z} - \underline{z}} \tag{15}$$

where F is fixed legal fine for violating the regulation, so that the probability that he does not offer the bribe is

$$1 - \frac{F - B_d - \underline{z}}{\bar{z} - \underline{z}} \Leftrightarrow \frac{\bar{z} - F + B_d}{\bar{z} - \underline{z}} \tag{16}$$

The officer will therefore maximize the following expected utility function

$$\max_{B_d} \; E(\Gamma) = \frac{\bar{z} - F + B_d}{\bar{z} - \underline{z}}[V^i(w, p_c, I_0)] + \frac{F - B_d - \underline{z}}{\bar{z} - \underline{z}}[V^j(w, p_c, I_0, B_d)] \tag{17}$$

The first-order condition from Eq. (17) is

$$\frac{\partial E(\Gamma)}{\partial B_d} = \frac{V^i}{\bar{z} - \underline{z}} + \frac{F - B_d - \underline{z}}{\bar{z} - \underline{z}} V_B^j - \frac{V^j}{\bar{z} - \underline{z}} = 0 \tag{18}$$

Proposition 3. *The enforcement officer will accept a bribe that is less than the legitimate fine (i.e., $B_d < F$).*

Proof. By rearranging Eq. (18), we have

$$V^i + (F - B_d - \underline{z})V_B^j - V^j = 0 \tag{19}$$

$$B_d = F - \underline{z} - \rho(B) \tag{20}$$

where $\rho(B) = (V^j - V^i)(V_B^j)^{-1}$, hence $B_d < F$. □

Suppose a resource user obtains a benefit of π from illegal harvest. If caught, he could either bribe (i.e., B_s) the enforcement officer or pay some fixed fine (F) to the court (i.e. legitimate fine). Furthermore, suppose that the resource user incurs z (i.e. some psychic cost of guilt) if he offers the bribe and let $m(B)$, with $m_B > 0$, define the probability that the bribe will be accepted by the enforcement officer. Consequently, if the resource user is caught by the officer, he will offer a bribe if the following condition holds

$$u(\pi - F) \le m(B)u^i(\pi - B_s - z) + (1 - m(B))u^j(\pi - F - z) \tag{21}$$

If he is an expected utility maximizer, his objective will be to maximize the term at the right hand side of Eq. (21). Thus

$$\max_B E(\Omega) = m(B)u^i(\pi - B - z) + (1 - m(B))u^j(\pi - F - z) \tag{22}$$

Taking the first-order condition from Eq. (22) and rearranging gives

$$\varepsilon(u^i - u^j) = -u_B^i B_s \tag{23}$$

where $\varepsilon = (m_B/m(B))B$ defines the elasticity of the probability of acceptance of the bribe with respect to the bribe price. From Eq. (23), in equilibrium, the expected marginal utility gained from paying the bribe price rather than paying the legal fine (i.e., $\varepsilon(u^i - u^j)$) must be equal to the marginal disutility of the bribe price paid (i.e., $-u_B^i B_s$).

Proposition 4. *If the illegal fisher is risk neutral, he will offer a bribe that is less than the fine (i.e., $B_s < F$) if $\varepsilon \in (0, \infty)$ and the bribe will be increasing in ε and F.*

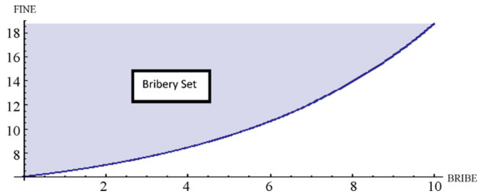

Fig. 2. The plot of the equilibrium relationship between paying legitimate fine and successful bribery.

Proof. Assume for simplicity that the resource user e.g. the fisher is risk neutral so that $u^i = \pi - B_s - z$ and $u^j = \pi - F - z$,

$$\varepsilon(F - B_s) = B_s \tag{24}$$

$$B_s = \left(\frac{\varepsilon}{1+\varepsilon}\right)F \tag{25}$$

For all $(\varepsilon/1+\varepsilon) \in (0,1)$, $B_s < F$. Taking the comparative statics of Eq. (25) with respect to the two arguments, we have the following: $\partial B_s/\partial\varepsilon > 0$ and $\partial B_s/\partial F > 0$, implying that the violator will offer higher bribe if the legitimate fine and the elasticity of the probability of acceptance of the bribe increases (the derivation of the comparative statics has been presented in Appendix). In addition, for any given fine, the maximum amount that the violator will offer is the legitimate fine (i.e., $B_s = F$) since $\lim_{\varepsilon\to\infty} \to (\varepsilon/(1+\varepsilon)) = 1$. On the other hand, $\lim_{\varepsilon\to 0} \to (\varepsilon/(1+\varepsilon)) = 0$, therefore the violator will offer no bribe (i.e. $B_d = 0$) if the size of the bribe does not determine if the officer will accept it or not.□

2.2.4. Condition for successful bribery

In this subsection, the condition under which a bribe may be offered and received is deduced. This condition follows directly from Eqs. (24) and (25).

Proposition 5. *A bribe will be offered and will be accepted if* $F \geq (\rho(B) + \underline{z})/(1-\sigma)$.

Proof. The proof for this requires verifying the condition under which $B_s \geq B_d$. This implies that

$$F\left(\frac{\varepsilon}{1+\varepsilon}\right) \geq F - \underline{z} - \frac{V^j - V^i}{v_B} \tag{26}$$

Eq. (26) could be rewritten as

$$F \geq \frac{\rho(B) + \underline{z}}{(1-\sigma)} \tag{27}$$

where $\sigma = (\varepsilon/(1+\varepsilon))$. Eq. (27) defines the bribery set and Fig. 2 presents a sketch of the set.□ Furthermore, increasing the probability of detection of receiving the bribe and firing the officer will increase ρ (B) and consequently deter successful bribery. In addition, increasing the psychic cost (i.e. guilt $\underline{z}$) of bribing may deter successful bribery.

From Fig. 2, for any given level of B there is a corresponding minimum level of F that is necessary for the bribe to be offered and accepted. Any F above the threshold (i.e. in the shaded area) engenders successful bribery.

3. Conclusions

In this paper, a neoclassical utility maximization framework has been extended to incorporate social considerations that characterize the enforcement of natural resource management regulations in developing countries. Notably, natural resource management regulations are weakly enforced in developing countries although there are obvious indications of resource degradations. There seems to be an inefficient equilibrium where resource users do not strictly comply with the laws. Also, government appointed agents do not completely enforce these regulations, especially if they are likely to suffer social disapproval from enforcing the rules. This paper, therefore, develops a simple theoretical model to characterize this situation and derive some interesting policy outcomes.

Our theoretical model produces key propositions for describing the behavior of law enforcement officers and their strategic interaction with communities within which they are required to enforce these environmental regulations. We found that the divergence between equilibrium enforcement effort, with and without the possibility of social disapproval, increases with the degree of social exclusion but decreases in the proportional change in utility with respect to the composite good. Thus, in communities where the social exclusion is higher, there will be higher divergence between the actual and desirable enforcement effort levels. This finding is consistent with the notion that if behavior is guided mainly by the desire for social acceptance, then economic incentives can have much weaker effects than predicted by the traditional economic models. In addition, if the proportional change in utility with respect to the composite good is higher, there will be lesser wedge between the effort levels. Furthermore, if the wage rate increases, the bribe that could plunge the system into only-bribery equilibrium has to be higher. Thus, higher wages offered to government appointed agents who enforce the environmental, could increase enforcement effort. Finally, the government appointed agent will accept bribes that are less than the legitimate fine. On the other hand, if the resource user is risk-neutral, he may also offer a bribe that is less than the fine that he would have paid to the law court.

Appendix A.

Proposition A.1. *Recalling* Eq. (7), *we have*

$$\Delta E = \frac{\beta\theta L}{(\alpha+\beta)(\alpha+\beta-\theta)} \tag{1A}$$

Taking the first-order derivative of Eq. (1A) *with respect to* θ *and* α, *Eqs.* (1B) and (1C) *are obtained.*

$$\frac{\partial(\Delta E)}{\partial\theta} = \frac{(\alpha+\beta)(\alpha+\beta-\theta)\beta L + (\alpha+\beta)\beta\theta L}{((\alpha+\beta)(\alpha+\beta-\theta))^2} > 0 \tag{1B}$$

$$\frac{\partial(\Delta E)}{\partial\alpha} = \frac{\beta\theta(\theta-2\alpha-2\beta)L}{((\alpha+\beta)(\alpha+\beta-\theta))^2} < 0 \tag{1C}$$

Proposition A.2. *From* Eq. (17),

$$E_1 = \frac{Be^{\phi B}(B-\theta) + wL(\theta-\alpha) + ((\alpha wL - w\theta L + \theta Be^{\phi B} - B^2e^{\phi B})^2 - 4Be^{\phi B}L\theta w(\theta-\alpha-\beta))^{0.5}}{(2w(\theta-\alpha-\beta))} \tag{2A}$$

$$E_2 = \frac{Be^{\phi B}(B-\theta) + wL(\theta-\alpha) - ((\alpha wL - w\theta L + \theta Be^{\phi B} - B^2e^{\phi B})^2 - 4Be^{\phi B}L\theta w(\theta-\alpha-\beta))^{0.5}}{(2w(\theta-\alpha-\beta))} \tag{2B}$$

Equating Eqs. (2A) and (2B) *gives the following equation for the bifurcation point*:

$$(\alpha wL - w\theta L + \theta Be^{\phi B} - B^2 e^{\phi B})^2 - 4Be^{\phi B} L\theta w(\theta - \alpha - \beta) = 0 \quad (2C)$$

Taking the partial derivative of the implicit function (*i.e.*, Eq. (2C)) *gives* $\partial B/\partial w > 0$.

Proposition A.3. *From* Eq. (23), $B_d = F - \underline{z} - \rho(B)$, *where* $\rho(B) = (V^j - V^i)(V_B^j)^{-1}$. *From the specific preferences* $\rho(B) = (\theta \ln(E_i^*/E_j^*) - \alpha \ln(c_i^*/c_j^*) - \beta \ln(l_i^*/l_j^*) - \kappa B^*)/(\kappa - \lambda(wE_j^* P_B + 1))$, *where* $E_i^* > E_j^*$, $c_j^* > c_i^*$ *and* $l_j^* > l_i^*$. *In addition, from envelop theorem* $V_B^j = (\kappa - \lambda^*(wE_j^* P_B + 1)) > 0$. *Since all the terms of the numerator, except the last, term are positive,* ρ *will be positive for low values of* κ, *hence* $B_d < F$.

Proposition A.4. *From the resource officer's expected utility function* (*i.e.*, Eq. (26)), *the first-order condition with respect to the bribe is*

$$\frac{\partial E(\Omega)}{\partial B} = m_B u^i + m(B) u_B^i - m_B u^j = 0 \quad (4A)$$

$$\frac{m_B}{m(B)}(u^i - u^j) = -u_B^i \quad (4B)$$

which is $\varepsilon(u^i - u^j) = -u_B^i B_s$, *where* $\varepsilon = (m_B/m(B))B$. *Assuming risk neutrality that* $u^i = \pi - B_s - z$, $u^j = \pi - F - z$ *and* $B_s = (\varepsilon/1 + \varepsilon)F$. *Therefore:*

$$\frac{\partial B_s}{\partial \varepsilon} = \frac{1}{(1+\varepsilon)^2} > 0 \text{ and } \frac{\partial B_s}{\partial F} = \left(\frac{\varepsilon}{1+\varepsilon}\right) > 0. \quad (4C)$$

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Paper 2

Bioeconomic model of spatial fishery management in developing countries*

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Abstract

Fishers in developing countries do not have the resources to acquire advanced technologies to exploit offshore fish stocks. As a result, the United Nations Convention on the Law of the Sea requires countries to sign partnership agreements with distant water fishing nations (DWFNs) to exploit offshore stocks. However, for migratory stocks, the offshore may serve as a natural marine reserve (i.e. a source) to the inshore (i.e. sink); hence these partnership agreements generate spatial externality. In this paper, we present a bioeconomic model in which a social planner uses a landing tax (ad valorem tax) to internalize this spatial externality. We found that the tax must reflect the biological connectivity between the two patches, intrinsic growth rate, the price of fish, cost per unit effort and social discount rate. The results are empirically illustrated using data on Ghana.

Keywords: *Spatial fishery management, ad valorem tax, exclusive economic zone, developing countries*

JEL Classification: N57, Q22, Q28, Q56, Q57

* Acknowledgement: The authors gratefully acknowledge financial support from the Swedish Agency for International Development Cooperation (Sida) to Environmental Economics Unit at the University of Gothenburg. We also acknowledge comments from Håkan Eggert, Jesper Stage and two anonymous reviewers. An earlier version was presented at the Fourth World Congress of Environmental and Resource Economists in Montreal, Canada and comments received from the audience are also appreciated.

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1. INTRODUCTION

Fisheries resources in many parts of the world are under threat of extinction due to high mortality rate and habitat destruction (FAO, 2004, 2009; Pauly et al., 1998). For example, a conservative estimation by Mullon et al. (2005) reveals that about 25% of the 1519 FAO world fisheries have collapsed over the last 50 years. With the expected increase in global temperature and human population, the future of wild fisheries remains uncertain and bleak.

Patterns have emerged in natural resource management due to biological differences in habitats, deliberate regulatory measures instituted to control access to these resources in different habitats, different management regimes, differences in harvesting technologies, among other factors. The differences in the abundance of fish stocks in habitats are important requirement for ecosystem resilience since a biomass collapse in one habitat could be revived by the inflow of biomass from an adjacent habitat. According to Elmqvist et al. (2003), response diversity is a crucial requirement for ecosystem resilience[1] and it is required to overcome the temporal and spatial variations in disturbances for continuous provision of ecosystem services and for reorganization. The management strategy that fails to recognize sub-stock diversity may as a consequence lead to overestimations of the stock levels, harvest potential, and subsequently to the collapse of fisheries resources (Sterner, 2007; Akpalu, 2009). Mills (1972) has also demonstrated that when spatial externalities are involved, resource allocation that does not consider the spatial externality will be inefficient.

Despite seemingly adequate fisheries management policies in developed countries compared to developing countries, overfishing has been more pronounced in developed countries where improved technologies e.g. radar tracking device, bottom trawling, acoustic fish finders are employed in fisheries. As indicated by Pauly et al. (2002), technological progress tends to increase the catchability coefficient and renders ineffective any attempt that seeks to control fishing mortality by limiting only effort. Modernization of fishing gears and vessels, better knowledge on the spatial and temporal pattern of fish distribution have contributed to the

[1] The response diversity refers to the differentials in responses to an environmental change among species that contribute to an ecosystem function.

depletion of fish stocks (Hilborn and Walters, 1992; Freon and Misund, 1999). Fisheries in developing countries are predominantly artisanal with simple technologies. The decline in global fish production from the introduction of new technologies enable many countries to view marine fisheries as a zero-sum game, a situation which paved way to intense competition among industrial countries for marine resources in developing countries (Iheduru, 1995).

The ratification of the United Nations Convention on the Law of the Sea in 1982 establishes rules governing the management of the oceans and marine resources. The convention also encourages partnership among countries for the management of marine resources. Typically, the convention stipulates that if a country cannot fully utilize the fisheries resources in its Exclusive Economic Zone (EEZ), the country must make this surplus available to fleet of other countries. Because of differences in fishing technologies, many developing countries have partnership agreements with developed countries to harvest the surplus marine fish stocks in the EEZ of the developing countries. However, access rights are restricted to areas (i.e. offshore) where artisanal fishers do not fish. Although the allocation of EEZ to coastal developing countries was potentially supposed to create significant wealth to improve the economies of such countries, paradoxically, the majority of such countries have drawn down their stocks and deepened poverty simultaneously (Hannesson, 2008; Atta-Mills et al., 2004; Adler and Sumaila, 2004). This could partly be due to the nature of appropriation agreement between the resource rich developing countries and the developed countries and inadequacy of policy instruments employed to regulate catch by the foreign fleets.

Different theoretical models have been developed to analyse the interactions between coastal developing countries and Distant Water Fishing Nations (DWFNs) in the management of fish stock in the former countries. For example, Clark and Munro (1987; 1991) and Munro (1994) provide a principal-agent analysis since coastal states do not exercise full control over the DWFNs. These studies focus on the terms and conditions of granting access but ignore the spatial interactions between offshore and inshore stocks. In addition, Bischi and Lamantia (2007) provide a discrete dynamic model to assess time evolution of fish stocks in an ecosystem (environment) that is divided into two adjacent zones with different fishing policies. The steady state stock levels and their stability properties are derived for the case where one of the patches is a protected area. Although these studies have addressed the strategic interactions involved in fisheries agreements between coastal states and DWFNs, they provide little policy measures that coastal states can use to better manage the marine resources and to regulate harvest in EEZs for optimum social welfare. Specifically, whereas the previous studies allude to the relevance of using the policy instruments such as tax to regulate offshore fishing in developing countries, the present study develops a spatial bio-economic model and derived an optimal landing tax for two policy objectives: to maintain the offshore stock at a reserve level or maximize the fishery manager's net benefit. The theoretical results have been empirically investigated using data on artisanal and semi-industrial fishing in Ghana. Our results indicate that to optimize economic rents, the social planner should impose a landing tax that should be increasing with intrinsic growth rate, the price of fish and the dispersion parameter but decreasing with the social discount rate and the cost per unit effort.

