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Crop-Livestock Inter-linkages and Climate Change Implications for Ethiopia's Agriculture

A Ricardian Approach

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Crop-Livestock Inter-linkages and Climate Change Implications for Ethiopia's Agriculture: A Ricardian Approach

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Abstract

There have been few attempts to look into the economic impacts of climate change in the context of Ethiopia. Although mixed crop-livestock farming is a dominant farming style, most of the studies on climate change, at least in the context of Ethiopia, have emphasized only crop agriculture and disregarded the role of livestock. In this research, we analyze climate change and agricultural productivity in Ethiopia in its broader sense, inclusive of livestock production. We employ a Ricardian approach, estimating three modified versions of the Ricardian model. Results show that warmer temperature is beneficial to livestock agriculture, while it is harmful to the Ethiopian economy from the crop agriculture point of view. Moreover, increasing/decreasing rainfall associated with climate change is damaging to both agricultural activities.

Key Words: crop-livestock inter-linkages, agriculture, climate change, Ricardian model, Ethiopia

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Contents

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Introduction

Climate change is expected to have serious impacts on agriculture in Africa in general and sub-Saharan Africa in particular (Challinor et al., 2007). Ethiopia is an agrarian country. Agriculture contributes about 40 percent of Ethiopian GDP (Gross Domestic Product), about 80 percent of employment, more than 80 percent of commodity export earnings and 70 percent of raw material supply for agro-based industries (MoFED, 2011). Except for the lowlands and pastoralist areas, mixed crop-livestock farming is the dominant farm type in the country. Eighty-one percent of the peasant farmers – particularly those concentrated in the Ethiopian highlands – practice mixed farming. Crop production contributed about 65 percent of agricultural GDP during 2007/08; the rest comes mainly from the livestock sub-sector (CSA, 2008). About 95 percent of the total agricultural output comes from about 11.7 million individual smallholder peasant farmers (MoARD, 2010). Cereals – mainly *teff*, maize, sorghum, wheat, and barley – are the most important crops in the country in terms of land area. These crops accounted for about 80 percent of the total crop area in 2010/11 (CSA, 2011). The fact that agriculture is largely traditional and rain fed, making it dependent on weather conditions (Diao and Pratt, 2007), makes the issue of climate change particularly important for Ethiopia. The dimensions of climate change that need to be considered are also diverse. For example, how would external perturbations such as climate change affect crop and livestock production? How would this, in turn, affect Ethiopia's agricultural productivity and food

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security situation? Thus, in this study, using a Ricardian approach, we analyze the impact of climate change on agriculture production, i.e., crop net revenue; livestock net revenue; and whole farm net revenue (taking agriculture as a whole inclusive of livestock). We find that warmer temperature is beneficial to livestock agriculture, but harmful to crops. In addition, changes in rainfall associated with climate change are damaging to both agricultural activities.

Ethiopia is a country of more than 1.1 million square kilometers, located in the Horn of Africa. With more than 80 million inhabitants, Ethiopia is the second-most populous nation in Africa after Nigeria. The country has a sustained record of strong economic growth, which, during the last decade, contributed significantly to the sustainable development agenda: GDP has nearly tripled since 1992 with a corresponding reduction in head count poverty from 56 percent in 1992 to 29.5 percent in 2011 (MoFED, 2012). Ethiopia has witnessed double digit growth (i.e., 11.2% growth in real GDP) (MoFED, 2010). This growth performance effectively surpasses the 7% annual rate required for attaining the MDG of halving poverty by 2015 (ADBG, 2010).

Climate change has recently attracted the attention of various stakeholders in Ethiopia. The first conference organized by a newly established national Climate Change Forum, which was held in January 2009, was opened by the late Prime Minister Meles Zenawi. Besides his leading role in the international climate negotiations, he was co-chair of the High-Level Advisory Group on Climate Change (UNFCCC). A civil society network on climate change has also been established recently. In addition, Addis Ababa is part of the C40, a group of 40 large cities committed to tackling climate change. A national adaptation program of action (NAPA) and a nationally appropriate mitigation action (NAMA) have been submitted to UNFCCC. Impacts of current climate variability identified in the NAPA document include food insecurity due to drought and floods; outbreak of diseases such as malaria, water borne diseases and respiratory diseases; and land degradation due to heavy rainfall.

Since February 2011, Ethiopia has been developing a Climate Resilient Green Economy (CRGE) strategy, under the leadership of the Prime Minister's Office, the Environmental Protection Authority, and the Ethiopian Development Research Institute, in order to build a green economy. Under seven sectoral teams, more than fifty experts from twenty leading government institutions have been involved. The strategy identifies green economy opportunities and levers that could help Ethiopia reach its ambitious growth targets while keeping greenhouse gas emissions low. Preparation of the climate resilient part of the study is also currently underway. However, only a few studies have looked at vulnerability and impacts of climate change in the context of Ethiopia in a rigorous fashion. These include Deressa (2007); Deressa et al. (2008a); Deressa et al. (2008b); Deressa and Hassan (2009); and Yesuf et al. (2008). Even though climate change is expected to have an impact on both crops and livestock production, most of the studies concentrate only on crop agriculture, disregarding the role of livestock.

Thus, the purpose of this study is to analyze the impact of climate change on agriculture inclusive of livestock production. Specifically, the objectives of this study are threefold: (i) assess the impact of climate change on crop farming; (ii) analyze the impact of climate change on livestock farming; and (iii) analyze the combined (overall) impact of climate change on agriculture, that is, for crop and livestock farming combined. In doing so, by broadening and extending our understanding of climate change and agricultural productivity in Ethiopia and enhancing informed policy/decision making at various levels, this research will contribute to poverty reduction and environmental sustainability.

