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Impacts of climate change, agroecology and socio-economic factors on agricultural land use diversity in Bangladesh (1948–2008)

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ABSTRACT

The paper examines the impacts of climate change, agroecology and socio-economic factors on agricultural land use diversity (ALUD) using a panel data of 17 regions of Bangladesh covering a 61 year period (1948–2008) by applying a dynamic panel GMM estimator. Results revealed that ALUD and total rainfall have actually increased @ 0.19% and 0.02% per year whereas variability in temperature has declined @ 0.06% with significant differences across agroecological zones (AEZs). Among the climatic factors, total rainfall significantly increases ALUD. ALUD is also significantly influenced by agroecological characteristics. ALUD is significantly higher in Ganges River Floodplains but lower in Meghna River Floodplains and Chittagong Coastal Plain. Among the socio-economic factors, ALUD increases significantly with increase in the prices of vegetables, jute and phosphate fertilizer and R&D investment. ALUD significantly decreases with increase in the prices of lentil, onion, sugarcane, nitrogen and potassium fertilizers and extension expenditure. Policy implications include price policies to improve vegetable and jute prices, stabilise/reduce fertilizer prices and investments in R&D to develop crops that are suitable for high rainfall areas as well as specific AEZs in order to promote ALUD in Bangladesh.

1. Introduction

While the influences on the levels of agricultural production are multiple, inter-related and varied across different spatial scales, the impacts of climate change are increasingly recognised as a significant factor affecting livelihoods globally (Bharwani et al., 2005; Kurukulasuriya and Rosenthal, 2003). Nonetheless limitations remain in understanding the effects of global climate change on agriculture (Lobell et al., 2011). Land cover and land use changes are acknowledged to be related to environmental factors, including climate change, in complex ways (Dale, 1997; Lepers et al., 2005). While many have attempted to predict likely future impacts of climate change on food production (e.g., Benhin, 2008; Jackson, 2011), fewer studies addressed the relationship between climate change in the recent past and agricultural production over time at the regional scale—despite observed temperature increases over past decades (Lobell and Field, 2007). Similarly, very little attention has been paid to the ways in which climate change over the past may have impacted on land cover and agricultural land use. Instead, studies tend to examine the contribution of changing land use (e.g., de-forestation) to climate change (Gao and Liu, 2011). Where the question of agricultural land use is addressed, if often obliquely, is limited to the discussion of farm-level adaptation to climate change (e.g., Mercer et al., 2012; Manandhar et al., 2011). This increasingly rich and spatially-diverse literature examines the changes made by farmers in recent past in order to address perceived climate change at the local level. Although, these studies provide a valuable description of the heterogeneity of approaches to climate change adaptation by farmers and an exploration of the complex weave of social, economic, political, cultural and environmental factors influencing adaptation and how these vary across diverse geographical milieu, they do not provide a measure or quantitative evidence of the level and nature of influence of climate change on agricultural land use and/or agricultural productivity. As Gao and Liu (2011) explain, "…. few have studied the impact of climate change on land cover change, especially benign land cover change . . . nobody has explored the causal relationship between climate change and land use change except at the conceptual level" (p 477). Similarly, Salvati et al. (2013) explain that "up to now relatively few studies examine the changes in both land cover and selected climate variables over large areas at an adequate detailed spatial scale and over a long period of time" (p 402).

Furthermore, studies examining land use and land cover changes do not even mention climate as a significant factor. For example, Lambin et al. (2003) briefly mention climate as one aspect of natural variability affecting land use but climate is not listed in

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the authors' five fundamental high level causes of land-use change which include: resource scarcity; changing opportunities created by markets; outside policy intervention; loss of adaptive capacity and increased vulnerability; and changes in social organisation, in resource access and in attitudes. Similarly, Leper et al. (2005) while identifying land-use changes over a period of 1981–2000, the relationship between land-use change and climate change was not explored. Similarly, Qasim et al. (2013) examining land use change in the Swat District of Pakistan briefly mentioned the expansion of off-season vegetable production due to mild temperatures but there was no further discussion of the impact of global climate change.

Given such a dearth of information in the existing literature, the present paper is an attempt to examine the impacts of climate change, agroecology and a range of socio-economic factors on agricultural land use change or diversity (ALUD) at the regional scale over a 61 year period (1948–2008) using a panel data of 17 regions of Bangladesh, a country most vulnerable to climate change, increased flooding and other vagaries of nature.