The remainder of the paper is organized as follows. Section 2 presents the theoretical model and derives some important results. The expression for the optimal tax is discussed in section 3. In section 4, we use data from Ghana to illustrate overfishing in both inshore and offshore fisheries and compute the value for the tax. The conclusion is presented in the last section, i.e., section 5.

2. THE MODEL

In the fishery under consideration, artisanal fishers use rudimentary technologies to catch fish inshore. We begin by presenting a basic framework for which the offshore serves as a *natural reserve* (i.e. a source). After the basic framework, which provides a benchmark, we extend the model to a situation where the social planner grants access right to fleets from DWFNs. We extend the model to further derive an expression for an optimal landing fee (tax) that regulates harvest offshore. Finally, we characterize and provide empirical illustration of the optimal tax using data from artisanal and semi-industrial fishing in Ghana.

The Basic Framework

Suppose that a given exclusive economic zone of a developing coastal country is subdivided into inshore and offshore. The domestic fishing fleets catch fishes from inshore whilst the offshore serves as a natural reserve. We assume that the social planner does not grant access rights to foreign fishing fleets and there are common species such as sardine, mackerel and tuna in both the inshore and offshore. Let x_i denote the biomass density of fish in patch i ($i = 1, 2$), where x_1 is the density inshore (patch 1) and x_2 is the density offshore (patch 2).[2] For analytical tractability, we assume the biomass growth function is logistics. Thus

$$f(x_i) = r_i x_i (1 - x_i);\ i = 1, 2, \tag{1}$$

where r_i is the intrinsic growth rate in patch i. Let the intrinsic growth rates in the two patched be equal, i.e. $r_1 = r_2 = r$. Furthermore, suppose the general cost function is

$$c_i = c(x_i) h_i;\ i = 1, 2 \tag{2}$$

where h_i is harvest in patch i, and the following partial derivatives hold: $c_{x_1} = \frac{\partial c(x_i)}{\partial x_i} < 0$, $c_{x_1 x_1} = \frac{\partial^2 c(x_i)}{\partial x_i^2} > 0$ and $\frac{\partial c_i}{\partial h_i} = c(x_i) > 0$. Let the specific cost per unit harvest be:

$$c_i(x_i) = \frac{\sigma_i}{x_i};\ i = 1, 2 \tag{3}$$

where $\sigma_i = \frac{c_i}{\alpha_i}$, c_i is cost per unit effort, and α_i is catchability coefficient in patch i. Following Tuck and Possingham (1994) and Sanchirico and Wilen (1999) we assume a sink-

[2] The description of all notations used in the manuscript is presented in Table A1 of Appendix 1.

source relationship between the two patches where the fish stock from deep oceans replenishes the inshore. Let the sink-source (inshore-offshore) relationship be

$$\begin{aligned} \dot{x}_1 &= f(x_1) - h_1 + dx_2 \\ \dot{x}_2 &= f(x_2) - h_2 - dx_2 \end{aligned} \tag{4}$$

where $\dot{x}_1$ represents the stock dynamics inshore, $\dot{x}_2$ is the stock dynamics offshore and dx_2 is the net migration of the stock from offshore to inshore[3]. The assumption of sink-source stems from environmental gradient in the ecosystems, which allows for specialization in the patches in terms of spawning and recruitment. Furthermore, the variability in environmental and biological factors, e.g. sea surface temperature (SST) in the Gulf of Guinea Large Marine Ecosystem that influence the abundance of planktons as well as stocks, generates this natural specialization (see e.g. Perry and Sumaila, 2007). Moreover, a coastward migratory pattern during the first half of the year is observed for round sardinella and other stocks (Brainerd, 1991). This evidence is supported by data on fishing in Ghana presented in section 4 of this paper.

In addition, if there is no human predation in patch 2 (i.e. $h_2 = 0$) the stock dynamics will be in steady state offshore (i.e. $\dot{x}_2 = 0$), so that equation (4) becomes

$$f(x_2) = dx_2 \tag{5}$$

Using $f(x_2) = rx_2(1 - x_2)$ we can re-write equation (5) as

$$x_2 = (r - d)r^{-1} \tag{6}$$

and the inshore stock dynamic equation becomes

[3] Some studies have assumed density-dependent dispersion between the offshore and inshore (see e.g. Bischi and Lamantia, 2007). However this has a serious weakness due to the implicit assumption that the stock distribution is uniform, and spawning takes place in each patch. Thus, since the environment or ecosystem is rarely uniform, the uniform distributions are rare in reality (King, 2007)

$$\dot{x}_1 = f(x_1) - h_1 + \theta \tag{7}$$

where $\theta = d(r-d)r^{-1}$. With harvest inshore, the social planner's instantaneous profit function is

$$\pi(h_1, x_1) = ph_1 - c(x_1)h_1 \tag{8}$$

where p is the price per unit measure, say kilograms, of fish. The instantaneous profit is the difference between total revenue from harvest (i.e. ph_1) and the total cost of harvest (i.e. $c(x_1)h_1$). In a dynamic setting, the social planner will maximize the discounted profit function over the planning horizon subject to the resource dynamics. The social planner's optimization program is:

$$\max_{h_1} \int_0^{\infty} \left(ph_1 - c(x_1)h_1 \right) e^{-\delta t} dt \tag{9}$$

subject to

$$\dot{x}_1 = f(x_1) - h_1 + \theta \tag{10}$$

$$0 \le h_1 \le h_{1\max} \tag{11}$$

where $\delta > 0$ is social discount rate. The corresponding current value Hamiltonian is:

$$H = ph_1 - c(x_1)h_1 + \lambda\left(f(x_1) - h_1 + \theta \right) \tag{12}$$

where $\lambda = \lambda(t)$ is a costate variable. This formulation will produce three possible solutions including the bang-bang solution. The possible solutions are:

$$h_1 = \begin{cases} 0 & \text{if} \quad \lambda(t) > p - c(x_1) \\ h_1^* & \text{if} \quad \lambda(t) = p - c(x_1) \\ h_{1\max} & \text{if} \quad \lambda(t) < p - c(x_1) \end{cases} \tag{13}$$

Assuming an interior solution exists (i.e. $h = h^*$), we have:

$$\frac{\partial H}{\partial h_1} = p - c\left(x_1\right) - \lambda = 0 \Rightarrow p - c\left(x_1\right) = \lambda \qquad (14)$$

Equation (14) implies that the net marginal benefit from harvest (i.e. $p - c\left(x_1\right)$) reflects the user cost of the stock[4]. The costate equation is:

$$\dot{\lambda} - \delta\lambda = c_{x_1} h_1 - \lambda f_{x_1} \qquad (15)$$

where $f_{x_1} = \frac{\partial f\left(x_1\right)}{\partial x_1}$. From equation (15), in dynamic equilibrium, the sum of the capital gain (i.e., $\dot{\lambda}$) and the stock effect (i.e. $-c_{x_1} h_1 + \lambda f_{x_1}$) resulting from preserving a unit of the stock must equate the marginal benefit of harvesting the unit of the stock now and putting the proceed in a bank. Following Sydsaeter et al. (2005), the corresponding transversality condition is

$$\lim_{t \to \infty} \lambda\left(t\right) e^{-\delta t} \left(x\left(t\right) - x^*\left(t\right)\right) \geq 0 \text{ for all admissible } x\left(t\right) \qquad (16)$$

where $x^*\left(t\right)$ is the value of the stock of fish that maximizes the value function (i.e. equation 9). This condition must hold for h^* and x^* to maximize the value function. Moreover, it is assumed that the maximize Hamiltonian is concave in x (i.e. the Arrow's weak sufficiency condition is satisfied). In the steady state $\dot{\lambda} = \dot{x} = 0$ so that equation (15) becomes

$$\lambda = \frac{-c_{x_1} h_1}{\left(\delta - f_{x_1}\right)} \qquad (17)$$

Using equation (17), we can rewrite equation (14) as

$$p - c\left(x_1\right) = \frac{-c_{x_1} h_1}{\left(\delta - f_{x_1}\right)} \qquad (18)$$

[4] Henceforth, we suppress the time argument to minimize clutter.

where $f_{x_1} = r(1-2x_1)$, $c_{x_1} = -\frac{\sigma_1}{x_1^2}$; and $h_1 = f(x_1)+\theta$ in steady state. Substituting these into equation (18) gives

$$p-\frac{\sigma_1}{x_1}=\frac{\sigma_1\left(f(.)+\theta\right)}{x_1^2\left(\delta-f_{x_1}\right)} \tag{19}$$

With $\theta > 0$, the current result (i.e. equation 18) provides a different trajectory for the fisheries resource management compared to the conventional result where $\theta = 0$. Thus, if there is no natural reserve (or source), the trajectory that generates the optimal stock is:

$$2prx_1^2+\left(\delta p-rp-r\sigma_1\right)x_1-\delta\sigma_1=0 \tag{20}$$

After substituting the specific functions, equation (18) can be restated as:

$$2rpx_1^{*2}+\left(\delta p-rp-r\sigma_1\right)x_1^*-\delta\sigma_1-\frac{\sigma_1\theta}{x_1^*}=0 \tag{21}$$

From equations (20) and (21), the stock levels with and without reserve will be equal if $\theta = 0$. But we know that $\theta = d\left(\frac{r-d}{r}\right)$ implying $r = d$ or $d = 0$ implies $\theta = 0$. Thus, the optimum stock levels with and without the natural reserve (source) are equal if $r = d$ or $d = 0$. Furthermore, the stock level with the reserve is higher (less) than without the reserve if $r > d$ ($r < d$). In addition, all else being equal, the optimum steady state stock in patch 1 is maximized at $d^* = \frac{1}{2}r$. This derives from equating a partial derivative of equation (20) with respect to the dispersion parameter to zero and solving for d (i.e. $\frac{\partial x_1^*}{\partial d} = 0$). The plot of the relationship between stock levels in patch 1 (x_1) at various levels of dispersion parameter is presented in figure 1. The parameter values conveniently chosen illustrate the relationship between the stock level and the dispersion parameter are $r = 0.05$, $\delta = 0.03$, $\sigma = 0.8$ and $p = 1$. The choice of the values are guided by the following assumptions: $r \geq \delta, d$ and $\sigma \leq p$.

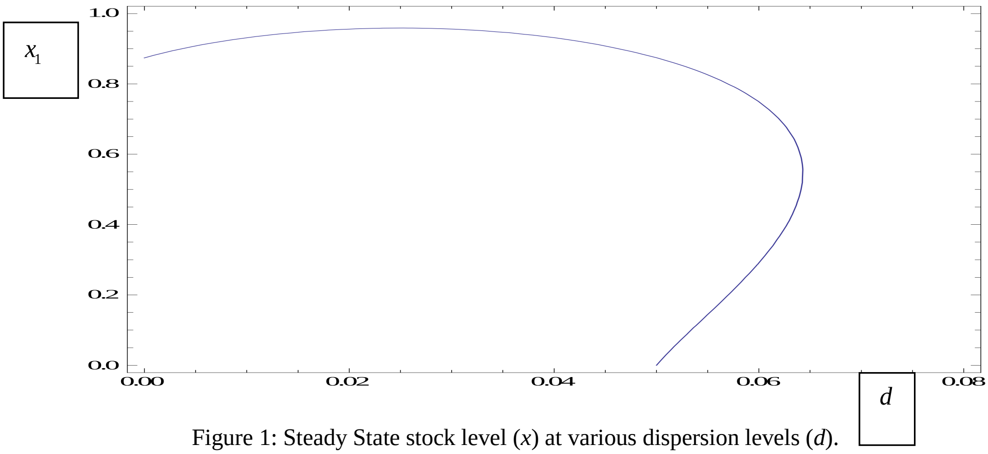

Figure 1: Steady State stock level (*x*) at various dispersion levels (*d*).

From Figure 1 above, it is clear the stock level in patch 1 increases, reaches a maximum, and decreases thereafter as the dispersion parameter increases. This underscores the fact that the stock level reaches a maximum at a certain level of dispersion. The maximum stock size is realized when $d = 0.025$. Furthermore we investigate the impact on the equilibrium stock of changes in the parameter values chosen. The simulated results are presented in Table 1.

Table 1: Comparison of conventional (i.e. $\theta = 0$) **and the new results** (i.e. $\theta > 0$)

r	δ	σ	p	d	x_{con}	x_{new}	$\frac{x_{con}}{x_{new}}$
0.05	0.03	0.8	1	0.025	0.874456	0.878161	0.995781
0.05	0.04	0.8	1	0.025	0.868466	0.873079	0.994716
0.07	0.03	0.8	1	0.025	0.880425	0.884037	0.995914
0.05	0.03	0.9	1	0.025	0.937883	0.941125	0.996555
0.05	0.03	0.8	1.2	0.025	0.78735	0.791129	0.995223
0.05	0.03	0.8	1	0.010	0.874456	0.876834	0.997288
0.05	0.03	0.8	1	0.00	0.874456	0.874456	1.0000

Results: *All else being equal, the optimum steady state stock size in the sink (patch 1) is decreasing in social discount rate (* δ *), the price of fish (* p *), and catchability coefficient but increasing in cost per unit harvest (* c_1 *) and intrinsic growth rate.*

The results obtained from the simulations have intuitive appeal. The positive relationship between discount rate and the stock level implies the more uncertain society is about the future, all other things being equal, the more likely it is to draw down the fish stock. Secondly, the higher the price the society receives by selling the fish caught, the lower the optimum stock in the management area. Thirdly, if the cost per unit effort increases or the catchability coefficient decreases, the optimum stock level in the management area will increase. Furthermore, a higher intrinsic growth rate will increase the stock within the management area.

Extended Model: Human Predation inshore and offshore

The Offshore Fisher's Problem

In this section, we present the model for a representative offshore fleet. Suppose the government of the coastal developing country (i.e. social planner) licenses fleets to fish offshore at an *ad-valorem* royalty tax (τ).[5] Many studies have also demonstrated that landing fees are superior to e.g. quotas especially in the presence of uncertainties (Weitzman, 2002; Jensen and Vestergaard, 2003; Hannesson and Kennedy, 2005). In addition, an ad valorem royalty tax is flexible enough for cases where there are temporary hikes in the price of fish. With the tax, the instantaneous profit is the difference between total revenue (i.e. $(1-\tau)ph_2$) and total cost of harvest (i.e. $c(x_2)h_2$). The profit function will be maximized subject to the resource dynamics offshore. The optimization program is

$$\max_{h_2} \int_0^{\infty} \left((1-\tau)ph_2 - c(x_2)h_2\right)e^{-\delta t}dt \tag{22}$$

subject to

$$\dot{x}_2 = g(x_2) - h_2 - dx_2 \tag{23}$$

The current value Hamiltonian is given as

$$H = (1-\tau)ph_2 - c(x_2)h_2 + \psi(t)\left(g(x_2) - h_2 - dx_2\right) \tag{24}$$

The maximum principle (i.e. $\partial H/\partial h_2$) generates the following possible solutions

$$h_2 = \begin{cases} 0 & \text{if} \quad \psi(t) > (1-\tau)p - c(x_2) \\ h_2^* & \text{if} \quad \psi(t) = (1-\tau)p - c(x_2) \\ h_{2\max} & \text{if} \quad \psi(t) < (1-\tau)p - c(x_2) \end{cases} \tag{25}$$

[5] An alternative is to use the quota to regulate the operations of the fleet from the DWFNs.

Assuming an interior solution exists, we have

$$\frac{\partial H}{\partial h_2} = (1-\tau)\,p - c(x_2) - \psi(t) = 0 \tag{26}$$

$$(1-\tau)\,p - c(x_2) = \psi(t) \tag{27}$$

The costate equation is

$$\dot{\psi}(t) - \delta\psi(t) = c_{x_2}(x_2)\,h_2 + \left(d - g_{x_2}(x_2)\right)\psi(t) \tag{28}$$

In addition we assume the following transversality condition holds

$$\lim_{t\to\infty} \psi(t)\,e^{-\delta t}\left(x(t) - x^*(t)\right) \geq 0 \tag{29}$$

Furthermore, in steady state we have $\dot{\psi} = 0$ and equation (28) becomes

$$\psi(t) = \frac{-c_{x_2}(x_2)\,h_2}{\delta + d - g_{x_2}(x_2)} \tag{30}$$

Substituting equation (30) into equation (27) we have

$$(1-\tau)\,p - c(x_2) = \frac{-c_{x_2}(x_2)\,h_2}{\delta + d - g_{x_2}(x_2)} \tag{31}$$

Using the specific functions, and $h_2 = g(x_2) - dx_2$ in steady state, we have

$$2rp(1-\tau)\,x_2^2 + \left(p(1-\tau)(\delta + d - r) - \sigma_2 r\right)x_2 - \sigma_2\delta = 0 \Rightarrow x_2^* = x_2(\tau) \tag{32}$$

Equation (32), is a quadratic function with two possible solutions but only one is admissible (i.e. $x_2^*(\tau) \geq 0$). The admissible solution is

$$x_2^*(\tau) = \frac{r\sigma_2 - p(d - r + \delta)(1-\tau) + \sqrt{(-r\sigma_2 + p(d - r + \delta)(1-\tau))^2 + 8pr\delta\sigma_2(1-\tau)}}{4pr(1-\tau)} \tag{33}$$

The comparative static analysis indicates a positive relationship between the tax rate and the equilibrium stock size (i.e. $\frac{dx_2}{d\tau} > 0$). The plot of the relationship between x_2^* and τ is presented in Figure 2.