The paper is organized as follows. The next section presents a review of climate change, agriculture and the Ricardian model. The third section presents the theory and model, while the fourth section presents the empirical model and data. The fifth section presents results and discussion. The paper ends with conclusions and policy implications.

Climate Change, Agriculture and Ricardian model: Literature Review

The Ricardian approach became popular in assessing the impact of climate change on agriculture following Mendelsohn et al (1994). Since then, there have been quite a few studies on climate change and agriculture that employed the Ricardian model or technique. The model is amenable to analyzing cross-sections of farms under different climatic conditions and examines the relationship between the value of land (Sanghi et al., 1998; Mendelsohn et al., 1994) or net revenue (Kumar and Parikh, 1998; Mendelsohn et al., 1994; Ouedraogo et al., 2006; Molua and Lambi, 2006; Kabubo-Mariara and Karanja, 2006; Eid et al., 2006; Benhin, 2006;Sene et al., 2006; Jain, 2006; Mano and Nhemachena, 2006; Deressa, 2006) and climatic factors (Mendelsohn et al., 1994; Sanghi et al., 1998; Kumar and Parikh, 1998), soils and socio-economic variables. It has been applied to value the contribution of environmental factors to farm income by regressing farm performance, with land values or net revenue taken as dependent variables, on a set of independent variables, including environmental factors, traditional inputs (land and labor) and support systems (infrastructure). Besides measuring the contribution of each factor, the Ricardian approach is also used to detect the effects of long-term climate change on farm values (Mendelsohn et al., 1994; Mendelsohn and Dinar, 1999). The Ricardian approach was named after David Ricardo (1772–1823) because of his original observation that land rents would reflect the net productivity of farmland (Mendelsohn and Dinar, 2003).

The Ricardian model was initially applied in the context of developed countries in general and US agriculture in particular (Mendelsohn et al, 1994; Adams et al, 1998; Polsky and Esterling, 2001; Polsky, 2004). It has been recently applied in specific developing countries contexts. Some of these recent studies include Sanghi (1998), Kumar (2009), Deressa and Hassan (2009), Benhin (2006), Gbetibouo and Hassan (2005), Ouedraogo et al., (2006), Sene et al. (2006), Seo et al. (2005), Kurukulasuriya and Mendelsohn (2008), Kabubo-Mariara and Karanja (2006), Molua and Lambi (2006), Eid et al. (2006), Jain, (2006), Mano and Nhemachena (2006) and Zahi et al. (2009). Not surprisingly, most of these studies have shown that agriculture in developing economies is very vulnerable to climate change. Most of these studies also reveal that the magnitude and direction of the impact may differ from region to region.

Deressa (2007), Deressa and Hassan (2009) and Kassahun (2009) are among the few studies that have investigated impacts of climate change in the context of Ethiopia using a Ricardian approach. Deressa and Hassan (2009) find that the climate variables have a significant impact on net crop revenue per hectare of farmers under Ethiopian conditions. They also find that, whereas marginally increasing seasonal precipitation during spring would significantly increase net crop revenue per hectare, marginally increasing seasonal temperature during summer and winter would significantly reduce net crop revenue per hectare. Moreover, their analysis of impact of predicted climate scenarios from three models (i.e., CGM2, HaDCM3 and PCM) for the years 2050 and 2100 show that there would be a reduction in net crop revenue per hectare by the years 2050 and 2100 and that the reduction in net revenue per hectare by the year 2100 would be higher than the reduction by the year 2050, suggesting that the damage posed by climate change will increase with time unless this negative impact is countered through adaptation efforts. Their results also indicate that the net revenue impact of climate change is not uniformly distributed across the different agro-ecological zones of Ethiopia. However, these studies looked at the impacts of climate change on crop agriculture only.

The Ricardian approach has also been applied to a broader African context. Some of these attempts include Seo and Mendelsohn (2006, 2008a, b); Kurukulasuriya et al. (2006); Kurukulasuriya and Mendelsohn (2008) and Seo et al. (2009). These studies suggest that hot and dry climate scenarios would reduce net crop revenues in Africa.

Most of these studies also reveal that the magnitude and direction of the impact may differ from region to region. For example, Kurukulasuriya and Mendelsohn (2006) find that climate change affects African countries with a dry climate, such as Niger and Burkina Faso, more than those with a relatively cooler climate. Moreover, in relation to livestock, earlier African studies suggest that small landholders would turn to livestock in response to, warming and that farmers with livestock would do much better than if they depended on crops alone (Kurukulasuriya et al., 2006; Seo and Mendelsohn, 2008a, b). These studies also imply that omitting livestock in analyses would overestimate climate damages.

The following issues stand out from the foregoing review. Firstly, climate change is a real threat to countries like Ethiopia. It also turns out that both the relatively least-developed, semi-arid, and arid regions, and the relatively well endowed regions are vulnerable to climate change, although the level of vulnerability varies. Thus, there is a real need for adaptation policies that are tailored to the anticipated impacts for that specific country; quantifying the impact of climate change on agriculture can therefore provide an important guide to policy. Secondly, whereas the mixed crop-livestock farming is the dominant farming style, rigorous studies of impacts of climate change on agriculture, at least in the context of Ethiopia, have looked at crop agriculture only, disregarding the role of livestock. Intuitively, however, the effect of climate change would be expected to be different with inclusion of livestock production of farmers, thereby affecting farm incomes. Hence, disregarding livestock production may misrepresent the impact of climate change. Moreover, and perhaps more importantly, there appear to be significant inter-linkages (and tradeoffs) between the crop and livestock subsystems within the farm household system (Fafchamps et al., 1998; Scoones and Wolmer, 2000; Kazianga, and Udry, 2004; Erenstein et al., 2007), particularly at times of stress, which is another dimension of interest in climate change study. Therefore, it would be important to look at climate change and agricultural productivity in a broad sense, inclusive of livestock production.