We undertake this task by estimating a model of crop choice based on a theoretical framework of the farm household model applying a micro-econometric approach. This is because, we conceptualize that the observation of ALUD at a regional level is an aggregate response of individual farmers' crop choice decisions and subsequent allocation of their farm area to chosen crops in response to a host of factors. In general, in these decision making processes, socio-economic and policy factors dominate and climate change is seen as either an additional factor or an enabler to observed land use change. For example, Reid et al. (2000) noted that the most significant factors influencing land use change during 1957–1993 in Ghibe Valley in Ethiopia are the socio-economic and political factors although climate was only attributed to influx of migrants in the area following drought. Similarly, Liu et al. (2010) noted that land use change across China between 2000 and 2005 are due to national land strategies (e.g., reforestation policy) whereas climate warming is mentioned as enabling factor for conversion of grassland to arable lands. Otwald and Chen (2006) noted strong correlation of policies and reforms than climate change on land use change in Loess Plateau, China since the early 2000s. In this study, we explicitly include climate change variables and agroecological characteristics in addition to a wide range of socio-economic factors to identify their individual influences on ALUD at the regional level covering a long 61 year period (1948–2008).

The rest of the paper is structured as follows. Section 2 presents the analytical framework of the study, develops the empirical model, and describes the data. Section 3 presents the results. Section 4 provides conclusions and draws policy implications.

2. Methodology

2.1. The theoretical model

First, we develop a general model of farm production to examine the determinants of land use diversity and or area allocated to different crops following Rahman (2008). The farmer produces a vector Q of farm outputs using a vector of inputs X. The decision of choice; however, is constrained by a given production technology that allows combination of inputs (X) and an allocation of a fixed land area ($A = A^0$) among j number of crops, given the characteristics of the farm (Z). The total output of each farmer i is given by a stochastic quasi-concave production function:

$$Q_{ij} = f\left(X_{ijk} \ldots X_{ijk}, \epsilon | A_i, Z_i\right) \quad (1)$$

where ϵ is the stochastic variable indicating impacts of random noise. It is assumed that $f_{Xk} > 0$ and $f_{XXk} < 0$. Each set of area shares (α_j) among j crops sums to 1, $\sum_j^J \alpha_j = 1, j = 1, 2, \ldots J$, which maps into the vector Q through physical input-output relationships. The choice of area shares implies the level of farm outputs. The profit of each farm i is given by:

$$\pi_i(Q, X, p, w|A_i, Z_i) = \sum_{j=1}^{J} p_j Q_{ij} - \sum_{k=1}^{K} w_j X_{ijk} \quad (2)$$

where p is the vector of output prices and w is the vector of input prices.

The farmer is assumed to have a von Neuman-Morgenstern utility function, $U(W)$ defined on wealth W with $U_W > 0$ and $U_{WW} < 0$. The wealth is represented by the sum of initial wealth (W_0) and the profit generated from farming (π). Therefore, the objective of each farm is to maximize expected utility as (Isik, 2004):

$$\mathrm{EW}(W_0 + \pi(Q, X, p, w|A_i, Z_i) \quad (3)$$

where E is the expectation operator defined over ϵ. The choice variables in (3), the farm's input levels X_{ijk}, are characterized by the first-order conditions.

$$\frac{\partial \mathrm{EU}}{\partial X_{ijk}} = \mathrm{EU}_W\left(p_j \times f_{Mijk} - w_k\right) = 0 \quad (4)$$

The second-order conditions are satisfied under risk aversion and a quasi-concave production function (Isik, 2004). The optimal input mix is given by:

$$X^*_{ijk} = X^*_{ijk}\left(p_j, w_k, \mathrm{U}|A_i, Z_i\right) \quad (5)$$

and the optimal output mix, depending on $\left(X^*_{ijk}\right)$ is defined as:

$$Q^*_{ij} = f\left(X^*_{ij1}, \ldots . X^*_{ijk}\right)|A_i, Z_i \quad (6)$$

2.2. Determinants of the choice of crops

To determine the factors affecting a farmer's choice of crops, we derive the equivalent wealth or income from the expected utility (Rahman, 2008):

$$E_i = E(W_0 + \pi_i(Q, X, p, w|A_i, Z_i) \quad (7)$$

This equivalent wealth or income in a single decision making period is composed of net farm earnings (profits) from crop production and initial wealth that is 'exogenous' to the crop choices (W_0), such as farm capital assets and livestock resources carried over from earlier period.

Under the assumption of perfect market, farm production decisions are made separately from consumption decisions and the household maximizes net farm earnings (profits) subject to the technology and expenditure constraints (Benin et al., 2004). Therefore, production decision of the farms, such as crop choices, are driven by net returns (profits), which are determined only by input and output prices, farm physical characteristics and socio-economic characteristics of the farm household (Benin et al., 2004). Therefore, the optimal choice of the household can be re-expressed as a reduced form function of input and output prices, market wage, farm size, initial wealth, and socio-economic characteristics of the farms (Rahman, 2008):

$$h^*_i = h^*_i\left(p_j, w_k, Z_i, A_i, W_{0i}\right) \quad (8)$$

Eq. (8) forms the basis for econometric estimation to examine the factors affecting diversity of crops on individual farms, an outcome of choices made in a constrained optimization problem.

After developing the model for individual farmers, we extend the model to regional level. The key assumption is that the factors affecting choice of crops at the individual farm household level