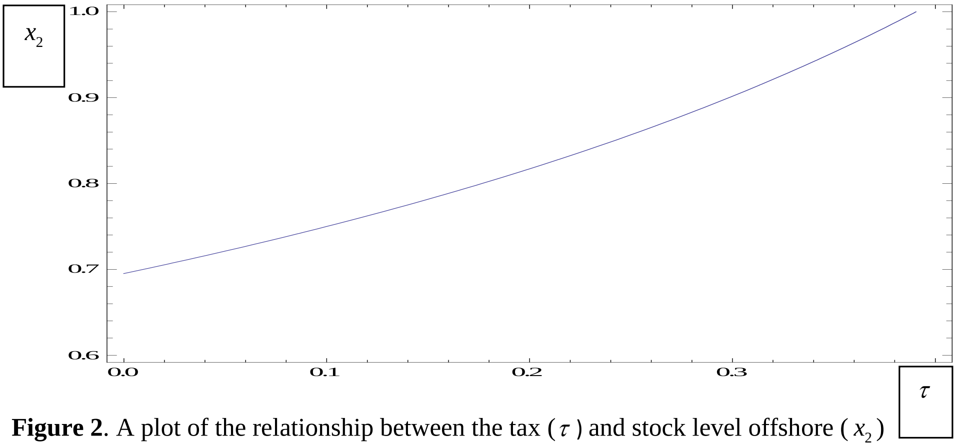

Figure 2. A plot of the relationship between the tax (τ) and stock level offshore (x_2)

An intuitive explanation of the relationship between the stock offshore and the tax rate is quite obvious: the offshore stock corresponding to a higher tax rate will be lower than that of a lower tax rate.

The social planner's problem

To account for the preceding extension, the instantaneous profit function is modified so that the social planner´s optimization program is:

$$\max_{\tau, h_1} \int_0^\infty \left(ph_1 - c\left(x_1\right) h_1 + \tau p h_2 \right) e^{-\delta t} dt \tag{34}$$

subject to equation (4), i.e.,

$$\dot{x}_1 = f(x_1) - h_1 + dx_2$$
$$\dot{x}_2 = f(x_2) - h_2 - dx_2 \tag{4}$$

Since the foreign fleet must at least break even after paying the tax, we impose an additional constraint, i.e. the isoperimetric constraint. This constraint guarantees that the discounted net revenue from commercial fisheries is non-negative over the entire planning horizon. The examples of applications of the isoperimetric constraints can be found in e.g. Caputo (1998, 1999); Dogerty and Posey (1997); and Akpalu and Parks (2007). The constraint is specified as:

$$\int_0^{\infty} \left[(1-\tau) p h_2 - c(x_2) h_2 \right] e^{-\delta t} dt \geq 0 \tag{35}$$

The current value Hamiltonian of the social planner's problem can be specified as:

$$H = ph_1 - c(x_1) h_1 + \tau p h_2 + \lambda \left(f(.) - h_1 + dx_2 \right) + \omega \left((1-\tau) p h_2 - c(x_2) h_2 \right) \tag{36}$$

The first order condition with respect to harvest inshore (i.e. $\partial H / \partial h_1$) is:

$$h_1 = \begin{cases} 0 & \text{if} \quad \lambda > p - c(x_1) \\ h_1^* & \text{if} \quad \lambda = p - c(x_1) \\ h_{1\max} & \text{if} \quad \lambda < p - c(x_1) \end{cases} \tag{37}$$

Also $\dfrac{\partial H}{\partial \tau} = 0$, which gives

$$p h_2 (1 - \omega) = 0 \Rightarrow \omega = 1 \tag{38}$$

Note that ω is not a user cost but a Lagrangian multiplier of the isoperimetric constraint. Since it takes a positive value, the isoperimetric constraint is binding. Assuming an interior solution exists for the harvest, the maximum principle can be restated as:

$$p - c(x_1) = \lambda \tag{39}$$

The costate equation is

$$\dot{\lambda} - \delta\lambda = -\frac{\partial H}{\partial x_1} = c_{x_1}\left(x_1\right)h_1 - \lambda f_{x_1}\left(x_1\right) \quad (40)$$

In steady state $\dot{\lambda} = \dot{x}_i = 0$ and equation (40) becomes

$$\lambda = \frac{-c_{x_1}\left(x_1\right)h_1}{\left(\delta - f_{x_1}\left(x_1\right)\right)} \quad (41)$$

Substituting equation (41), $f_{x_1}\left(x_1\right) = r - 2rx_1$; $c\left(x_1\right) = \frac{\sigma_1}{x_1}$ and $c_{x_1}\left(x_1\right) = -\frac{\sigma_1}{x_1^{\ 2}}$ into equation (39), gives

$$px_1 - \sigma_1 = \frac{\sigma_1 h_1}{x_1\left(\delta - r + 2rx_1\right)} \quad (42)$$

Furthermore, substituting $h_1 = f\left(x_1\right) + dx_2^*\left(\tau\right)$ into equation (42), gives

$$2prx_1^2 + \left(\delta p - rp - \sigma_1 r\right)x_1 - \delta\sigma_1 - \sigma_1 dx_1^{-1}x_2^*\left(\tau\right) = 0 \Rightarrow x_1^* = x_1\left(\tau\right) \quad (43)$$

However, due to the functional forms of some of the terms in the two equations, closed form solutions are difficult to obtain. Furthermore, from equation (33) we have shown the relationship between the stock in the sink and the tax rate is positive implying a relatively higher tax rate may results in a higher inshore optimum stock level, i.e.

$$\frac{dx_1^*}{d\tau} = \frac{\sigma_1 dx_1^{-1}\left(\frac{\partial x_2^*\left(\tau\right)}{\partial\tau}\right)}{4prx_1 + \left(\delta p - rp - \sigma_1 r\right) + \sigma_1 dx_1^{-2}x_2^*\left(\tau\right)} > 0, \text{ since } \left(\frac{\partial x_2^*\left(\tau\right)}{\partial\tau}\right) > 0$$

The relationship between inshore stock and the tax rate is plotted in Figure below:

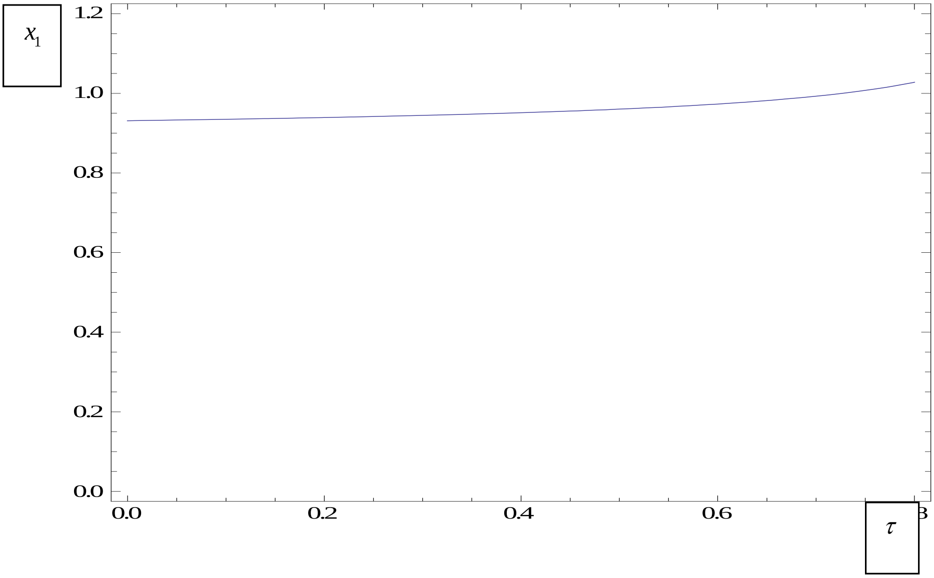

Figure 3. A plot of the relationship between the tax (τ) and stock level in inshore (x_1)

3. SEEKING AN EQUILIBRIUM ROYALTY TAX RATE

In this section, we present and characterize the expressions for equilibrium tax rate under two conditions: (1) if the social planner desires to keep the stock at the reserve level offshore, and (2) if the planner chooses the tax rate that maximizes net benefits.

Policy Options to Guarantee Natural Marine Reserve Offshore

The equilibrium tax that guarantees that the stock offshore is at its marine reserve level could be obtained by equating equation (6) to (33) and solving for τ . Thus

$$\frac{r\sigma_2 - p(d-r+\delta)(1-\tau) + \sqrt{(-r\sigma_2 + p(d-r+\delta)(1-\tau))^2 + 8pr\delta\sigma_2(1-\tau)}}{4pr(1-\tau)} = \frac{(r-d)}{r} \quad (44)$$

which gives

$$\tau^* = 1 - \frac{\sigma_2 r}{p(r-d)} \quad (45)$$

Using the parameter values of $r = 0.05$, $\delta = 0.03$, $\sigma_2 = 0.8$, $d = 0.001$ and $p = 1$, the equilibrium tax is $\tau^* = 0.184$. The following holds $\frac{\partial \tau^*}{\partial p} > 0$, $\frac{\partial \tau^*}{\partial \sigma_2} < 0$, $\frac{\partial \tau^*}{\partial d} < 0$ and $\frac{\partial \tau^*}{\partial r} > 0$. Intuitively, in order to keep the stock offshore at its marine reserve level, the tax rate must increase if the price of fish increases as this provides an incentive to the offshore fishers to catch more. Conversely, the tax must decrease if the cost of effort increases. Furthermore, if the dispersion of the stock from offshore to inshore increases, the tax rate should decrease in order to keep the stock at the reserve level. Finally, the tax rate must increase if the stock has a higher intrinsic growth rate implying that faster growing stocks must be taxed more.

Policy options for maximizing net benefits

To obtain the expression for the tax which maximizes total surplus of the fisheries manager, the two optimum stock expressions, i.e. $x_2^*(\tau)$ and $x_1^*(\tau)$ (i.e. equations 33 and 43, respectively), are equated and τ is solved for. However the parametric expression for the tax rate is complex. As a result, the two functions are graphed to obtain a point of intersection. Using the parameter values chosen for illustrative purposes only (i.e. $r = 0.05$, $\delta = 0.03$, $d = 0.001$, $\sigma = 0.8$ and $p = 1$), the estimated optimum tax rate of $\tau = 0.028$. Clearly, this tax rate is lower than what is required to keep the stock offshore at the reserve level. However, the lower tax rate generates a larger net benefit to the social planner. The interpretations of these are straightforward. A lower tax value increase catch offshore and generates lower stock level offshore but brings in higher instantaneous profit margin to the social planner. Conversely, as expected, the higher tax rate although increases the stocks offshore and inshore, it lowers the profit of the social planner.

Further sensitivity analysis presented in Table 2 reveals the tax is increasing in the price of fish and the dispersion parameter but decreasing in intrinsic growth of the stock, social discount rate and the cost of harvest.

Table 2: Sensitivity analysis of the tax

r	δ	$\sigma = \beta$	p	d	τ
0.05	0.03	0.8	1	0.001	0.028
0.06	0.03	0.8	1	0.001	0.025
0.05	0.04	0.8	1	0.001	0.024
0.05	0.03	0.9	1	0.001	0.026
0.05	0.03	0.8	1.2	0.001	0.030
0.05	0.03	0.8	1	0.002	0.054

4. EMPIRICAL ILLUSTRATION OF A SINK-SOURCE DISPERSION:

The case of offshore-inshore stocks in Ghana

To provide an empirical illustration of the sink-source dispersion that drives our theoretical results and also calculate the optimal royalty tax, we investigate the offshore-inshore fishing in Ghana. The West African coastal countries, including Ghana, are facing declining catches of wild fish stocks due to over-capitalization and habitat degradation. In addition, numerous reports attribute the declining catches of inshore fishers to intensive catches by large and extensive European Union fleet who fish offshore (Atta-Mills et al., 2004). In Ghana, the EEZ is divided into Inshore Exclusive Zone (IEZ) and Offshore Exclusive Zone. According to Fisheries Act, 2002 Act 625, exclusively small semi-industrial vessel (SIV), canoes and recreational fishing vessels shall use the IEZ whilst large semi-industrial vessel, or industrial vessel and canoe support vessel could only strictly fish in the Offshore Exclusive Zone. This is not peculiar to

Ghana as fisheries are often zoned such that each region adopts different sets of harvesting policies (Bischi and Lamantia, 2007). For numerical illustration, we use commercial species: mackerel and round and flat sardinella in the exclusive economic zone of Ghana.

Recent landing statistics for the artisanal fleet indicate that landings peaked in 1992, and then declined, due to overexploitation (Koranteng, 1998). In addition, the catch per unit effort of the semi-industrial fleet has generally declined throughout the period, a clear indication of overfishing. The descriptive statistics of the data is provided in Table A2 in the Appendix. From the descriptive statistics, the mean catch values for the three species are higher for artisanal fishers compared to the inshore fishers.

To investigate whether the stock of three major species (i.e. mackerel, round sardinella and flat sardinella) fished inshore and offshore are connected (i.e. the species are migratory), we perfomed a granger causality test on the harvest of each species. The results, which are reported in Table A3 in Appendix 2 indicates a unidirectional line of causality from offshore to inshore for the flat and round sardinela but bidirectional line of causality for mackerel in the two fisheries. This implies that the harvest of each of the species offshore could predict the harvest inshore. Invariably, these results confirm that the species are migratory and policies that address overfishing offshore could potentially affect the stock and harvest inshore.

An estimate of equilibrium tax rate for Ghana

To obtain an estimate for the royal tax rate that guarantees the stock offshore is at the reserve level, and the tax the maximizes net revenue within the management area in Ghana, we adapted figures from the literature. First, concerning the catch per unit effort and average revenue from catch, we used figures based on artisanal fishing in Ghana from Brinson et al. (2009). The median running cost and revenue per vessel (assuming that a vessel fishes 22 days in a month), which are used as proxies for CPUE and average revenue or price are $95.88US and $264.36US respectively. The intrinsic growth rate for sardines, which is one of the most commonly harvest stock in Ghana, adapted from FAO(2001) is 0.63. Furthermore, we used a social discount rate of 3 percent. We could not obtain a specific value for the dispersion parameter for the sardines so we used $d = 0.02$. The tax rate is calculated using these numbers and sentivity analysis is performed to illustrate how the tax rate could change in response to changes in some of the parameter values.

Based on these preceding values, the royalty tax that preserves the stock at the reserve level (i.e. combining equations 6 and 33) is $\tau = 0.62$ and the corresponding figures that maximises net benefit of the social planner (combining equations 33 and 43) is $\tau = 0.112$. From the two figures, the tax rate that maximizes net benefit is lower than the rate that mentains the stock offshore at the reserve level. Thus, if the objective of the social planner in Ghana is to maximise net benefit from harvest, the semi industrial fleets could be charged an approximate landing tax of 11.2% to internalize the spatial catch externality. The results from the sentivity analysis of our estimate are reported in Table 3.

Table 3. Ghana landing tax sensitivity

r	δ	$\sigma = \beta$	p	d	τ
0.63	0.03	0.123682	0.341024	0.02	0.112
0.70	0.03	0.123682	0.341024	0.02	0.102
0.63	0.04	0.123682	0.341024	0.02	0.110
0.63	0.03	0.123682	0.386479	0.02	0.121
0.63	0.03	0.169136	0.341024	0.02	0.091
0.63	0.03	0.123682	0.341024	0.03	0.158

Note: Price and cost per unit harvest are in $10,000US.

From Table 3, the optimal tax is increasing in the price of fish and dispersion parameter but decreasing in intrinsic growth rate, social discount rate, and the cost per unit harvest. The direction of relationships between the tax rate and the changes in the parameter values are consistent with what was obtained from the simulations that were based on the parameter values chosen conveniently.

In Ghana, foreign fleets are charged lincensing fees as well as fees to acquire fishing rights, which is a one time payment for a period of time[6]. The licensing fees have been raised over time from 0.05 percent mean value of catch in 1995, to 0.6 percent in 1996 and to 1 percent in 1997. Beginning 2003, vessel licensing fees have been tied to size of the vessel and the types of species of fish landed. Thus, trawlers up to 300 Gross Registered Tonnage (GRT) pay US$30 per GRT per annum, whilst, those in excess of 300 GRT pay US$55 for every GRT in excess of the recommended 300 GRT (Hutchful, 2008). Compared to our estimate, the fee is very low and unlikely to generate the optimum rent from the fishery.