Theory and Model

To analyze the impact of climate change and climate variation on Ethiopian agriculture, this study uses a Ricardian analysis following Mendelsohn et al (1994). Crops and livestock are likely to react to climate change differently. This study attempts to analyze the impact of climate change on crop farming and livestock farming, as well as on agriculture (crop and livestock farming combined). In order to capture the return from crop production, we specify land value, V_L , as:

$$V_L = \int_0^\infty [(P_i Q_i *(K_i, F) - C_i(Q^*, \Omega, F)) / L_i] e^{-rt} dt \tag{1}$$

where P_i is the price of output of good *i*, in our case, crop *i*; Q_i is the quantity of output of good *i*,, in our case, crop *i*; $K_i = (k_{i1}, k_{i2}, ..., k_{ij}, ...k_{iJ})$ is a vector of all purchased inputs *j* used to produce Q_i ; k_{ij} is the purchased input j $(1, 2, ..., J)$ in the production of good (crop) i . $F = (F_1, F_2, ..., F_m, ..., F_M)$ is a vector of site specific exogenous environmental factors such as climate (e.g., temperature and precipitation) and soil in *M* sites. C_i is the cost of production of good (crop) i and Ω $(\omega_1, \omega_2, ..., \omega_n)$ is a vector of all other factor prices except land. L_i is the land employed for the production of crop *i* (in hectares), *r* is interest rate and *t* is time period. Note also that the *-rt* term represents discounting. The farmer is assumed to choose K to maximize crop net revenues given farm characteristics and market prices.

Now let's turn to the framework for capturing returns from livestock farming (production). Assuming the farmer maximizes net revenue by choosing which livestock to purchase and which inputs to apply:

$$Max(\pi) = P_{qj} Q_j (L_G, S, H, K, F, A, Z) - P_F S - P_W L - P_K K \tag{2}$$

where π is net revenue from livestock (animal) *j*, P_{qj} is market price of animal *j*, Q_j a production function for animal *j*, L_G is grazing land, *S* is feed, *H* is a vector of labor inputs, *K* is a vector of capital such as barns and milking equipment, *F is* a vector of climate variables, *A* is available water, *Z* is a vector of soil characteristics of grazing land, P_F a vector of prices for each type of feed, P_W is a vector of prices for each type of labor, and P_K the rental price of capital.

Suppose that the farmer chooses rearing the species (animal) *j* and the number of animals that maximize profits. Then, the profit maximizing condition to the representative farmer's problem can be specified as:

$$\pi^* = \pi(P_q, F, A, Z, P_S, P_W, P_K) \tag{3}$$

Note that equation (3) is the Ricardian equivalent to livestock production; it explains how profits change across all the exogenous variables the representative farmer is facing (Seo and Mendelsohn 2006).

Empirical Model and Data

Empirical Model

In this section, we outline the empirical model we employed in our analysis. As noted, the Ricardian model is based on a set of explanatory variables such as climate, soils and socio-economic variables that affect farm value or revenue. The model uses actual observations of farm performance (Mendelsohn et al., 1994). Note also that the standard Ricardian model relies on a quadratic formulation of climate variables. Therefore, we specify the empirical model as:

$$V = B_0 + B_1 F + B_2 F^2 + B_3 Z + B_4 G + u \tag{4}$$

where *V* stands for land value, *F* is vector of climate variables, F^2 is square of vector of climate variables Z is the set of soil variables, *G* is the set of socio-economic variables, *u* is an error term, and F and F^2 capture linear and quadratic terms for temperature and precipitation, B's are parameters to be estimated with B_0 standing for the constant term and the rest are coefficients. The introduction of quadratic terms for temperature and precipitation reflects the non-linear shape of the response function between crop net revenue and climate. From past studies, one expects that farm revenues will have a U-shaped or hill-shaped relationship with temperature. When the quadratic term is positive, the net revenue function is U-shaped, and when the quadratic term is negative, the function is hill shaped. The idea is that for each crop, there is a known temperature range in which that crop grows best across the seasons, although the optimal temperature varies from crop to crop (Mendelsohn et al., 1994).

Given equation (4), one can derive the marginal impact of climate variables (f_i) on crop revenue evaluated at mean, which can be specified as follows:

$$E\left[\frac{dV}{dF_i}\right] = E[\beta_{1i} + 2\beta_{2i} * F_i],$$

$$= \beta_{1i} + 2 * \beta_{2i} * E(F_i), \tag{5}$$

where *E* is the expectations operator *β*'s are parameters to be estimated as in above. The change in economic welfare, ΔW , resulting from a change in the state of the environment from A to B, which causes environmental inputs to change from F_A to F_B, can be measured as in equation (5) (Kurukulasuriya and Mendelsohn, 2006). Here one can analyze the impact of exogenous changes in environmental variables on net economic welfare (ΔW). The net economic welfare is the change in welfare induced or caused by a change in the state of the environment from a given state, i.e., from A to B, which causes environmental inputs to change from F_A to F_B. The change in annual welfare from this change in the state of the environment is, therefore, given by:

$$\Delta W = W(F_B) - W(F_A)$$

$$= \int_0^{Q_B} [(P_i Q_i(K_i, F_B) - C_i(Q_i, \Omega, F_B))/L_i] e^{\sigma t} dQ - \int_0^{Q_A} [(P_i Q_i(K_i, F_A) - C_i(Q_i, \Omega, F_A))/L_i] e^{\sigma t} dQ \tag{6}$$