5. CONCLUSIONS

Many coastal developing countries lack the fishing technology to fully utilize the EEZ allocated under the United Nations Convention on the Law of the Sea. As a result, these countries enter into agreements with Distant Water Fishing Nations (DWFNs) to maximize rents from wild fish catches. Although short term rents from taxes on offshore catches are crucial for such poor countries, long-term stream of overall economic rents could easily be jeopardized since most stocks are generally migratory and given that the offshore serves as a natural reserve (evidence from the fishery in Ghana has been provided in support of this). In addition, the natural reserve offshore improves the resilience of the exclusive economic zone. In this paper, we have provided a theoretical model to shed light on the problem and developed optimum policy instruments that these countries could employ to maximize overall rents for catches in the EEZ.

We found that coastal developing countries could use ad valorem royalty tax to regulate catch offshore and maximize overall economic benefit. The royalties should reflect the ecology of the marine ecosystem as well as relevant socio-economic characteristics. Thus, the royalty should reflect the stock externality of harvesting offshore, dispersion or connectivity between the two subdivisions, the intrinsic growth of the fisheries, catchability coefficient of species, the discount rate of the society and the price of the fishes. In effect, these countries should balance the opportunity costs of the access rights against the benefits from granting access rights.

[6] As at 2003, a company is supposed to pay an application and processing fees of US$500 and US$010 000, respectively.

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APPENDIX 1: TABLES

Table A1: Description of Variables and Parameters

Variables	**Description**
x_1	Biomass in patch 1 (i.e. for artisanal fisheries zone)
x_2	Biomass in patch 2 (i.e. for commercial fisheries zone)
c_1	Cost per unit effort in patch 1
c_2	Cost per unit effort in patch 2
α_1	Catchability coefficient in patch 1 or in artisanal fisheries
α_2	Catchability coefficient in patch 2 or in commercial fisheries
δ	Generic discount rate or social planner's discount rate
σ_1, σ_2	Normalized cost per unit effort by catchability coefficient

Table A2: Descriptive statistics of Canoe and Semi-industrial Catch in Ghana (1971 – 2007)

Species	Type of Vessel	Observations	Mean Catch (tons)	Standard Deviation
Round Sardinella	Canoe	37	48909.14	30522.04
	Semi-industrial	37	3360.765	2119.29
Flat Sardinella	Canoe	36	13924.23	4939.27
	Semi-industrial	36	702.4642	665.2124
Chub Mackerel	Canoe	37	4454.018	5153.297
	Semi-industrial	36	931.6838	894.7166

Table A3: **Granger causality between canoe and semi-industrial catch of three species**

Fisheries	**Equation**	**Fisheries**	**Excluded**	**Chi Square**
Canoe	Round sardinella	Semi-industrial	Round sardinella	14.319**
	Round sardinella		ALL	14.319**
Semi-industrial	Round sardinella	Canoe	Round sardinella	3.6743
	Round sardinella		ALL	3.6743
Canoe	Flat sardinella	Semi-industrial	Flat sardinella	34.669***
	Flat sardinella		ALL	34.669***
Semi-industrial	Flat sardinella	Canoe	Flat sardinella	0.36298
	Flat sardinella		ALL	0.36298
Canoe	Chub mackerel	Semi-industrial	Chub mackerel	22.682***
	Chub mackerel		ALL	22.682***
Semi-industrial	Chub mackerel	Canoe	Chub mackerel	26.495***
	Chub mackerel		ALL	26.495****

* Significant at 10%, ** Significant at 5% and *** Significant at 1%.

Paper 3

What do respondents bring into contingent valuation? A comparison of monetary and labour payment vehicles

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Abstract

In the Contingent Valuation Method (CVM), both the goods being valued and the payment vehicles used to value them are mostly hypothetical. However, although numerous studies have examined the impact of experience with the good on the willingness to pay, less attention has been given to experience with the payment vehicles. This paper examines how experience with payment vehicles influences responses to a CV scenario on the maintenance of irrigation canals. Specifically, the paper uses a split-sample survey to investigate the effects of experience with monetary and labour payment vehicles on the acceptance of a CV scenario and protest bids. Using convergent validity tests, we found that experience acquired from using both monetary and labour payment vehicles reduces the asymmetries in acceptance rates. These findings suggest that experience with payment vehicles reduces time/money response asymmetries in the CVM.

Keywords: *contingent valuation, payment vehicles, numéraires, experience*

JEL Classification: Q51, Q56

[1]The author gratefully acknowledges financial support from the Swedish International Development Cooperation Agency (Sida) to the Environmental Economics Unit at the University of Gothenburg. Comments from Fredrik Carlsson, Håkan Eggert, Jesper Stage, Ståle Navrud and Gunnar Köhlin are also acknowledged.

1.0: Introduction

A recurrent finding from contingent valuation (CV) studies in developing countries is that respondents are more likely to state a positive willingness to pay (WTP) and a higher mean WTP when the valuation is based on a labour payment vehicle rather than a monetary payment vehicle (see Swallow and Woudyalew, 1994; Echessah et al., 1997; Hung et al., 2007). The relatively higher acceptance rates for non-monetary payment numéraires have also been observed in revealed preferences (Lee et al., 1999) and in experimental settings (Ellingsen and Johannesson, 2009). These variations in responses to CV surveys hinder pooling of CV data (Layton and Lee, 2006), and according to Diamond and Hausman (1994), also question the credibility of the CVM. Meanwhile, the attitude–behaviour models (Fishbein and Ajzen, 1975; Ajzen, 1991) and the Discovered Preference Hypothesis (Plott, 1996), postulate that decision bias is reduced in repeated and familiar choice environments. Therefore, the time/money response asymmetry should decrease with experience and in familiar decision-making environments. The purpose of the present paper is to investigate the effects of experience with monetary and labour payment vehicles on the acceptance of CV scenarios and protest bids.

In the Contingent Valuation Method (CVM), both the environmental goods/scenarios and payment vehicles are hypothetical. The hypothetical framing in CV studies creates discrepancies between actual and stated preferences (see e.g. Neill et al., 1994; Loomis et al., 1996; List, 2001). This hypothetical bias remains a concern to the design and conduct of CV surveys and the use of the CV in public policy. However, a number of theories suggest that respondents with experience provide more valid WTP responses in stated preferences (see e.g. Plott, 1996; Bjornstad et al., 1997; Kahneman and Sugden, 2005). According to Plott (1996), repeated decisions about WTP choices and feedback on the consequences of these decisions promotes institutional and value learning, i.e. discovering the features of one's own preferences. Thus, when respondents face new decisions, they may experience uncertainties which introduce a systematic bias. However, when these decisions are repeated, the uncertainties and consequent systematic biases are reduced. The attitude-behaviour models of Fishbein and Ajzen (1975) and Ajzen (1991) arrive at similar conclusions. Furthermore, studies show that market experience attenuates hypothetical bias and reduces the WTA-WTP discrepancy in the CVM (List, 2003). Therefore, familiarity with the decision-making environment addresses a number of anomalous behaviours.

Both experimental and non-experimental literature have analyzed how experience of environmental goods affects preferences for them (e.g. Whitehead et al., 1995; Cameron and Englin, 1997; Turpie, 2003; Kniivila, 2006; Carlsson and Martinsson, 2008). These studies conclude that the welfare values for goods with which respondents have experience differ from the welfare values for goods with which they have no experience. However, although much attention has been given to the issue of how experience with the good being valued affects the respondent's WTP, considerably less attention has been given to the issue of whether experience with the payment vehicle matters in the CVM.

Payment vehicles play a crucial role in CV studies. Such vehicles provide a context for the payment, and their credibility has a major influence on convincing the respondents of the genuineness or frivolity of the survey. For this reason, most recommendations for the design and conduct of CV surveys postulate payment vehicles that are realistic and neutral (see e.g. Mitchell and Carson, 1989; Arrow et al., 1993). As a result, a number of empirical studies assess the effect of payment vehicles on the WTP. For instance, Bergstrom et al. (2004) compare mean WTP for water quality protection in the United States (US) under tax reallocation and special tax, and find that mean WTP under tax reallocation is higher than mean WTP under special tax. Wiser (2007) compares mandatory with voluntary payment vehicles used for valuing renewable energy among US households. Wiser finds higher mean WTP under mandatory payment mechanisms than under their voluntary equivalents. In a related study, Ivehammar (2009) compares using a local tax as a payment vehicle with three other payment vehicles in the valuation of environmental externalities (so-called environmental encroachment) in road transportation in Sweden. She concludes, among other things, that payment vehicles influence the mean WTP. Using an open-ended CVM, Bateman et al. (1995) compare proportions of zero WTP bids under general donations, donations to a specific fund, and direct taxation. In the latter study, significant differences in the proportions of zero bids were observed among the three donation mechanisms. Thus, there is overwhelming evidence that the choice of payment vehicle influences both the level of WTP and the acceptance rates of a scenario. However, whether experience with the payment vehicle may itself have an impact remains to be investigated.

Different numéraires have been adopted in the elicitation of preferences in the CVM. The monetary numéraire, whereby the WTP for goods is stated in monetary units, is the most common for eliciting WTP. However, an increasing number of CV studies in developing countries have adopted non-monetary numéraires. Shyamsundar and Kramer (1996) adopt rice as the numéraire to estimate losses to rural households from tropical forest protection in Madagascar due to a limited cash economy among the respondents. Also, the respondents in a study may be more familiar with non-monetary numéraires in mobilising resources for the provision of local public goods. For instance, it is common for common pool resource users to mobilise labour and/or money to support natural resource management. For this reason, Swallow and Woudyalew (1994) and Echessah et al. (1997) adopt money and labour to value tsetse fly control in Kenya and Ethiopia, respectively. Similarly, Hung et al. (2007) elicit WTP values for forest fire prevention using labour and money in Vietnam. Results from these studies indicate that a labour numéraire is associated with higher acceptance among respondents in comparison with a monetary numéraire. Moreover, using the average wage rate of a casual worker, Echessah et al. (1997) found that the mean WTP is higher under the labour payment vehicle than under the monetary payment vehicle. Eom and Larson (2006) argue that, theoretically, when choices are constrained by both time and money, welfare values can be elicited using either numéraire. In addition to the theoretical model, these authors suggest that the higher acceptance rates and higher mean WTP for labour could be linked to a low valuation of time and hypothetical bias.

Two broad explanations can be found for the higher acceptance rates under non-monetary payment vehicles in the CVM. The first holds that market imperfections may restrict the substitution among different endowments. For instance, liquidity constraints could compel respondents to adopt non-monetary payment vehicles rather than their monetary counterparts. The second explanation, the Discovered Preference Hypothesis, suggests decay in decision biases in repeated-choice environments (see Braga and Starmer, 2005). Therefore, in repeated-choice environments, the money/time asymmetry tends to disappear in the CVM. Hung et al. (2007) argue that the acceptability of payment in workdays in the CVM may be due to prior use of such payments, and, thus, offers a much more realistic payment vehicle. This has been the basis for adopting labour numéraires to elicit preferences in the CVM in developing countries (see Swallow and Woudyalew, 1994; Echessah et al., 1997). While market imperfections may imply different mean WTP values depending on payment vehicles, increased familiarity with the payment vehicles should reduce these differences according to the second explanation.

In this study, we evaluate the effects of experience with monetary and labour payment vehicles on responses to a CV scenario by comparing acceptance rates and protest bids of two sub-samples. Respondents in one of the two sub-samples have experience with both monetary and labour payment vehicles, while respondents in the other sub-sample have been using only the labour payment vehicle to mobilize resources to maintain common irrigation canals.

The paper is structured as follows: the next section describes the study area and how resources are mobilised to maintain the irrigation canals. The third section provides the analytical framework of the study and explains the CV scenario as well as the sampling method. The fourth section presents the results from the study, while the conclusions are provided in the final section.

2.0 Afife Irrigation Project in Ghana

The 2008 World Development Report notes that the irrigation infrastructure in sub-Saharan African countries is inadequate. Only about 4% of total land in the region is irrigated (World Bank, 2007). In addition, the existing infrastructure is poorly maintained – further reducing the actual percentage of land irrigated. Evidence of poor maintenance of irrigation dams and canals is manifest in eroded dam walls, inoperative spillways, and siltation. The World Bank (2007) also notes that the operation and maintenance of public irrigation systems remain a problem in many developing countries. Public irrigation systems suffer from chronic underinvestment in maintenance. Even in countries where farmers are charged with operation and maintenance costs, persistently low collection of irrigation fees is a common problem due to the high incidence of non-compliance. Thus, improved management of the inadequate irrigation canals in sub-Saharan African countries is imperative.

Devolution is a common mandate for managing common pool resources; and devolution policies require resource users to make monetary and non-monetary sacrifices to support participatory resource management. The devolution of resource management in Ghana has been an integral part of decentralizing governance, according to the Ghanaian Government's Structural Adjustment Programme and its Ministry of Food and Agriculture's Accelerated Agricultural Growth and Development Strategy, since the 1980s (Ofori, 2000). In the early 1990s, the Government introduced Participatory Irrigation Management programmes. These decentralization programmes have transferred responsibility for the maintenance of irrigation canals from the central government to local governments and farmers.

Among the many projects promoting irrigation farming in Ghana is the Afife Irrigation Project. With technical assistance from China, a dam was constructed in 1983 to irrigate more than 1,000 hectares of plots for rice production. It operates gravity-type irrigation and, therefore, relies on the canals supplying irrigation water being maintained. The plots are divided into 11 sections, with each section measuring about 100 hectares, and were allocated to about 2,000 peasant households. Currently, the project falls under the Ghana Irrigation Development Authority.

When the project began in 1983, the Ghanaian Government was responsible for maintaining the canals, and it employed workers to do so. At that time, the canals were properly maintained. However, after 1990, these responsibilities were transferred to the farmers themselves. Farmers mobilised labour to maintain the canals. However, many reports have indicated that the canals have not been properly maintained under the new management regime; this lack of maintenance is reflected in increased siltation in the canals. Under the current management, which started around 1997–2000, farmers in sections 1 to 8 switched to contributing money for the maintenance of the canals. They contribute about 3 Ghana Cedi (GHS) or output equivalents per hectare per season to finance the canals' maintenance. This was equivalent to about 2 US dollars at the time of the survey in 2009. However, farmers in sections 9 to 11 continue to mobilise time of about 3 hours per season to maintain the canals. According to the extension officers, each section has its own leaders who decide what methods to employ to mobilise resources for the canals' maintenance. The decision to adopt monetary or labour contributions to finance canal maintenance in a specific section largely reflects the preferences of the section leader.

3.0: Methodology, Data and Models

3.1: Theoretical Model

Two different comparisons were made in the present study, i.e. between monetary and non-monetary payment vehicles, and between experience and no experience with a certain payment vehicle. These comparisons were made for a CV scenario for the mobilisation of resources among users of a common resource pool. The welfare estimates for the change in environmental goods (i.e. maintenance of the irrigation canals) are elicited in both monetary and non-monetary (i.e. labour) payment vehicles. The welfare estimate for the improvement of the quality of irrigation canals when the monetary payment vehicle is used is –

$$V_m\left(y - WTP_m, \mathbf{p}, q_1; Z\right) = V_m\left(y, \mathbf{p}, q_0; Z\right) \tag{1}$$

where $V_m\left(\bullet\right)$ is the indirect utility function, y is the income, q_0 is the existing quality of the irrigation canals, q_1 is the improved quality of the irrigation canals and $q_1 > q_0$, WTP_m is the willingness to pay for the improvement in irrigation canals elicited in monetary units, $\mathbf{p}$ is the vector of prices, and Z denotes socio-economic variables.

Similarly, labour time can be mobilised to provide for change in the environmental quality. Since time is an economic resource, the value of environmental change can be expressed in terms of the value of time. Following the theoretical model devised by Eom and Larson (2006), we can derive WTP for maintenance of the irrigation facility using labour as the numéraire (WTP_l), as follows:

$$V_l\left(l^f - WTP_l, \mathbf{p^f}, q_1; Z\right) = V_l\left(l^f, \mathbf{p^f}, q_0; Z\right) \tag{2}$$

where $V_l\left(\bullet\right)$ is the indirect utility function, WTP_l is the willingness to pay for the improvement in the irrigation facility elicited in labour units, l^f is the full budget, $\mathbf{p^f}$ is the vector of full prices, q_0 is the existing quality of the irrigation canals, q_1 is the improved quality of the irrigation infrastructure and $q_1 > q_0$, and Z denotes socio-economic variables. The notion of full budget (or price) combines income (or price) and time endowments. Note that the full budget and full prices can be stated in either monetary or non-monetary units (see Eom and Larson, 2006). In this case, the full budget and full prices are stated in labour units.

The extensive adoption of labour to provide common pool resources in developing countries has permitted the conduct of CV studies using labour as the payment vehicle. These studies include those done by Swallow and Woudyalew (1994) and Echessah et al. (1997) to value tsetse control in Ethiopia and Kenya, respectively, and Hung et al. (2007) for fire prevention in Vietnam. These studies also compare the responses under labour and monetary payment vehicles. The findings indicate that the acceptance rates are higher under labour payment vehicles than under their monetary payment counterparts. Echessah et al. (1997) also compare mean WTP under the two payment vehicles. Their conclusions indicate that mean WTP is higher under the labour than the monetary payment vehicle. However, the effects of the choice of payment vehicles on protest bids were not presented in these studies.