If market prices do not change as a result of the change in *F*, then the above equation, that is, equation (6), reduces to:

$$\Delta W = W(F_B) - W(F_A)$$

$$= [PQ_B(K_i, F_B) - \sum_{i=1}^{n} C_i(Q_i, \Omega, F_B)] - [PQ_A(K_i, F_A) - \sum_{i=1}^{n} C_i(Q_i, \Omega, F_A)] \tag{7}$$

Substituting $P_L L_i = P_i Q_i * - C_i(Q_i *, \Omega, F)$ into (7), we have that:

$$\Delta W = W(F_B) - W(F_A) = \sum_{i=1}^{n} (P_{LB} L_{Bi} - P_{LA} L_{Ai}) \tag{8}$$

where P_{LA} and L_A are at F_A and P_{LB} and L_B are at F_B.

The present value of welfare change is thus:

$$\int_0^{\infty} \Delta W e^{\sigma t} = \sum_{i=1}^{\infty} (V_{LB} L_{Bi} - V_{LA} L_{Ai}) \tag{9}$$

The Ricardian approach takes either (8) or (9), depending on whether data are available on annual net revenues or capitalized net revenues (land values, V_L). However, data on land prices were not available for the selected samples, as these are often difficult to find in developing countries. Therefore, model (8) was employed for this study to measure the impact of climate change on crop, livestock and agriculture for the whole of Ethiopia.

The empirical estimation of the Ricardian model for Ethiopia follows the work of Seo and Mendelsohn (2007a) and Kabubo-Mariara (2008) and takes into account changes in temperature and precipitation patterns in the study area resulting from climate change.

Letting $F = T,R$, with T and R respectively standing for temperature and precipitation, and noting that the standard Ricardian model relies on a quadratic formulation of climate variables, the final empirical model is then specified as:

$$\pi = \beta_0 + \beta_1 T + \beta_2 T^2 + \beta_3 R + \beta_4 R^2 + \beta_5 Z + \beta_6 G + \varepsilon \qquad (10)$$

where T and T-squared capture levels for temperature, while R and R-squared capture levels for precipitation. Z and G respectively stand for a vector of soil characteristics and socio-economic variables, as above.

From equation (10), the expected marginal impact of, for example, changes in temperature and rainfall on livestock net revenue can be derived in the following form:

$$E(\frac{\partial \pi}{\partial T}) = \beta_1 + 2\beta_2 E(T)$$
$$E(\frac{\partial \pi}{\partial R}) = \beta_3 + 2\beta_4 E(R) \qquad (11)$$

The change in welfare, ΔW, resulting from changes in the state of the environment, such as climate change, from some initial state F_0 to F_1 can be measured as follows (Kurukulasuriya and Mendelsohn, 2006):

$$\Delta W = NR(F_1) - NR(F_0), \qquad (12)$$

where NR stands for net revenue. Note that if the change in welfare ΔW in equation (12) is positive, implying increases in livestock net revenue, it will be beneficial. Otherwise, the change will be harmful; i.e., if it is negative, it implies decreases in livestock net revenue.

Accordingly, climate change impact using the Ricardian model for the Nile basin of Ethiopia is specified using net revenue obtained separately from crop and livestock, as well as for agriculture as a whole. Note that, in our case, net revenue, such as that for crops, is defined as gross crop revenue less the total associated cost of production calculated for each agricultural household. Then, this net revenue is used as a dependent variable and specified as a function of the following set of regressors: (i) climate variables (temperature and precipitation); (ii) soil types/characteristics, and (iii) socio-economic variables, such as household characteristics (and characteristics of the farm firm), institution support and infrastructure. We run three Ricardian models that consider crop net revenue, livestock net revenue and (whole) farm net revenue, inclusive of livestock, as dependent variables, which are regressed separately. STATA statistical software and its econometric package were used to estimate the Ricardian model.

Outliers, heteroscedasticity, multicollinearity and endogeneity of explanatory variables are major econometric problems often faced with cross-sectional data. In light of the fact that these econometric issues will likely affect the robustness of the regression results, the following remedies were undertaken: leverage, Cook's D, DFITS and DFBETA for unusual and influential data; White's general heteroscedasticity test for heteroscedasticity; a variance inflation factor for continuous variables; and chi-square tests for independence of dummy variables for multicollinearity.

The Data

The dataset we used for this study comes from a cross-sectional survey of 1000 farm households in the Nile Basin of Ethiopia. The survey was carried out during the 2004/05 production year by Environmental Economics Policy Forum for Ethiopia (EEPFE) at the Ethiopian Development Research Institute (EDRI) in collaboration with the International Food Policy Research Institute (IFPRI), with the objective of analyzing the potential impact of climate variability and climate change on household vulnerability and farm production. The household survey covered five regional states of Ethiopia and 20 districts. The sample districts were purposely selected to include different attributes of the basin, such as agro-ecological zones in the basin, the degree of irrigation activity (percent of cultivated land under irrigation), average annual rainfall, rainfall variability (coefficient of variation for annual rainfall), and vulnerability. One peasant association was selected from each district, making a total of 20, by a purposive sampling method designed to include households that irrigate their farms. Once the peasant associations were chosen, 50 farmers were selected at random from each peasant association, making the total sample size 1,000 farmers.[1]

The Nile basin of Ethiopia is suitable for the cultivation of a large variety of crops. A total of 48 annual crops were grown in the basin. The main crops of the basin are *teff*, maize, wheat, barley, and beans, which cover 65 percent of the plots during the study period (Yesuf et al., 2008). The data covered farm production, climate, and soils, as well as socio-economic information. As explained earlier, this study employs three main sets of the modified Ricardian model for crop net revenue, livestock net revenue, and whole farm net revenue (i.e., taking agriculture as a whole, inclusive of livestock). The

[1] Further details about the dataset can also be found in Deressa et al., 2008 and Yesuf et al., 2008.

respective net revenues are taken as dependent variables. Respective net revenue variables are calculated (generated) from the dataset. In this paper, net revenue (gross margin) is calculated as total revenue less costs/expenses involving cash outlay. Moreover, the Ricardian model for the case of crop agriculture analyzed land value or net revenue per hectare. However, it is very difficult to measure the amount of land that farmers use for livestock, because they tend to rely on open, communal and public land. Therefore, the dependent variable in our model is livestock net revenue per farm. It is also worth mentioning that the data we used have limited information about costs of raising livestock. Thus, the definition of livestock total cost includes the cost of feed, tools, machinery and medicines. But we didn't include the household's own labor or hired labor as part of the total cost. In the case of crop, total cost is calculated by adding cost for fertilizer, seed, compost, manure and all other chemical inputs. Net revenues are a function of three sets of regressors: (i) climate variables (temperature and precipitation); (ii) soil types/characteristics, and (iii) socio-economic variables, such as household characteristics, institution support and infrastructure. The independent variables considered in the estimated models also included the linear and quadratic temperature and precipitation terms for the four seasons: summer (the average for June, July and August), winter (the average for December, January and February), spring (the average for March, April and May) and fall (the average for September, October and November). The effects of the seasonal climate variables vary across the three models. Table 1 presents descriptive statistics of the variables used in the analysis. As can be seen from the table, for the year 2004/05, the mean total net farm revenue of the study area was around 3,521 Birr; the larger percent, 83%, from crop agriculture (2870 Birr) and a much smaller percent, 17%, from livestock (615 Birr). Most of the study area was covered with red soil (61%). A very small portion of the Nile Basin had access to electricity during the study period (19%). About nine-tenths of the households in the Nile Basin own livestock. Nearly 50% of them have farm extension and credit access. Households in the study area, on average, have 23 years of farming experience.

Table 1. Descriptive Statistics of Variables Used in the Three Regressions (Crop, Livestock and Total Agriculture)

Variable	Mean	Std. Dev.	Min	Max
Crop net revenue	2,870.31	3,574.76	31.98	34,867.09
Livestock net revenue	651.10	2,252.29	(9,281.00)	18,967.00
Net farm revenue	3,521.42	4,438.08	(7,695.81)	34,937.09
Summer temperature	18.25	2.1649	12.86	26.83
Winter temperature	18.94	3.2203	11.84	26.44
Spring temperature	20.70	2.6685	16.01	25.85
Fall temperature	18.16	2.4439	13.11	24.18
Summer precipitation (mm)	265.12	72.4330	3.90	368.18
Winter precipitation (mm)	9.66	11.4851	0.07	105.21
Spring precipitation (mm)	89.54	48.6278	17.65	196.36
Fall precipitation (mm)	100.86	49.3686	1.42	190.38
Clay soil (0/1)	0.19	0.3885	0	1
Sandy soil (0/1)	0.17	0.3767	0	1
Dark soil (0/1)	0.59	0.4926	0	1
Red soil (0/1)	0.61	0.4873	0	1
Electricity (0/1)	0.189	0.39170	0	1
Irrigation (0/1)	0.17	0.3732	0	1
Crop land area (ha)	2.06	1.2585	0.05	11.07
Distance to output market (km)	5.70	3.8682	0.05	45
Distance to input market (km)	5.66	4.1970	0	50
Livestock ownership (0/1)	0.92	0.2775	0	1
Crops extension (0/1)	0.54	0.4986	0	1
Livestock extension (0/1)	0.48	0.4997	0	1
Farm extension (0/1)	0.48	0.4998	0	1
Credit availability (0/1)	0.50	0.5002	0	1
HH heads years of education	1.71	2.7979	0	14
Farming experience (years)	23.42	12.9218	1	68

Results and Discussion

This study employs three main sets of the modified Ricardian model for crop net revenue; livestock net revenue; and whole farm net revenue (i.e., taking agriculture as a whole inclusive of livestock), with the respective net revenues taken as dependent variables. In this paper, the Ricardian approach for the case of crop agriculture analyzed land value or net revenue per hectare. Net revenues are a function of three sets of regressors: (i) climate variables (temperature and precipitation); (ii) soil types/characteristics, and (iii) socio-economic variables such as household characteristics, institution support and infrastructure.

The empirical question is to find out how and to what extent would the three sets of explanatory variables, i.e., the soil, climate, and socio-economic variables, help explain variability in net revenue. Table 2 depicts the regression estimates of crop net revenue model. The coefficient of the soil variables (clay, dark and red) are positive and significant in explaining the variability in crop net revenues across farmers, indicating the importance of soil types for determining the value of land. Among the socio-economic variables, access to irrigation and household size significantly enhanced crop net revenue. Surprisingly, access to extension programs and access to credit have a negative and significant correlation to net revenue from crop agriculture; perhaps this is because the programs might not be demand-driven. Unexpectedly, distance from input market also has a positive impact on crop net revenue. Size of land for crop cultivation is also positively associated with crop net revenue, suggesting that larger farms are more productive on a per hectare basis than smaller ones.