In the context of the CVM, a number of theories can explain behaviour or response. The Discovered Preference Hypothesis suggests changes in responses to WTP questions. According to Plott (1996), rational choices go through three stages, with decreasing levels of error in the decision-making. In Stage 1, where experience is completely absent in the choice environment, responses are impulsive and make little sense. However, Stages 2 and 3 involve repeated choices and, as a result, incorporate awareness and experience. Choices in Stages 2 and 3 approach rational ones. Therefore, there is institutional and value learning in choices (Braga and Starmer, 2005). Whereas *institutional learning* enables one to learn how to avoid errors, *value learning* offers an agent the environment to learn about one's preferences.

Similarly, attitude-behaviour models in the social psychology of Fishbein and Ajzen (1975) and Ajzen (1991) offer explanations on the motives behind planned behaviour; and Spash et al. (2009) relate these attitude-behaviour models to responses in the CVM. For instance, Fishbein and Ajzen (1975) discuss how correspondence, proximity and familiarity criteria influence the degree of association between attitudes or intentions and behaviour. The greater the correspondence between attitude and intention, the closer the behaviour will be to the intention. Also, the proximity criterion concludes that, if the intervening stages between a component in a model and behavior are few, then the predictive power of that component should be higher. Finally, the familiarity condition states that, the more familiar an agent is with a specific behaviour, the greater the predictive power of the agent's attitude in respect of his/her behaviour. A number of studies use the CVM to investigate how experience and access to more information affects WTP. Some of these studies conclude that experience with the goods or giving respondents more information about the goods increases the mean WTP (e.g. Whitehead et al., 1995; Cameron and Englin, 1997; Turpie, 2003; Kniivila, 2006; Carlsson and Martinsson, 2008); and giving respondents time to think about the CV scenario enables them to submit lower bids for the scenarios offered (Whittington et al., 1992). The conclusions of these studies indicate that provision of information and time and having previous experience with the good matters in CVM.

Market imperfections affect both the probability of accepting a CV scenario and the value of the WTP. Under market imperfections, one resource endowment cannot easily be converted into another, and different payment vehicles will exhibit different probabilities of accepting the CV scenario and will lead to different WTP values. The market imperfections argument will indicate that the results from the conduct of CV will depend on the resource endowment – and, for that matter, the payment vehicle. Different payment vehicles could provide a different total WTP for environmental goods. In terms of devolution policies, this will also imply that different methods of involving resource users will yield different outcomes.

In our context, the respondents have varying degrees of experience with two payment vehicles, namely monetary and labour; the CV scenario itself is fairly tangible; the study area is well served by transport and market networks; and credit constraints are limited and fairly uniform in the study area. These permit us to isolate the effects of experience from other effects.

3.2: Estimation Strategy

The principal method used in this study is to compare the two sub-samples in terms of the convergence of the responses to the CV scenario under the two payment vehicles. Thus, we perform convergent validity tests on acceptance rates and protest bids between monetary and labour payment vehicles. This is performed for the respondents who have experience with both payment vehicles, and for those who used the labour payment vehicle only. The convergent validity approach can be adopted only when measurements of phenomena are available using two different techniques (Carson et al., 2001).

In addition to the convergent validity tests, we estimated bid curves. Bid curves provide a statistical relationship between WTP and a set of independent variables; and for the open-ended CVM, bid curves can be estimated for several reasons (Alvarez-Farizo et al., 1999). One reason is theoretical validity in which the expected signs of the independent variables are compared with *a priori* expectations. The statistical relationships can also be estimated as a test of discriminant validity, i.e. whether or not a statistical relationship that is explained by variations in the independent variables exists. Bid curves could also be used for value transfers, whereby the estimates estimated for a study are used in a different context.

The econometric model presented in this section follows Tobin (1958). The linear regression model for the bid function is specified as –

$$y_{ij} = \mathbf{x\beta} + \varepsilon_i; \qquad j = l, m \tag{3}$$

where $y_i = WTP_i$ represents the *i*:th respondent's willingness to pay for improved maintenance of irrigation canals, $\mathbf{x}_i$ is a vector of independent variables, $\boldsymbol{\beta}$ is the vector of parameters to be estimated and ε_i is error term. The subscript j denotes the payment vehicle used in the preference elicitation, with l indicating that WTP was elicited under the labour payment vehicle, and m indicating its elicitation under the monetary payment vehicle.

For a sample of N independent observations, the censored Maximum Likelihood Estimator (MLE) maximises the log-likelihood function for censoring from below (see Cameron and Trivedi, 2005):

$$\ln L(\boldsymbol{\theta}) = \sum_{i=1}^{N} \left(d_i \ln f\left(y_i \mid \mathbf{x_i}, \boldsymbol{\theta}\right) + \left(1 - d_i\right) \ln F\left(L_i \mid \mathbf{x_i}, \boldsymbol{\theta}\right) \right) \tag{4}$$

where $\boldsymbol{\theta}$ are the parameters of the distribution of y_i, d_i is an indicator variable which assumes the value of 1 if $y_i > 0$, and is 0 if $y_i = 0$. Note that, in this instance, the lower bound is zero $(\text{i.e. } L = 0)$. The $f(\bullet)$ is the conditional probability density function, while $F(\bullet)$ is the cumulative density function. Depending on the correct specification of $f^*\left(y_i \mid \mathbf{x_i}, \boldsymbol{\theta}\right)$, the censored MLE is consistent and asymptotically normal (Cameron and Trivedi, 2005). We follow the existing studies with regard to the specification of $f^*\left(y_i \mid \mathbf{x_i}, \boldsymbol{\theta}\right)$. We select the independent variables based on previous studies, e.g. Swallow and Woudyalew (1994); Echessah et al. (1997); Köhlin and Amacher (2005); Hung et al. (2007), and Barton and Bergland (2010).

3.3: Data

The present study conducts a CV study among farmers at the Afife Irrigation Project in Ghana where monetary and labour payment vehicles are being used to maintain irrigation canals. Within the present set-up, some of the farmers currently contribute labour towards maintaining the canal, while the others contribute money or its output equivalence. Those farmers who are currently using money had once used labour, but had later switched to money/output instead. Thus, a farmer participates in only one scheme for maintaining irrigation canals. In a 2x2 factorial design, the study compares monetary and labour payment vehicles among sub-samples which have used these two payment vehicles and those who have used only labour. Therefore, labour and monetary payment vehicles were employed to value the maintenance of irrigation canals among the respondents who currently pay in labour, and those who once used labour but have now transferred to money as a payment vehicle. Within this framework, we will be able to compare the acceptance rates and protest bids under the two payment vehicles between the two sub-samples.

To value the preferences for the maintenance of the irrigation canals, we propose to restore the quality and maintenance of irrigation canals to the level that existed until 1990, when the Ghanaian Government provided resources for such maintenance.

More than 40% of the farmers in the sample have been farming since 1990. The canal conveys water from the dam into lateral and sub-lateral channels, and this enables rice farmers to gain access to the water for their plots. The change proposed in the scenario requires farmers to contribute labour or money to maintain the canals. The change also aimed to ensure compliance with rules and regulations designed by farmers for maintaining the canals. The change will also be sufficient to halt the degradation of the canals and restore their quality to the level enjoyed when the Government employed workers to maintain the irrigation system. This scenario is unique in the sense that the respondents have good practical knowledge of the CV scenario. That is, the good valued in the study is clear and practical and the respondents know the quality they can expect under a more effective canal management system.

The data for the analyses was collected through a survey of smallholder rice farmers at the Afife Irrigation Project from February to May 2010. A random sample of 550 farmers was interviewed, using a stratified sampling technique in which respondents were sampled from each of the 11 sections as well as from towns and villages in the study area. A questionnaire was administered to each farmer in a face-to-face interview. Out of the total sample of 550, only 2 refused to participate in the survey. This gave us a participation rate of over 99%. The survey was conducted during the minor farming season.

The questionnaire involves questions about socio-economic variables such as the farmer’s age and marital status; the number, age and gender of any dependents; his/her farming experience; the characteristics of the plot; each farmer’s total investment in soil and water conservation;

fertilizer adoption; and his/her current participation in joint works. To determine the individual discount rate, each farmer was presented with two hypothetical work programmes and was asked to choose one. The first, Option A, involves a programme which would reward a farmer with 150 GHS in a month's time, while Option B would pay the farmer 200 GHS in six months' time. The farmer was also asked to quote a value for Option B that would make him/her indifferent between the two programmes. The farmer's discount rate is then calculated as $\delta = \log\left(\frac{\eta_2}{\eta_1}\right)$, where η_2 is the value indicated by the farmer and η_1 is the value of Option A, i.e. 150 GHS. Thus, if a respondent is indifferent in respect of both Options A and B, it implies an individual discount rate of about 33% per season. Currently, the moneylenders charge farmers a rate of 50% per season. Finally, we also used the replacement value method to estimate each farmer's total household wealth.

3.3.1 The CV Scenario

The CV scenario starts with a general discussion of difficulties involved in maintaining irrigation canals. It highlights the breakdown of irrigation systems throughout the country. This is attributed to the lack of maintenance and clearing of the canals. Farmers generally assume other farmers will provide resources for the maintenance of irrigation canals and, therefore, shirk their own responsibility to provide for such maintenance. This often results in a situation where nobody maintains the canals. In addition, Government funds are scarce and too little is used for canal maintenance.

In the CV scenario, a new ten-year management plan is proposed in order to restore the maintenance of irrigation canals. To achieve the plan's aims will require farmers to contribute money or labour each year. The new management system will halt the canals' degradation, and will ensure that irrigation water reaches all the farmers' plots. The plan's implementation depends on the respondents' monetary or labour contributions as well as those of other farmers. If the majority of the farmers in an irrigation scheme support the plan, it will be implemented, and all farmers will have to make their annual monetary or non-monetary contributions for ten years. Assuming that the new management plan mobilises enough resources, it should adequately improve the current system. Also, because of its mandatory nature, free riding will be curtailed. From the descriptions above, we offer the respondents a choice between the present situation (q_0) and the quality that existed until 1990 (q_1).

3.3.2 Payment Vehicles

Two versions of the questionnaire were designed: one for each of the two payment vehicles. Thus, one questionnaire dealt with payments made in money, and the other with payments made in labour. In both versions of the questionnaire, we used an open-ended rather than closed-ended CV format to elicit WTP. We opted for the open-ended CV format because, in close-knit communities, information about surveys and the choices involved moves quickly among community members; thus, giving different choices to different respondents could distort the responses (Whittington, 1998). The payment vehicles are described as *mandatory* since the voluntary payment mechanism in CV surveys does not resolve the difference between contingent valuation and actual payment (Hanemann, 1994; Veisten and Navrud, 2006). This is because the voluntary payment mechanism is subject to free-riding behaviour. Furthermore, we adopted a ten-year planning horizon for both versions of the questionnaire. This is believed to make the scenario credible.

4.0: Results

The composition of the sample is presented in Table 1. Out of the 548 respondents, 348 currently use the monetary payment vehicle to maintain the irrigation canals. Since this sub-sample had used the labour payment vehicle in the past, they are familiar with both payment vehicles. A total of 246 respondents from this sub-sample were interviewed using the monetary-payment-vehicle version of the questionnaire, while 102 respondents were interviewed with its labour payment alternative. The remaining 200 respondents currently use, and previously used, the labour payment vehicle to maintain the canals. Of these 200 respondents, 44 were interviewed using the monetary-payment-vehicle questionnaire, while the remaining 156 were interviewed with its counterpart.

TABLE 1: COMPOSITION OF THE SAMPLE

Payment Vehicles	WTP in Money	WTP in Labour	Total
Currently using money	246	102	**348**
Currently using labour	44	156	**200**
Total	**290**	**258**	**548**

Table 2 presents the description of variables and their means, as well as the test of mean differences of the data. The descriptive statistics are presented for farmers who use either the monetary payment vehicle (MPV) or the labour payment vehicle (LPV) to maintain the irrigation canals. Under each of these sub-samples, the table also presents separate summary statistics for those interviewed with the two versions of the questionnaires.

The findings show that the farmers' average age is 46 years, in a household of 5.33 persons on average, working on a plot size of 2 hectares on average. Leaseholders constitute about 8% of the total sample. The leaseholders acquire their plots from owners for a given duration, and are responsible for the canal maintenance during the tenure of the lease agreement. The subjects under consideration are small-scale farmers.

As part of the survey, we asked extension officers to rank the level of soil fertility, the degree of slope, the soil type, and the degree of erosion on the plots we sampled. On a scale of 1 to 10, where 1 represents the lowest and 10 the highest, the average slope was set at about 3. This indicates the plots are fairly levelled out. As a result, the degree of erosion is also quite low, namely an average of 2.21 on the 1–10 scale. The average distance between the town or village of residence and the plot in question measured about 4.18 km.

The Ghanaian Government has also implemented a fertilizer subsidy programme since 2007, so we captured the participation in this subsidy scheme as well. About 40% of the total respondents benefit from the national subsidy programme. Fertilizer intensity is about 300 kg per hectare.

TABLE 2: DESCRIPTION OF VARIABLES, MEANS, AND TEST OF MEAN DIFFERENCES

			Currently using MPV				Currently using LPV		
VARIABLES	**VARIABLES DESCRIPTION**	**MPV**	**LPV**	**DIFF**	**Pooled**	**MPV**	**LPV**	**DIFF**	**Pooled**
Independent Variables									
Age	Age of the farmer (in years)	45.920	45.270	0.650	45.666	47.819	47.197	0.623	47.624
Gender	Dummy variable for farmer's gender (1 = Male)	0.752	0.775	-0.023	0.761	0.776	0.629	0.147**	0.730
Household size	Household size, i.e. number of household members	5.301	5.426	-0.126	5.350	5.239	5.308	5.459	5.308
Alternative employment	Respondent has alternative employment (1 = Yes)	0.552	0.558	-0.006	0.555	0.530	0.606	-0.076	0.554
Discount rate	Discount rate	0.565	0.560	0.005	0.560	0.550	0.640	-0.09**	0.580
Plot size	Plot size (in hectares)	1.984	1.996	-0.012	1.989	2.108	1.960	0.148	2.059
Plot location	Plot location on distributary canal (Tail = 1, Middle/Head = 0)	0.299	0.258	0.041	0.283	0.315	0.356	-0.041	0.328
Fertilizer	Number of fertilizer bags used per hectare	5.916	5.254	0.662**	5.656	6.052	6.290	-0.238	6.127
Leasehold	Dummy for leasehold (1 = Farmer leases plot)	0.089	0.087	0.002	0.088	0.089	0.048	0.041	0.076
Distance	Distance from where the farmer lives to the plot (in km)	4.230	4.379	-0.149	4.288	4.075	3.814	0.261	3.996
Erosion	Level of erosion on scale of 1 to 10 scale (1 is lowest)	2.325	2.500	-0.175**	2.392	1.854	1.914	-0.060	1.873
Marital status	Dummy variable for marital status (1 = Married)	0.883	0.877	0.006	0.881	0.903	0.903	-0.000	0.903
Wealth	Total wealth of the farmer's household (in GHS)	4,918.45	3,881.82	1,036.63	4,512.16	7,000.45	3,161.64	3,838.81**	5,793.40
Current money payment	Annual contributions towards maintenance of canals (in GHS)				6				0
Current labour payment	Annual contributions towards maintenance of canals (in hours)				0				6
Dependent Variables									
WTP (in money)	WTP elicited in monetary units (GHS) per hectare per year	13.974			13.974	14.590			14.590
WTP (in labour)	WTP elicited in labour hours per hectare per year		14.750		14.750		16.765		16.765
WTP with minimum wage	WTP elicited in labour, converted to GHS using minimum wage	13.442	5.687	7.755***	10.335	14.223	6.517	7.705*	11.911
WTP with sample wage	WTP elicited in labour, converted to GHS using sample wage	13.442	13.753	-0.310	13.566	14.223	15.759	-1.536	14.683

The statistical significance is designated as follows: * represents $p < 0.1$, ** represents $p < 0.05$, *** represents $p < 0.01$.

Among those who pay, the mean WTP is GHS 14.22 for the monetary payment vehicle and 15.34 hours per hectare per year for the non-monetary payment vehicle. These values for the WTP are substantially higher than current level of contributions towards canal maintenance, namely GHS 6 for money contributions, and six hours per hectare per year for labour contributions.

The two sub-samples – i.e. the farmers who currently use the MPV and those who use the LPV – are very similar. The sub-sample pooled means are almost identical. With regard to the sub-sample that currently uses the MPV to maintain the canal, the mean differences for fertilizer use and level of erosion are statistically significant (i.e. $p < 0.05$). These indicate that fertilizer use is higher among the farmers who were interviewed according to the MPV version of the questionnaire. Also, the degree of erosion is higher among the farmers who were interviewed with the LPV questionnaire. However, among the farmers who are currently using LPV to maintain irrigation canals, the mean differences of gender, discount rate and total household wealth are statistically significant (i.e. $p < 0.05$). The extrapolated average discount rate per six months among those farmers using the MPV and LPV for canal maintenance is 56% and 58%, respectively. These discount rates are comparable to the seasonal interest rate of 50% which the moneylenders charge on loans per season. Studies that estimate the rate of time preference in developing countries consistently report high individual discount rates (see e.g. Holden et al., 1998).