The results for the climate variables also show that both linear and squared terms are significant in all seasons (except linear winter precipitation and squared fall precipitation), implying that climate has a nonlinear effect on crop net revenues. There is also a connection between the interaction terms and crop net revenue (except the winter interaction term). Concerning the linear terms, results suggest that an increase in seasonal temperatures reduces crop net revenue per hectare, specifically for the summer, winter and spring seasons, whereas increases in fall temperature increases net revenue. An increase in precipitation, particularly for summer and spring, also has positive effects on crop net revenues. In addition, an increase in precipitation in the fall leads to higher crop net revenue. However, the effect of quadratic seasonal climate variables on crop net revenue is not obviously determined by looking at the coefficients, as both the linear and the squared terms play a role (Kurukulasuriya and Mendelsohn, 2006). Therefore, the climate coefficients will have to be interpreted based on the marginal effects of climate variables (temperature and precipitation).

Table 2. Ricardian regression estimates of crop net revenue model

Variables	Coefficients	t-statistics
Summer temperature	-18165.05***	-3.85
Summer temperature sq	431.74***	3.78
Winter temperature	-4977.89***	-2.92
Winter temperature sq	104.75*	2.18
Spring temperature	-15875.88***	-3.07
Spring temperature sq	433.88***	3.62
Fall temperature	25354.25***	4.76
Fall temperature sq	-763.56***	-4.93
Summer precipitation	-416.82***	-4.21
Summer precipitation sq	0.18***	3.01
Winter precipitation	184.65	0.63
Winter precipitation sq	-4.37***	-4.50
Spring precipitation	-397.78***	-4.26
Spring precipitation sq	0.22***	1.74
Fall precipitation	515.07**	5.25
Fall precipitation sq	-0.15	-1.37
Summer temp X precip	21.49***	4.89
Winter temp X precip	6.75	0.52
Spring temp X precip	16.19***	3.87
Fall temp X precip	-30.15***	-5.53
Soil - clay	353.48*	2.02
Soil - sandy	273.16	1.45
Soil - dark	368.58*	2.27
Soil - red	319.75*	2.07
Livestock Ownership	-319.05	-1.17
Crop land area	451.08***	5.60
Distance from output market	-29.21	-1.23
Distance from input market	44.70*	1.83
Extension program (crop)	-317.53*	-2.02
Credit	-353.00***	-2.74
HH head years of education	10.84	0.39
Family size (log)	630.72***	3.68
Farming experience (years)	-5.74	-1.17

Irrigation	520.88**	2.47
Constant	178954.60***	4.80
F(30, 890)	**19.19**	
Prob> F	**0.000**	
R-sq	**0.531**	
Root MSE	**1911**	
n	**925**	
*** p<.05; ** p<.01; *** p<.001**		

The Ricardian model results for livestock net revenue show that the coefficients of the soil variables (red and clay) have a significant and positive effect (Table 3). Among the socio-economic variables, access to formal extension (for livestock) and years of education of head of household turned out significant and positive, supporting the fact that increased access to extension services and education are associated with improved farming information, which is important for livestock productivity and revenue. As expected, livestock ownership is significant and positively associated with net revenue from livestock. Distance to the nearest input market is negative and very significant, perhaps because farmers incur more transaction costs in terms of money and time as the market place becomes further from their farm gates/plots. On the contrary, distance from output market is positively related to net revenue, perhaps because, as distance from output market increases, the product price might become very high and thus add revenue for the seller. Similar to the results for crop net revenues, access to credit is negatively and significantly related to livestock net revenue. Irrigation access also turned out to be significant and positive. Irrigation increases the number of crop harvests per year, which also means more crop residues available as feed for livestock. Irrigation also allows grasses to grow on plot boundaries and ridges. Farm size turns out significant and positive, suggesting that large farms are more productive than small farms. Not surprisingly, access to irrigation and years of experience in farming increase livestock net revenue. Regarding the climate coefficients, both linear and squared terms are significant in most of the seasons, implying that climate has a non-linear effect on net revenue. The interpretations of the signs and magnitudes of impacts are further explained in the marginal analysis below.

Table 3. Ricardian regression estimates of net livestock revenue model

Variables	Coefficients	t-statistics
Summer temperature	-10078.2***	-4.66
Summer temperature sq	238.88***	4.57
Winter temperature	381.24	0.35
Winter temperature sq	1.03	0.03
Spring temperature	-5776.53*	-1.87
Spring temperature sq	137.48**	1.99
Fall temperature	10560.03***	4.06
Fall temperature sq	-294.64***	-3.84
Summer precipitation	-140.83***	-3.06
Summer precipitation sq	-0.003	-0.09
Winter precipitation	-992.70***	-3.71
Winter precipitation sq	2.23***	3.93
Spring precipitation	44.17322	1.14
Spring precipitation sq	0.130071	1.51
Fall precipitation	118.6232**	2.34
Fall precipitation sq	-0.04298	-0.58
Soil - clay	373.8652***	3.02
Soil - sandy	72.39039	0.62
Soil - dark	-53.1719	-0.55
Soil - red	174.4503*	1.77
Livestock Ownership	251.146*	1.65
Crop land area	66.83165*	1.74
Distance from output market	89.21277***	5.16
Distance from input market	-63.9982***	-3.52
Extension program (livestock)	348.5848***	3.61
Credit	-143.589*	-1.78
HH head years of education	37.98163**	2.32

Family size (log)	96.93869	0.92
Farming experience (years)	6.818176**	1.99
Irrigation	300.4892**	2.5
Constant	6389.63***	3.04
F(30, 921)	**8.54**	
Prob> F	**0.000**	
R-sq	**0.235**	
Root MSE	**1207.5**	
n	**952**	