There is no standard method for converting WTP or preferences for the maintenance of irrigation canals elicited under the MPV and LPV. Among farmers using the MPV to maintain canals, the monetary WTP is 13.97 GHS per hectare per year, whilst the labour WTP is 14.75 hours per hectare per year. Using Ghana's minimum wage to convert the WTP computed under the LPV, we found that the mean difference between monetary WTP and labour WTP is statistically significant (i.e. $p < 0.01$). This means that WTP estimated under the MPV is higher than that computed under the LPV. However, this mean difference is not statistically significant when we use the mean wage rate of hired labour (i.e. the farmers' reported mean hourly costs for hiring labourers) to convert the labour WTP. For farmers using the LPV to maintain the canal, the mean WTP is 14.59 GHS under the MPV, and 16.76 hours under the LPV. The mean difference in WTP between the MPV and LPV is statistically significant when Ghana's minimum wage is adopted to convert the hours into monetary units (i.e. $p < 0.1$). This result indicates that WTP is higher under the MPV than under the LPV, but when one applies the farmers’ mean wage for hiring labourers, the difference in mean WTP under the two payment vehicles is not statistically significant.

The degree to which respondents accept the scenario is an important criterion for judging the overall performance of the CV survey. There is significant support among the respondents in respect of improving the irrigation canals. Overall, 92% (548-55=493) of the respondents supported the scenario by stating a positive WTP, i.e. they accepted the scenario. For the monetary version, the acceptance rate was 90%, while the corresponding figure for the labour input contribution was 95%. The high acceptance rates for the CV scenarios may also indicate farmers’ dissatisfaction with the current state of irrigation canals.

During the survey, we explored the reasons for zero WTP bids. Of the 55 respondents, 19 motivated the zero WTP by stating either that other farmers would not contribute, or that they believed that the Government would not use the resources as intended. These are classified as *protest* responses. In addition, 15 respondents indicated a lack of resources to contribute. The remaining 21 wanted to change the payment vehicle: 14 of them wanted to change it from labour to money, while 7 of them wanted to change it from money to labour.

TABLE 3: CONVERGENT VALIDITY TESTS BETWEEN MONETARY AND LABOUR PAYMENT VEHICLES

Hypotheses	**Monetary**	**Labour**	**Difference**
Equality of proportions accepting scenario by payment vehicle	0.905	0.955	-0.049**
Equality of mean WTP by payment vehicle using minimum wage	13.749	5.931	7.818***
Equality of mean WTP by payment vehicle using sample wage	13.749	14.340	-0.592

The statistical significance is designated as follows: * represents $p < 0.1$, ** represents $p < 0.05$, *** represents $p < 0.01$.

TABLE 4: CONVERGENT VALIDITY TESTS FOR EXPERIENCE WITH PAYMENT VEHICLES

	ACCEPTANCE RATES			**PROTEST RESPONSES**		
	WTP in Money	WTP in Labour	DIFFERENCE	WTP in Money	WTP in Labour	DIFFERENCE
Currently use MPV	0.897	0.942	-0.044	0.070	0.037	0.033
Currently use LPV	0.918	0.984	-0.066*	0.052	0.016	0.036

The statistical significance is designated as follows: * represents $p < 0.1$, ** represents $p < 0.05$, *** represents $p < 0.01$.

We also explored the potential differences in mean WTP for the monetary and non-monetary payment vehicles. The results are presented in Table 3. Firstly, we adopted Ghana’s legislated minimum wage to convert the WTP elicited in labour units into monetary units. The mean WTP for the MPV came to GHS 13.75, while GHS 5.93 was registered for the LPV. The difference between the two means is statistically significant (i.e. $p < 0.01$). However, if we use the rice farmers’ wage rate for hired labour in our sample, the mean WTP for the LPV is 14.34 GHS, which is not statistically different from the 13.75 GHS registered for the MPV.

Approximately 40% of the respondents benefit from the Government’s fertilizer subsidy programme, which could make them more benevolent towards the CV scenario. Hence, we tested whether those who benefitted from the subsidy programme were more likely to accept the CV scenario we designed for improving the management of the irrigation facilities. The results indicate that participation in the subsidy programme had no statistically significant effect on the acceptance rates for the new management plan.

Table 4 provides further analyses of the acceptance rates and protest responses for the MPV and LPV under both sub-samples. These results indicate that for the sub-sample who had experience with using both payment vehicles to maintain irrigation canals, the acceptance rates of the CV scenario does not differ between those who were interviewed using the MPV and LPV versions of the questionnaire. However, with regard to the sub-sample who only used the LPV to maintain irrigation canals, the difference in proportions who accepted the CV scenario under the two payment vehicles is statistically significant (i.e. $p < 0.1$). This finding indicates that the acceptance rate is similar for both payment vehicles if respondents have experience with both, but is different when the respondents have experience with only one of the payment vehicles.

With regard to the protest behaviour, there are no differences in the proportions of protest responses among farmers who were interviewed either with the MPV or the LPV questionnaire in the respective sub-samples. These results indicate that experience with payment vehicles reduces time/money response asymmetries.

As indicated earlier, market imperfections could also create disparities among acceptance rates and mean WTP under different payment vehicles. Holden et al. (1998) argue that market imperfections lead to variations in the rate of time preference. Hence, we compared the two sub-samples in terms of the extrapolated individual discount rates. The result indicates that the difference between the discount rates among farmers who have experience with both payment vehicles and those who use only the LPV is not statistically significant. The differences in wage rates, wealth, household size and plot size for the sub-samples are also not statistically significant. These conclusions indicate that the farmers were behaving under similar market environments. Thus, the earlier finding with regard to time/money response asymmetries can be linked to experience with payment vehicles.

The Maximum Likelihood Estimation results using the Tobit Model is presented in Table 5. The dependent variables for Models 1 and 3 are WTP stated in monetary units (GHS) and those of Models 2 and 4 are WTP stated in labour units (hours). In order to be able to compute the natural logarithm of zero bids, all the dependent variables' values are computed as $\log\left(WTP_i + 1\right)$. The Likelihood Ratio indicates that specifications as a whole are statistically significant in all four model specifications. Therefore, we reject the null hypothesis that the coefficients for all the independent variables are simultaneously equal to zero in all model specifications.

TABLE 5: REGRESSION RESULTS

Independent Variables	Currently use MPV		Currently use LPV	
	WTP in money [1]	WTP in labour[2]	WTP in money[3]	WTP in labour [4]
Discount rate	-0.370	0.713***	-0.954**	0.380
	(0.35)	(0.27)	(0.43)	(0.31)
Logarithm of age	-0.194	0.448*	0.344	0.300
	(0.33)	(0.23)	(0.46)	(0.28)
Gender	-0.124	0.119	0.327	0.354**
	(0.22)	(0.15)	(0.22)	(0.16)
Location of main distributary canal (Tail end)	0.380*	0.303**	0.600***	0.173
	(0.20)	(0.14)	(0.20)	(0.14)
Logarithm of household size	0.399	-0.065	-0.174	-0.757***
	(0.26)	(0.20)	(0.34)	(0.20)
Logarithm of distance between plot and place of residence	0.120	-0.036	0.208	-0.142
	(0.17)	(0.14)	(0.27)	(0.15)
Leasehold	0.250	-0.375*	1.221**	0.170
	(0.31)	(0.22)	(0.47)	(0.25)
Logarithm of plot size	0.671*	-0.334	-0.239	-0.482**
	(0.36)	(0.27)	(0.39)	(0.22)
Logarithm of fertilizer use	-0.077	0.230	-0.244	0.493***
	(0.21)	(0.14)	(0.27)	(0.18)
Logarithm of total household wealth	-0.172**	0.026	-0.213***	-0.008
	(0.07)	(0.04)	(0.07)	(0.05)
Alternative employment	0.502***	-0.164	0.757***	0.198
	(0.19)	(0.14)	(0.21)	(0.13)
Constant	2.863*	0.170	2.660	1.661
	(1.50)	(1.00)	(1.76)	(1.05)
McFadden's *R square*	0.0884	0.0757	0.3784	0.1521
Number of observations	98	137	42	92
Likelihood Ratio Test $\chi^2(13)$	23.797***	24.373**	42.882***	29.915***

The statistical significance is denoted as follows: * p<0.10, ** p<0.05, *** p<0.01. The standard errors are given in parentheses.

Models 1 and 2 provide results for the farmers who currently use the MPV to maintain irrigation canals. Whereas Model 1 provides the results for respondents interviewed using the MPV version of the questionnaire, Model 2 presents the results for respondents interviewed using the LPV version. The location of plots is significant in both models. Farmers whose plots are located at the tail end of the distributary canal indicate higher WTP for canal maintenance. Barton and Bergland (2010) arrive at the same conclusion in their study on farmers in India. Farmers with alternative employment indicate higher WTP to maintain irrigation canals under Model 1. Similarly, farmers with relatively bigger plot sizes indicate a higher WTP for canal maintenance. Total household wealth is, however, negatively associated with WTP for canal maintenance in Model 1.

With regard to Model 2, farmers who lease their plots are less willing to pay for the maintenance of irrigation canals. This is also intuitive, since the leasehold is for a limited period: the incentive for improving the quality of irrigation infrastructure is attenuated, therefore. This result supports the theoretical model devised by Yoder et al. (2008) on contract duration and investment in soil conservation, which suggests that, in comparison with their landlords, tenants invest less in soil conservation.

In Model 2, the age of the farmer and the discount rate are also statistically significant. These results indicate that farmers with higher discount rates state a higher WTP in labour hours for the maintenance of canals.

Models 3 and 4 provide the regression results for farmers who use the LPV to maintain irrigation canals. Model 3 provides the results for those interviewed using the MPV version of the questionnaire, while Model 4 presents the results for those interviewed using the LPV version. In Model 3, the discount rate is negatively associated with monetary contributions towards the maintenance of irrigation canals. In a study by Holden et al. (1998) in three different developing countries in Africa and Asia, it was found that households with immediate cash needs had higher rates of time preference; our results are in line with this finding. Also, the farmers whose plots are located at the tail end of the distributary canal stated a higher monetary WTP. Furthermore, farmers with leasehold contracts and alternative employment indicated higher monetary WTP, while household wealth is negatively associated with monetary WTP.

With regard to Model 4, male farmers are likely to contribute labour hours for the maintenance of irrigation canals. Fertilizer use also increases with a farmer’s willingness to contribute labour to maintain the canals. However, household size and plot size are negatively associated with labour contributions towards canal maintenance. In terms of comparisons of regression results under the same payment vehicle, we pooled the data together and ran regressions for both payment vehicles separately, with dummy variables for experiencing both payment vehicles. These dummy variables are not statistically significant in either model, indicating that Model 1 is similar to Model 3, and Model 2 is similar to Model 4.

5.0: Conclusion

The main purpose of this study is to investigate the effect of experience with monetary and labour payment vehicles on the relative acceptance of CV scenarios and protest bids in terms of these two payment vehicles. A split-sample survey was designed for this purpose. We used convergent validity tests to evaluate how experience affected potential differences in the farmers' willingness to pay for maintaining the irrigation canals that fed their plots. The results indicate that there is an asymmetry in acceptance rates between the two payment vehicles (although not in the rate of protest bids) when respondents only have experience with one of the vehicles. However, this asymmetry disappears when respondents have experience with both payment vehicles.

These results suggest that being familiar with monetary and labour payment vehicles attenuates time/money response asymmetry in the CVM. The study has implications for the conduct of the CVM and devolution policies in developing countries. In terms of the conduct of the CVM, these results suggest that the payment vehicles we adopt in the CVM should not be of paramount concern. Thus, if the respondents are fairly familiar with the payment vehicles, both acceptance and total WTP could be comparable across different payment vehicles. Also, devolution policies do not need to adopt a particular payment vehicle to promote participation.

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Paper 4

Nudging Boserup? The impact of fertilizer subsidies on investment in soil and water conservation

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Abstract

The new fertilizer subsidies in Sub-Saharan Africa are intended to increase agricultural production and ensure fertilizer market development. Fertilizer adoption requires complementary inputs such as investment in soil and water conservation for efficient and optimal nutrient uptake, and many fertilizer subsidy programmes implicitly assume that fertilizer subsidies crowd in such investments. The present study, therefore, evaluates the impact of fertilizer subsidies on the provision of soil and water conservation efforts in Ghana. The results indicate that beneficiaries of the studied fertilizer subsidy programme do not invest significantly more in soil and water conservation, which advises against excessive reliance on farmers to respond to fertilizer subsidies with substantial investment in soil and water conservation. Thus, in order to achieve increased investment in soil and water conservation for sustainable agricultural development, more comprehensive measures that include these investments explicitly (such as integrated soil fertility management programmes) may be needed.

Keywords: *soil and water conservation, soil fertility, fertilizer subsidy, endogenous switching*

JEL Classification: N57, Q15, Q18

[1]The author gratefully acknowledges financial support from the Swedish International Development Cooperation Agency (Sida) to the Environmental Economics Unit at the University of Gothenburg. Beneficial comments from Håkan Eggert, Jesper Stage, Måns Söderbom and Precious Zikhali are also acknowledged.

1.0: Introduction

The principal objective of this paper is to empirically evaluate the impact of fertilizer subsidies on investment in soil and water conservation. Specifically, the study evaluates the extent to which fertilizer subsidies nudge soil and water conservation efforts among smallholders in Ghana. Soil fertility depletion is a fundamental biophysical factor that accounts for the declining agricultural production in Sub-Saharan Africa (SSA) (Scoones and Toulmin, 1999). Moreover, the low agricultural production and income reinforce the decline in soil fertility as the degradation of land and water resources also reduces the capacity of farmers to undertake investments in soil and water conservation (see e.g. Pender and Hazell, 2000; Shiferaw and Bantilan, 2004; Shiferaw et al., 2009). Despite the failure of past fertilizer subsidy programmes in SSA, many experts still maintain that fertilizer subsidies are needed to create demand and supply for fertilizer market development and higher sustainable agricultural production, and in the end facilitate development. Although the extent to which these multiple objectives are met depends on investment in soil and water conservation, many of the existing fertilizer subsidy programmes implicitly assume that subsidizing fertilizer alone will lead to significant investments in soil and water conservation. Therefore, the relationship between fertilizer subsidies and investment in soil and water conservation is fundamental to the design of new fertilizer subsidy programmes, and the purpose of this study is to explore this relationship.

For far too long, the net effect of agricultural production on soil fertility has been negative in SSA (see e.g. Stoorvogel and Smaling, 1990; Stoorvogel et al., 1993; de Jager et al., 1998), and this is costly to agricultural production (see e.g. Alfsen et al., 1997; Biggelaar et al., 2004; Diao and Sarpong, 2007). For example, using an economy-wide multimarket model for Ghana, Diao and Sarpong (2007) estimate the impact of agricultural soil loss on agricultural gross domestic product to be 5% from 2006 to 2015 (i.e. about US$4.2 billion). The reasons for land degradation include population growth and inappropriate land practices (Scoones and Toulmin, 1999). However, Boserup (1965) argues that these same factors should constitute the basis for investment in soil fertility through technological innovations and recognizes the role of public policies in nudging these technological innovations. Specifically, land scarcity and degradation provide farmers with incentives to invest in technological innovations and cultivation practices such as soil and water conservation to boost agricultural production and income (Boserup, 1965).

It is a paradox that fertilizer adoption in SSA is low given the high rate of return to fertilizer use and the high levels of land degradation and nutrient mining related to agricultural production. The fertilizer intensity in Africa in 2000 was 8 $kgha^{-1}$ as compared to 96 $kgha^{-1}$ for East and Southeast Asia and 101 $kgha^{-1}$ for South Asia (Morris et al., 2007). Explanations for this seeming anomaly range from market imperfections to systematic biases in dynamic decisions. Holden et al. (1998) suggest that credit market imperfections and a high rate of time preference could generally hinder investment in soil fertility, and provide a basis for public intervention. For instance, if farmers cannot obtain credit, they may not be able to invest in profitable investments. Specifically, the market imperfections and high rate of time preference generate inter-temporal externalities that distort investment decisions. In addition to these demand-side factors, problems could also come from the supply of fertilizer (Crawford et al., 2003; Morris, et al., 2007). For instance, poor infrastructure, high transaction costs and a non-competitive marketing system can also make fertilizer supply unviable. Duflo et al. (2010) invoke systematic behavioural biases involved in investment decisions to explain the low adoption of fertilizer despite its high rate of return. Their model predicts that some farmers will plan to buy fertilizer, yet will fail to follow through on these plans. Therefore, fertilizer subsidies should increase fertilizer use among farmers who are hyperbolic and lead to overuse of fertilizer among those who are time-consistent. The model also implies that fertilizer subsidies need not be huge to induce farmers to use fertilizer when they are offered just after harvest. In addition to the theoretical model, Duflo et al. (2010) also find that a significant proportion of the farmers in Kenya are present-biased.

The primary role of input subsidies in agricultural development should be to promote adoption of new technologies and accelerate agricultural production (Ellis, 1992). Despite the failure of past fertilizer subsidy programmes, many agricultural experts still view fertilizer subsidies as a viable means to restore soil fertility and hence ensure food security and eliminate malnutrition and poverty in SSA (Morris et al., 2007; Denning et al., 2009). Yet, Crawford et al. (2003) note that the huge fiscal burden of the earlier fertilizer subsidy programmes contributed to the macroeconomic crises. Moreover, Morris et al. (2007) hold that the past efforts to promote fertilizer in Africa were too narrowly concentrated on stimulating increases in fertilizer use without crowding in other complementary inputs such as investment in soil and water conservation.

However, the new subsidy programmes rely on innovations in programme implementations to overcome the shortcomings of the past fertilizer subsidy programmes (Banful, 2010). For instance, World Bank (2008) and Morris et al. (2007) maintain that the new subsidy programmes in SSA must be temporary and help develop fertilizer markets. The new subsidy programmes serve as mechanisms to provide subsidized inputs and services designed both to promote market development and to enhance the welfare of the poor. Investment in soil and water conservation is required in order to stimulate the demand for fertilizer (Place et al., 2003; Morris et al., 2007). This is because it increases agricultural productivity and incomes and consequently increases the demand for fertilizers. Minot and Benson (2009) hold that voucher programmes provide an opportunity to train farmers and input suppliers on efficient and profitable fertilizer use. Under a voucher system, farmers are given vouchers to be sent to private input suppliers to acquire fertilizer cheaper. Thus, a voucher is an income transfer which can promote investment in soil and water conservation if credit is a binding constraint to such investments. The vouchers are also a way to guarantee a demand for fertilizer, which in turn ensures a reliable fertilizer supply. To a large extent, these objectives will be met if the subsidy programmes increase fertilizer uptake and at the same time crowd in investment in soil and water conservation.

Public discussions on the design and implementation of fertilizer subsidies in SSA can be linked to two different viewpoints. The first is based on the premise that soil resources have been so extensively degraded that fertilizer adoption alone will be inadequate to address the protracted nutrient mining (see e.g. Stoorvogel and Smaling, 1990; Stoorvogel et al., 1993; de Jager et al., 1998). As such, Integrated Soil Fertility Management (ISFM) programmes have been suggested to overcome the protracted land degradation. ISFM programmes are comprehensive in the sense that they increase fertilizer adoption and investment in soil and water conservation (Conway, 1997; Heerink, 2005; Misiko and Ramisch, 2007; Place et al., 2003). Each of the components in ISFM relies on a different household resource endowment, with fertilizer requiring financial resources and investment in soil and water conservation requiring labour. Scoones and Toulmin (1999) suggest that a combination of organic and inorganic materials in agriculture promotes agronomic efficiency and sustainability. Janssen (1998) notes that both uptake efficiency and utilisation efficiency depend on factors such as availability of water and other nutrients, and balanced provision of nutrients is the best guarantee for their optimal use. Furthermore, ISFM programmes ensure that soil fertility and plant nutrient supply from all possible sources of plant nutrients are optimized, i.e. that soil fertility is achieved through a balanced use of mineral fertilizers and biological sources of plant nutrients.

The second viewpoint is that a well-designed, fertilizer-only, programme may be preferable to the wider-reaching programmes outlined above. This viewpoint emerges from actual implementations of fertilizer subsidy programmes in SSA. The historical experiences from 1960s and 1970s suggest that wide- ranging policy packages with large number of different components can be distortionary, and that more limited interventions are likely to be successful in practice. There are also fiscal constraints which make more targeted programmes attractive. For these reasons, many governments have chosen to adopt fertilizer subsidy programmes that only promote fertilizer adoption. For instance, whereas Malawi and Kenya have adopted the provision of fertilizer with improved seed, Ghana and Nigeria only subsidize fertilizer. Thus, in reality, the current fertilizer subsidies dwell on the provision of fertilizer and there is little attempt to promote labour-intensive sustainable land management directly (Heerink, 2005). The promotion of fertilizer only through fertilizer subsidies can be a cost effective way of investing in soil fertility for sustainable agricultural production especially if the fertilizer use provides a strong incentive for farmers to invest in soil and water conservation. There will then be an indirect promotion of the required complementary inputs, without any need for the government to be actively involved in promoting these inputs directly.

A number of studies evaluate the impact of public programmes on investment in soil and/or water conservation and fertilizer adoption. As regards the impact of public programmes on investment in soil and/or water conservation, Berg (2002) finds that public works and self-employment programmes reduce fertilizer use; thus, employment programmes cannot be used to promote fertilizer adoption. The mechanism is that public employment programmes reduce the effect of risk on fertilizer use, and there is thus no component in this programme that directly promotes fertilizer adoption. Gebremedhin and Swinton (2003) analyze the effects of public programmes (i.e. existence of food-for-work programmes and mandatory community labour) on investment in soil conservation in Northern Ethiopia. The evidence suggests that availability of food-for-work programmes increases the adoption of stone terraces but decrease the adoption of soil bunds. Moreover, direct public involvement in constructing soil conservation structures on private lands undermines incentives for private conservation investments; however, public conservation activities on public lands encourage private soil conservation through demonstration effects. Holden and Shiferaw (2004) develop a bioeconomic model with market imperfections to evaluate the impact of hypothetical seed and fertilizer credits on adoption of sustainable soil and water management strategies in Ethiopia. The model results indicate that fertilizer credits reduce soil and water conservation work on the fields, but that this negative effect could be mitigated through linking a conservation requirement to the fertilizer credit. Hagos and Holden (2006) also assess the relationship between public-led conservation programmes and private investment in soil conservation in Ethiopia, and their findings indicate a positive relationship. Similarly, Holden and Lunduka (2010) evaluate the impact of fertilizer subsidies on agricultural yields and manure use. They find that fertilizer and manure are complements, since the studied farmers who applied more fertilizer also used more manure. However, the subsidy dummy is not statistically significant. As can be seen, the existing evidence on the impacts of public programmes on conservation investments is thus mixed.

The present paper seeks to extend the existing literature on the impact of public programmes on soil and water conservation by evaluating the impact of fertilizer subsidies on investment in soil and water conservation. The remainder of the paper is structured as follows. Section 2 discusses the fertilizer subsidy programme as implemented in Ghana. Section 3 presents a brief discussion of the study area and the sampling method. Section 4 explains the econometric models used in the estimation. Section 5 presents the results, and Section 6 concludes the paper.

2.0: The Fertilizer Subsidy Programme in Ghana

The global food crisis of 2007/2008 was a source of major concern all over the world and politically destabilized a number of governments. Governments responded to the crisis in many different ways. In Ghana, the government implemented a fertilizer subsidy programme in 2008 to promote the domestic production of agricultural output.

The subsidy programme involves a number of innovations in programme implementation in order to achieve its objectives (Banful, 2009). First, the government adopted a voucher system where the government prints region-specific and product-specific vouchers. The vouchers are then distributed by agricultural extension agents to farmers within their so-called operational areas. Subsidized fertilizer can be purchased upon presentation of a voucher and a matching cash amount. Instead of allowing government officials to distribute fertilizer – which was a major drawback of many fertilizer programmes in the past – the current programme relies on private agents to distribute fertilizer vouchers. Secondly, an advantage of the new system noted by e.g. Minot and Benson (2009) is that it creates an opportunity for farmers to interact with extension officers regarding efficient and profitable use of fertilizer and investment in soil and water conservation.

In this way, the programme nurtures a relationship between farmers and extension officers that could outlast the subsidy programme. According to Banful (2009), the involvement of extension officers in the distribution channel offers additional benefits as it facilitates dissemination of information regarding extension services. Moreover, by interacting with extension officers, farmers gain access to information on the adoption of sustainable agriculture practices. These new measures have the potential to promote investment in soil and water conservation. However, the fertilizer subsidy programme in Ghana is not an integrated soil fertility management programme since it only provides fertilizer vouchers without any other visible effort to stimulate investment in soil and water conservation.

There are elements in the fertilizer subsidy programme that could promote demand for and supply of fertilizer and hence facilitate fertilizer market development in Ghana in the long run. For instance, the adoption of the voucher system could have this effect. Voucher systems represent income transfers that promote demand for fertilizer in the short run, but this could sustain the demand for fertilizer beyond the duration of the fertilizer subsidy programme because of higher profits and investment in complementary inputs. That the vouchers are used to acquire fertilizer from private fertilizer agents in Ghana enables the fertilizer agents to benefit from economies of scale, and provides incentives for fertilizer agents to develop new distribution networks that could remain after the fertilizer subsidy programme. Also, as previously mentioned, the interaction between farmers and extension officers permits extension officers to educate farmers on fertilizer use and sustainable land management. A number of studies have found that access to information and extension officers increase investment in soil and water conservation (see e.g. Place and Dewees, 1999; Pender and Gebremedhin, 2008; Kassie et al., 2009).

3.0: Study Area and Sampling Method

The questionnaire for this study was administered among smallholder farmers at the Afife Irrigation Project in the Volta Region of Ghana in February-May of 2010. The Afife Irrigation

Project is located in one of the rice growing districts in the country. The cross-sectional data for the analyses was collected through a survey of smallholder rice farmers. We randomly selected 550 farmers, of which 548 chose to participate. Due to item non-responses, the final sample was reduced to 460 farmers, implying a participation rate of 84%. A total of 190 farmers benefitted from the fertilizer subsidy programme, and the remaining 270 acquired fertilizer from the open market.

The questionnaire includes questions about socio-economic variables such as age of the farmer; marital status; number, age and gender of dependents; farming experience; plot characteristics; investment in soil and water conservation; fertilizer adoption; and participation in collective work. Also, to determine the individual discount rate, each farmer was presented with two hypothetical work programmes from which they had to choose one. The first programme (Option A) involved a programme that would pay the farmer 150 GHS (Ghana cedis) in one month's time, whereas Option B would pay the farmer 200 GHS in six months to reflect seasonal decision making. The farmer was also asked to quote a value for Option B that would make him/her indifferent between the two programmes. The discount rate of the farmer was then calculated as the $\log\left(\frac{\eta_2}{\eta_1}\right)$ where η_2 is the value indicated by the farmer and η_1 is the value of Option A (i.e. 150 GHS).

As part of the study, the extension officers at the Afife Irrigation Project were asked to rank the fertility, slope, soil type and level of erosion of plots. Soil fertility, slope and degree of soil erosion were ranked on a 1-10 scale. Investment in soil and water conservation was measured as the number of days that the farmer engaged in soil and water conservation activities per hectare. Also, we collected data on the distance that farmers travelled to their plots. Based on this information, we also calculated the distance to the fertilizer voucher distribution depot.

4.0: Econometric Model

Many of the stated goals of the new subsidy programmes seek to increase the demand for fertilizer in the long run. However, the success in this respect depends on the extent to which fertilizer subsidy programmes crowd in investments in soil and water conservation for higher productivity and income, since such investments help farmers afford fertilizer inputs in the future. Two factors determine the choice of the econometric model.

The first one is that the dependent variable, i.e. investment in soil and water conservation, is a count data variable. That is, we measure investment in soil and water conservation as the number of farm days a farmer devotes to investing in soil and water conservation per hectare. Thus, models designed for continuous dependent variables are inappropriate.

The second factor to consider is the potential problem of endogeneity of participation in the fertilizer subsidy programme. Selection into the programme can be determined by unobserved factors, and these factors can also affect investments in soil and water conservation. Ignoring the selection into the endogenous dummy variable could thus lead to biased and inconsistent estimates of the impact of the subsidy programme on investment in soil and water conservation, especially in the presence of unobserved individual heterogeneity (Heckman, 1979; Mullahy, 1997).

Terza (1998) outlines three estimation methods to address the endogenous dummy explanatory variable problem in count data models. In the first alternative, a two-stage method of moments could be used, following the Heckman's sample selection model. In this procedure, a probit model constitutes the first stage, and it is estimated for the endogenous dummy dependent variable. The second stage involves the estimation of a regression model with the multiplicative correction factor by non-linear least squares. A second alternative is estimation of non-linear weighted least squares. A third alternative is to use a full information maximum likelihood endogenous switching estimation procedure which, according to Terza (1998) provides the statistically most efficient estimator subject to distributional assumptions.

Here, we use the full information maximum likelihood endogenous switching model to evaluate the impact of fertilizer subsidy on soil and water conservation effort. The derivation of the econometric model in this section follows Terza (1998), Miranda (2004) and Miranda and Rabe-Hesketh (2006). Conditional on a set of explanatory variables denoted as x_i in this instance, an endogenous dummy variable denoted Sub_i and an error term denoted ε_i, the investment in soil and water conservation effort follows a standard Poisson distribution:

$$f\left(SWC_i \mid \varepsilon\right) = \frac{\exp\left\{-\exp\left(x_i'\beta + \gamma Sub_i + \varepsilon_i\right)\right\}\left\{\exp\left(x_i'\beta + \gamma Sub_i + \varepsilon_i\right)\right\}^{SWC_i}}{SWC_i\,!}, \tag{1}$$

where $f(\bullet)$ is the conditional probability distribution and SWC_i represents the investment in soil and water conservation for the *i*:th farmer. The unobserved latent variable Sub_i^* is defined by the process

$$Sub_i^* = z_i\alpha + u_i, \tag{2}$$

where z is a vector of exogenous variables, α are the corresponding unknown parameters and u is the error term. The latent variable is related to the endogenous variable through the process defined as

$$Sub_i = \begin{cases} 1 \text{ is observed if } Sub_i^* > 0 \\ 0 \quad \text{otherwise} \end{cases}. \tag{3}$$

Assuming that the two error terms are jointly normal with zero mean, the covariance matrix (Σ) is given as

$$\Sigma = \begin{pmatrix} \sigma^2 & \sigma\rho \\ \sigma\rho & 1 \end{pmatrix}. \tag{4}$$

There is exogenous switching (i.e. Sub_i is exogenous) if $\rho = 0$. In this case, consistent estimates of β and γ can be obtained by estimating only the investment equation. However, if $\rho \neq 0$, there is endogeneity.

The conditional joint probability density function is given as

$$f(SWC, Sub \mid w) = \int_{-\infty}^{\infty} f(SWC \mid w, Sub, \varepsilon)\left(d\Phi^*(\varepsilon) + (1 - Sub_i)(1 - \Phi^*(\varepsilon))\right) f_\varepsilon(\varepsilon \mid w)\, d\varepsilon, \tag{5}$$

where $\Phi^*(\varepsilon) = \Phi\left(\dfrac{z\alpha + (\rho/\sigma)\varepsilon}{\sqrt{1-\rho^2}}\right)$ and $f_\varepsilon(\varepsilon \mid w)$ is the conditional distribution of ε given the exogenous variables, which are represented by w. The joint normality of the two error terms ε and u conditional on w indicates that $f_\varepsilon(\varepsilon \mid w)$ is normal with zero mean and variance σ^2.

Given the functional form of $f(SWC_i \mid w, Subsidy_i, \varepsilon)$, the log-likelihood is specified as

$$L(\mu \mid w) = \sum_{i=1}^{n} \ln f\left(SWC_i, Subsidy_i \mid w_i\right) \tag{6}$$

where n is the sample size, μ is the set of parameters to be estimated including variance and covariance of the two error terms. One notable problem with maximizing equation (6) is that $f\left(SWC_i, Sub_i \mid w_i\right)$ cannot be evaluated in closed form (Terza, 1998). However, by defining $\zeta = \left(\frac{\varepsilon}{\sqrt{2\sigma}}\right)$ and rewriting the normal probability distribution function, we can rewrite the likelihood function under the Poisson version of the model as

$$f\left(SWC_i \mid w_i, Sub_i, \varepsilon\right) = \frac{\exp\left\{x_i^{'}\beta + \gamma Sub_i + \varepsilon\right\}^{SWC} \exp\left\{-\exp\left\{x_i^{'}\beta + \gamma Sub_i + \varepsilon\right\}\right\}}{SWC_i!}, \tag{7}$$

and with the change in variable by replacing ε with $\sqrt{2\sigma}\zeta$, the $f(\bullet)$ can be re-written as

$$f\left(SWC_i \mid w_i, Sub_i, \sqrt{2\sigma\zeta}\right) = \frac{\exp\left\{x_i^{'}\beta + \gamma Sub_i + \sqrt{2\sigma\zeta}\right\}^{SWC} \exp\left\{-\exp\left\{x_i^{'}\beta + \gamma Sub_i + \sqrt{2\sigma\zeta}\right\}\right\}}{SWC_i!}. \tag{8}$$

The full information maximum likelihood endogenous switching model will estimate both the investment in soil and water conservation and the participation in the fertilizer subsidy programme. Thus, the above model will capture the effects of the subsidy programme on investment in soil and water conservation efficiently. Kassie et al. (2010) use the same framework to evaluate the impact of sustainable land management practices on the net value of agricultural production in different agro-ecological areas in Ethiopia.