* p<.05; ** p<.01; *** p<.001

In the case of Ricardian estimates of total farm net revenue (i.e., net revenue from agriculture as a whole inclusive of livestock), among the soil variables considered in the model, clay turned out to be significant and positive (Table 4). Similar to those of the crop and livestock revenue regression results reported above, access to credit is negatively and significantly correlated with agricultural revenue. The result also suggests that access to irrigation increases net revenue from agriculture, because using irrigation water increase agricultural production, productivity, and the number of times farmers produce per year. Family size is significantly and positively associated to agricultural revenue, indicating that crop as well as livestock agriculture is labor demanding. Surprisingly, distance from input market turned out positive and significant. In line with prior expectations, farming experience increases net revenue from agriculture. The positive and significant effect of farm size suggests the economics of scale that large farms have as compared to small ones. Surprisingly, the result depicts that livestock ownership leads to less agriculture net revenue.

Considering linear, squared and interaction terms, the climate coefficients reveal that agricultural net revenue is generally sensitive to climate variables. However, as explained earlier, the effects of the climate variables on agriculture net revenue cannot be determined by looking at the coefficients, as both the linear and the squared terms play a role. Hence, the climate coefficients need to be interpreted based on the marginal effects of climate variables (temperature and precipitations).

The Fisher-Snedecor test is used to validate the total significance of the models and the Student *t* test for the individual significance of each coefficient or parameter estimate. The Fisher-Snedecor test shows that all three regressions are significant at the 1% level. The coefficient of determination (R^2) is 53%, 24%, and 53% for the crop, livestock and total agriculture models, respectively.

Table 4. Ricardian regression estimates of whole farm net revenue model

Variables	Coefficients	t-statistics
Summer temperature	-21725.88***	-4.9
Summer temperature sq	499.52***	4.67
Winter temperature	-4691.91**	-2.48
Winter temperature sq	114.01**	2.12
Spring temperature	-23244.23***	-4.14
Spring temperature sq	605.83***	4.66
Fall temperature	30648.82***	5.96
Fall temperature sq	-912.59***	-6.12
Summer precipitation	-498.13***	-5.38
Summer precipitation sq	0.14**	2.46
Winter precipitation	-389.66***	-1.02
Winter precipitation sq	-1.35***	-1.4
Spring precipitation	-379.14**	-3.77
Spring precipitation sq	0.32**	2.05
Fall precipitation	632.24***	6.18
Fall precipitation sq	-0.25*	-2
Summer temp X precip	26.27***	6.44
Winter temp X precip	26.05	1.55
Spring temp X precip	15.9***	3.54
Fall temp X precip	-35.22***	-6.05
Soil - clay	598.77**	2.71
Soil - sandy	259.89	1.22
Soil - dark	231.81	1.21
Soil - red	207.83	1.11
Livestock Ownership	-750.28**	-2.69
Crop land area	640.99***	7.21
Distance from output market	-84.48	-1.57
Distance from input market	124.66*	2.15
Extension program	-229.55	-1.28
Credit	-516.47***	-3.4
HH head years of education	59.32*	1.82
Family size (log)	655.78***	3.5
Farming experience (years)	2.19	0.36
Irrigation	654.51**	2.61
Constant	243993.70***	6.05
F(34, 845)	**23.39**	

Prob> F	**0.000**	
R-sq	**0.5274**	
Root MSE	**2200.8**	
n	**880**	
*** p<.05; ** p<.01; *** p<.001**		

Marginal Effect of Climate Variables

The estimated marginal effects of temperature and precipitation on crop net revenue, livestock net revenue, and total farm net revenue are presented in Table 5. The table shows the net annual and seasonal marginal effect of increases in temperature by 1°C and increases in precipitation by 1 mm per month.

The marginal impact analysis indicated that a 1°C increase in annual temperature will lead to a change in net revenue of -1577.72 Birr from crop agriculture, 282.09 Birr from livestock production, and -694.15 Birr from total agriculture inclusive of livestock. All these changes are statistically significant at the 5% and 10% level, respectively.

Table 5. Marginal effects of climate variables based on coefficients from Tables 2, 3 and 4

Climate variables	Crop	Livestock	Agriculture(total)
Temperature	**-1577.72*** **	**282.09** **	**-694.15*** **
Summer	*2496.01****	537.16**	*3166.97*
Winter	*-617.71***	733.49**	*-273.37****
Spring	*2042.11***	-249.85**	*2455.61***
Fall	*-5498.13****	-738.71	*-6043.36****
Precipitation	**183.19** **	**-163.78**	**88.75* **
Summer	*67.84****	-11.71*	*55.2****
Winter	*192.72***	-183.72**	*83.2*
Spring	*-23.59*	29.55*	*7.4*
Fall	*-53.78****	2.1	*-57.05****

Note: * Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level

The marginal impacts of precipitation on net revenues indicate that an annual increase of 1mm/month of precipitation will have significant positive effects on crop net revenues and net farm revenue, but negative impact on livestock net revenue. For the Nile basin of Ethiopia, an annual net gain of 183.19 Birr and 88.75 Birr is expected from crop agriculture and from total agriculture, respectively. A net loss of 163.78 Birr is expected from livestock production. The seasonal impacts of temperature and precipitation are also indicated in Table 5. The results are consistent with Seo and Mendelsohn (2007a): an increase in temperature is related to lower net revenue from crops because farmers shift from crops to livestock, natural ecosystems shift from forests to grasslands, and diseases become less prevalent. Moreover, from an adaptation point of view, livestock becomes an option, as long as there is enough precipitation to support grassland. On the other hand, livestock net revenue decreases as precipitation increases. Farmers shift from livestock to crops, grasslands shift to forests, and the prevalence of animals' diseases increases.