The main identifying assumption used here is that access to information and the mode of voucher distribution determine the participation in the fertilizer subsidy programme. Thus, we rely on the distance to the source of information to achieve exclusion restrictions, i.e. the distance between the farmer's place of residence and the voucher distribution point. This means that we implicitly assume that farmers who live farther away from the distribution point are less likely to access information about the vouchers and thus less likely to participate in the programme. Hence, we adopt distance to voucher distribution point as the instrument. This follows the findings in the literature that proximity to subsidy programmes enhances participation (e.g. Allard et al., 2003). As regards the elements in the x_i vector, we follow the empirical studies on investment in soil and/or water conservation, e.g. Berg (2002), Gebremedhin and Swinton (2003), Holden and Shiferaw (2004), Hagos and Holden (2006), Solis et al. (2007), Kassie, et al. (2010).

5.0: Results

5.1: Description and summary statistics

Table 1 presents the description and the summary statistics of the data. Approximately 75% of the farmers are male, and this proportion is similar among both the farmers who participated in the fertilizer subsidy programme and those who did not. An average farmer had about 17 years of farming experience, and the mean difference in years of experience between those who received fertilizer under the fertilizer subsidy programme and those who did not is not statistically significant. The average plot size is 2 ha among both beneficiaries and non-beneficiaries of the programme, which implies that our sample consists of smallholder irrigation farmers. Half of the sampled households were engaged in alternative employment in addition to farming. The household labour endowment is significantly lower among programme beneficiaries.

However, the discount rates are higher among beneficiaries of the subsidy programme: The extrapolated average discount rate per six months is 62% and 53% among the farmers who did and did not participate in the fertilizer subsidy programme, respectively. The mean difference in discount rate between beneficiaries and non-beneficiaries is statistically significant $(\text{i.e. } p < 0.01)$. Holden et al. (1998) suggest that high time preferences reduce incentives for investment in soil conservation. Thus, one potential explanation could be that the beneficiaries may want to compensate for the low investment in soil conservation with fertilizer use. The average discount rate is 56.5% per season, which is similar to the interest rate charged by money lenders, which is 50% per season.

The average ranking for soil fertility is about 5, and the ranking for soil erosion is 2. Also, the rankings indicate that the fertility of the plots was the same among the farmers who benefitted from the programme and those who did not. Soil erosion is also quite low. However, the level of erosion of the plots was ranked lower for farmers who benefitted from the programme than for those who did not. Two dummy variables were constructed to capture the locations of the plots. The proportion of plots located at the tail end of the canal is the same for the two groups. However, the proportion of plots located in the middle of the canal is lower among the farmers who benefitted from the fertilizer subsidy programme than among those who did not. The soil types are the same for both groups.

Lease holding is not common among the farmers: Only 8% of the total sample were lease holders. Moreover, this share was higher among the farmers who did not participate in the fertilizer subsidy programme. One possible explanation for the low share is that since lease holders are not registered with the authorities, the probability of being considered for the fertilizer subsidy programme is low.

TABLE 1: DESCRIPTION AND SUMMARY STATISTICS OF VARIABLES

Variables	Descriptions	Non-beneficiaries	Beneficiaries	Difference	Pooled
Gender	Dummy variable for farmer gender (= 1 if male)	0.743	0.758	-0.015	0.749
Age	Age of the farmer in years	46.55	46.17	0.38	46.39
Experience	Years of farming experience	16.513	17.762	-1.250	17.028
Household wealth	Total household wealth (in Ghana cedis)	3784.02	5451.51	-1667.49**	4480.61
Discount rate	Discount rate of the farmer for a period of six months	0.532	0.618	-0.086***	0.56
Alternative employment	Farmer being in alternative employment	0.589	0.511	0.078*	0.556
Household labour	Number of household members who work on the farm	3.758	3.427	0.330**	3.621
Hired labour	Hired labour (days)	10.955	18.883	-7.928***	14.227
Collective work	Number of days a farmer participates in collective work per season	2.401	3.049	-0.648**	2.668
Other soil conservation	Dummy variable for other soil conservation measures	0.313	0.251	0.062	0.287
Plot size	Plot size (in hectares)	2.006	2.019	-0.012	2.011
Middle plot	Dummy variable for plot being located in the middle	0.216	0.089	0.127***	0.163
Tail plot	Dummy variable for plot being located at the tail end	0.310	0.281	0.028	0.298
Leasehold contract	Dummy variable for leasehold (=1 if the farmer was leasing the plot)	0.102	0.057	0 .045*	0.084
Soil erosion	Soil erosion as ranked by extension officers on 1-10 scale	2.261	2.145	0.116*	2.213
Plot slope	Slope of plot as ranked by extension officers on 1-10 scale	3.020	2.944	0.076	2.988
Soil fertility	Soil fertility as ranked by extension officers on 1-10 scale	4.888	5.005	-0.116	4.936
Clayey-loam soil	Dummy variable for clayey-loamy soil	0.616	0.564	0.052	0.594
Sandy-loam soil	Dummy variable for sandy-loamy soil	0.142	0.123	0.019	0.134
Distance to agent	Distance between place of residence and voucher point (in km)	6.466	4.983	1.483***	5.856
SWC	Days devoted to soil and water conservation per ha	4.854	4.489	0.365	4.704

Statistical significance: * = $p<0.10$, ** = $p<0.05$, *** = $p<0.01$.

We also counted the number of times farmers participated in collective work related to maintenance of irrigation canals. The level of participation reported is statistically higher among the programme participants than among the others. On average, farmers participated in this type of work about 3 times per season, while the average number of days per season that farmers reported engaging in soil and water conservation was almost 5. These investments in soil and water conservation entail construction of bunds and are interventions that increase productivity of land and inputs in SSA (Ouedraogo and Bertelsen, 1997; Kazianga and Masters, 2002). The average number of days is not significantly different between beneficiaries and non-beneficiaries. Despite the fact that the mean difference in terms of soil and water conservation effort is not statistically significant, we still need to empirically evaluate the impact of the fertilizer subsidy on the soil and water conservation effort since the mean difference does not account for the effects of unobserved heterogeneity in the participation in the fertilizer subsidy. Also, there could be differences in the frequency distribution. We also quantified the amount of labour hired to work on the plots of the farmers. The hired input will only benefit the farmer. The average labour hired was 14 days, and this value is significantly higher among the farmers who benefitted from the programme.

The assumption we used to justify the choice of the instrumental variable appears valid. The farmers who benefitted from the fertilizer subsidy programme on average live closer to the fertilizer voucher distribution point: The average distance between the farmer's place of residence and the fertilizer distribution point is 6.47 km, whereas the distance for the farmers who did not benefit from the fertilizer subsidy programme is 4.98. The mean difference between the two averages is statistically significant $(p < 0.01)$.

5.2: Evaluation of the Impact of the Fertilizer Subsidy Programme on Soil and Water Conservation Efforts

The results for three different models are presented in Table 2. Models 2 and 3 are the results for the endogenous switching model while Model 1 is for the exogenous model. The results of the exogeneity assumption in Model 1 are presented for comparison purposes; our main results are presented under Model 2. Plot characteristics such as plot slope, soil fertility and soil type are unlikely to affect the distribution of vouchers. We therefore exclude these variables from the subsidy equation in Model 3 to check the robustness of our results to different model specifications. The results in Model 3 are similar to those in Model 2.

Model 1 reports the results under the assumption of exogeneity. That is, the results of Model 1 are estimated under the restriction that there is no correlation between the error terms of the investment equation and the subsidy equations (i.e. $\rho = 0$). The results under Model 1 indicate evidence of overdispersion and unobserved heterogeneity since σ is positive and statistically different from zero ($p < 0.01$). These results provide a justification for the estimation of the full information maximum likelihood endogenous switching model, which is presented in Model 2. It is also important to highlight the fact that participation in the fertilizer subsidy programme does not affect investment in soil and water conservation in Model 1. This is because the subsidy dummy is not statistically significant. The coefficient for the subsidy dummy is negative, though not statistically significant.

The log-likelihood ratio test was used to test for the null hypothesis that $\rho = 0$ in Models 2 and 3. The log-likelihood ratio test comparing the exogenous model to Model 2 is statistically significant ($\chi_1^2 = 916.54;\ p < 0.01$). Similarly, the test comparing the exogenous model to Model 3 is also statistically significant ($\chi_1^2 = 916.64;\ p < 0.01$). These test results imply that participation in the programme is endogenous, which justifies the adoption of the endogenous switching models.

Models 2 and 3 present the results for the full information maximum likelihood endogenous switching model, which relaxes the exogeneity assumption and caters for unobserved heterogeneity found in Model 1. The results for Model 2 indicate that participation in the programme does not crowd in investment in soil and water conservation. The subsidy dummy is not statistically significant in this specification either.

TABLE 2: REGRESSION RESULTS

Independent variables	MODEL 1		MODEL 2		MODEL 3	
	Investment	**Subsidy**	**Investment**	**Subsidy**	**Investment**	**Subsidy**
Subsidy	-0.087		0.264		0.318	
	(0.095)		(0.354)		(0.340)	
Natural logarithm of age of farmer	-0.027	-0.225	-0.025	-0.221	-0.029	-0.154
	(0.197)	(0.275)	(0.268)	(0.299)	(0.269)	(0.283)
Natural logarithm of household wealth	0.022	0.097**	0.023	0.098**	0.022	0.095**
	(0.035)	(0.046)	(0.043)	(0.046)	(0.043)	(0.045)
Other investments in soil conservation	-0.078	-0.169	0.033	-0.171	0.041	-0.201
	(0.112)	(0.154)	(0.141)	(0.158)	(0.140)	(0.151)
Gender	0.023	0.060	0.022	0.068	0.021	0.057
	(0.108)	(0.156)	(0.147)	(0.164)	(0.147)	(0.156)
Discount rate	0.591***	0.883***	0.420	0.887***	0.411	0.832***
	(0.169)	(0.259)	(0.262)	(0.262)	(0.257)	(0.254)
Natural logarithm of hired labour	0.100***	0.155***	0.092**	0.157***	0.090**	0.145***
	(0.030)	(0.040)	(0.043)	(0.040)	(0.041)	(0.038)
Collective work	0.071***	0.031*	0.053***	0.031	0.052***	0.032*
	(0.009)	(0.019)	(0.017)	(0.019)	(0.017)	(0.018)
Natural logarithm of labour endowment	0.285**	-0.190	0.297**	-0.183	0.309**	-0.245*
	(0.117)	(0.148)	(0.123)	(0.149)	(0.125)	(0.140)
Middle plot	0.566***	-0.611***	0.614***	-0.628***	0.629***	-0.655***
	(0.153)	(0.220)	(0.193)	(0.223)	(0.193)	(0.210)
Leasehold contract	0.331*	-0.279	0.203	-0.265	0.206	-0.255
	(0.169)	(0.261)	(0.219)	(0.252)	(0.219)	(0.237)
Tail plot	-0.019	-0.277*	0.031	-0.278*	0.024	-0.180
	(0.106)	(0.148)	(0.144)	(0.149)	(0.140)	(0.142)
Alternative employment	0.058	-0.282**	0.133	-0.280**	0.138	-0.280**
	(0.098)	(0.141)	(0.129)	(0.140)	(0.128)	(0.134)
Plot slope	-0.053	0.067	-0.094	0.069	-0.086	
	(0.081)	(0.115)	(0.098)	(0.111)	(0.098)	
Soil erosion	-0.001	-0.139	0.117	-0.141	0.102	
	(0.085)	(0.123)	(0.103)	(0.116)	(0.101)	
Soil fertility	0.081*	0.120	0.052	0.115	0.064	
	(0.046)	(0.074)	(0.063)	(0.077)	(0.064)	
Clayey-loam soil	-0.164	-0.045	-0.252	-0.050	-0.258	
	(0.137)	(0.208)	(0.178)	(0.208)	(0.175)	
Sandy-loam soil	-0.237	0.120	-0.254	0.102	-0.245	
	(0.178)	(0.274)	(0.224)	(0.269)	(0.222)	
Natural logarithm of experience	-0.330***	0.260*	-0.379***	0.261*	-0.384***	0.263**
	(0.098)	(0.144)	(0.127)	(0.141)	(0.128)	(0.133)
Natural logarithm of plot size	-0.022	-0.357**	0.084	-0.358**	0.081	-0.281*
	(0.124)	(0.166)	(0.149)	(0.158)	(0.147)	(0.151)
Natural logarithm of distance to agent		-0.374***		-0.376***		-0.299***
		(0.102)		(0.102)		(0.087)
Constant	0.566	-0.643	0.594	-0.660	0.555	-0.477
	(0.818)	(1.092)	(1.048)	(1.176)	(1.051)	(1.054)
Sigma		1.035***		1.004***		1.008***
		(0.049)		(0.063)		(0.065)
Rho				-0.202		-0.234
				(0.204)		(0.194)
Wald χ^2	162.55***		157.72***		149.13***	
Number of observations	460		460		460	

Standard errors in parentheses. Statistical significance: * = p<0.1, ** = p<0.05, *** = p<0.01.

The regression results identify a number of determinants of investment in soil and water conservation. Hired labour and investment in soil and water conservation are complementary. Similarly, farmers with higher household labour endowment invest more in soil and water conservation. Both results reveal that investment in soil and water conservation requires labour resources. Also, farmers who participate in joint work with other farmers also invest significantly more in soil and water conservation. However, farmers who have extensive experience in farming allocate less days to investment in soil and water conservation. Farming experience could endow farmers with higher labour quality for investment in soil and water conservation. The location of plots affects investment in soil and water conservation in that farmers whose plots are located in the middle of blocks spend more days on investment in soil and water conservation as compared to the base category, the farmers with head plots.

The results also indicate a number of factors that determine participation in the fertilizer subsidy in Ghana. First, farmers who live farther away from the fertilizer voucher distribution point are less likely to participate in the fertilizer subsidy programme. This provides a justification for the exclusion restriction, and also supports existing literature that proximity to a welfare programme affects participation (Allard et al., 2003). Similarly, participation in joint work with other farmers increases the likelihood of participating in the fertilizer subsidy programme. These two determinants of participation could be interpreted to mean that access to information is relevant for participation. Farmers with higher household wealth are more likely to participate in the fertilizer subsidy programme. Also, farmers with higher rate of time preference are more likely to participate in the fertilizer subsidy programme. Furthermore, hired labour affects participation in the fertilizer subsidy programme. Farmers who engage in alternative employment are less likely to participate in the fertilizer subsidy programme. However, farmers with more years of farming experience in farming are more likely to do so.

6.0: Conclusions

The main objective of the present paper is to evaluate the impact of fertilizer subsidies on investment in soil and water conservation. This follows an implicit assumption in many fertilizer subsidy programmes that fertilizer subsidies will nudge investment in soil and water conservation. We adopt a full information maximum likelihood endogenous switching model that handles unobserved heterogeneity in the selection into the studied subsidy programme to simultaneously estimate soil and water conservation efforts and participation in the programme.

The results indicate that beneficiaries of the fertilizer subsidy programme do not invest more in soil and water conservation efforts as compared to non-beneficiaries. These findings suggest caution on reliance on farmers to respond to fertilizer subsidies with complementary inputs to ensure efficient and optimal nutrient uptake for agricultural production and fertilizer market development. The interaction between farmers and extension officers that was promoted as part of the fertilizer subsidy programme in Ghana does not result in significant investment in soil and water conservation. Previous studies of similar programmes (see e.g., Place and Dewees, 1999; Pender and Gebremedhin, 2008; Kassie et al., 2009) have indicated that access to information and extension officers can increase investment in soil and water conservation, but this does not appear to be happening with the fertilizer subsidy programme in Ghana.

The results that the participation in the fertilizer subsidy programme does not yield significant investment in soil and water conservation appear to be consistent with the broader interpretations of the theoretical model and empirical findings of Duflo et al. (2010) that farmers may not undertake profitable fertilizer investments. It is likely that the behavioral biases that prevent profitable fertilizer investment (e.g. hyperbolic discounting) could also account for lack of investments in soil and water conservation to support fertilizer adoptions.

The combination of increased fertilizer use with soil and water conservation investments would not only help ensure efficient and optimal nutrient uptake but could also offer a protection of agricultural production in SSA against climate change. The investment in soil and water conservation is seen as a measure to hedge agricultural production in SSA against climate change since these soil and water conservation investments will mitigate the growing water shortages, worsening soil conditions, and drought and desertification (IPCC, 2001; Kurukulasuriya and Rosenthal 2003). Given the importance of investment in soil and water conservation for achieving the stated objectives of the new fertilizer subsidies, efforts should be made to promote investment in soil and water conservation in addition to the fertilizer subsidies. These measures would increase output and income among the farmers. The finding from the study that participation in the fertilizer subsidy programme does not lead to such investments thus suggests that further intervention may be needed.

Thus, the fertilizer subsidy programme alone does not nudge Boserup (1965). This suggests that for the programme to crowd in investments in soil and water conservation, comprehensive measures that promote fertilizer adoption and investment in soil and water conservation simultaneously, such as an integrated soil fertility management programme, may be preferable.

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