Regarding seasonal differentiation, marginally increasing temperature during summer and spring seasons increases crop net revenue per hectare by 2496.01 Birr and 2042.11 Birr, respectively. Marginally increasing temperature during the winter and fall seasons reduces crop net revenue per hectare by 617.71 Birr and 5498.13 Birr, respectively. During spring season, a slight increase in temperature with the same level of precipitation enhances germination; it is well-known that spring is the planting season in Ethiopia. Increasing precipitation during the summer and winter seasons increases crop net revenue per hectare by 68 Birr and 193 Birr, respectively. Marginally increasing precipitation during spring and fall reduces net revenue per hectare very slightly, by 24 Birr and 54 Birr, respectively. The increase in net revenue per hectare with increasing summer precipitation indicates that the existing current level of precipitation is not enough for planting. The reduction in net revenue per hectare with an increase in precipitation during the fall is due to crops' reduced water requirements during the harvesting season.

Concerning livestock, a marginal increase in temperature increases income by 537 Birr and 733 Birr during summer and winter season, respectively. However, warmer temperature during spring and fall reduces livestock net revenue by 249 Birr and 738 Birr, respectively. A marginal increase in precipitation reduces livestock net revenue per farm both during summer and winter.

The Impacts of Forecasted Uniform Climate Scenarios

We also analyze the impact of forecasted uniform climate scenarios. The uniform climate scenarios used are based on the projections made by IPCC (2001). According to these projections, the global average surface temperature will increase by 1.4°C to 5.8°C during the period from 1990 to 2100. In the Sahel, of which Ethiopia is part, the trend during the past decades shows a reduction in precipitation. For this reason, it is imperative to simulate this reduction in precipitation and increase in temperature in our analysis. The simulations for this study are based on scenarios prepared for Ethiopia (Deressa, 2006) from a study carried out under a Global Environmental Facility (GEF)-World Bank project (Kurukulasuriya and Mendelsohn, 2006). On the basis of this information, this study examined the effect of climatic change for the following scenarios: an increase in temperature by 2.5°C and 5°C and a reduction in the average rainfall by 7% and 14%.

Table 6. Impacts of forecasted uniform climate scenarios (based on coefficients from Tables 2, 3, and 4)

Climate Change Scenarios	Change in net revenue (in ETB)		
	Crop	Livestock	Agriculture
+ 2.5^0C Temperature	-1812.43	-274.02	-1035.46
+5^0C Temperature	-3039.67	368.52	363.8
-7% in precipitation	-1609.01	-1112.45	-645.08
-14 % in precipitation	-2676.71	-1833.42	-1141.63

Note that the impacts of uniform climate change scenarios are analyzed using coefficients in Tables 2, 3 and 4, and assume uniform climate changes. The results are presented in Table 6.As is obvious from the tables, the results indicate that an increase in temperature of 2.5^0C will reduce agricultural net revenue by 1035 Birr, livestock net revenue by 274 Birr and crop net revenue by 1812 Birr on a per hectare basis. Similarly, a loss of 3040 Birr from crop agriculture, and a gain of 364 Birr from total agriculture and 368 Birr from livestock agriculture, will be expected with a 5^0C increase in temperature in the Nile basin of Ethiopia. A 7% decrease in precipitation will reduce net revenue by 1609 Birr, 1112 Birr and 645 Birr for crop, livestock and total agriculture, respectively. A 14% reduction in precipitation will reduce net revenue by 2677 Birr from crop, 1833 Birr from livestock and 1142 Birr from total agriculture.[2] All the above explained outcomes are consistent with the marginal analyses reports in Table 5.

Specific Climate Change Scenarios – Atmospheric-Oceanic Global Circulation Models (AOGCMs)

A set of specific climate change scenarios predicted by AOGCMs (Atmospheric-Oceanic Global Circulation Models) is also used to see the likely impact of climate change for about five and ten decades in the future. In particular, we depend on three scenarios which are consistent for Ethiopia. Specifically, we used the scenarios from the following models: CGCM2, HadCM3, and PCM. The predicted values for the scenario analysis are taken from Strzepek and McCluskey (2007) and Deressa and Hassan (2009).

Appendix Table 1 summarizes the specific climate scenario considered from the three models: CGCM2, HadCM3, and PCM. The mean temperature and rainfall predicted for the current year and for years 2050 and 2100 for Ethiopia are presented. The temperature projections of all the models steadily increase over time. The models also provide a range of precipitation predictions. These predictions do not steadily increase, but rather have a varied pattern over time. For instance, CGM2 predicts a declining trend in rainfall. On the other hand, PCM and HadCM models predict an increasing pattern in precipitation.

Table 7 summarizes impacts on net revenue of the specific climate scenarios from the different three AOGCM models for the years 2050 and 2100. These three different scenarios reflect a realistic range of climate outcomes. Because of warming, an increasing loss in net revenue from crops will occur in all of the A2 and B2 scenarios of the three models. However, when we come to net revenue from livestock, all the models predict large gains from increasing temperature. In particular, the HadCM predicts the largest gains of all three models. Livestock net revenue is predicted to increase 149% by 2050 and 188% by 2100.

In the case of reduction in precipitation, all the models predict the largest loss for both crop and livestock net revenue. For crops, the net revenue will decrease at an

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[2] See the details on how the impacts of forecasted uniform climate scenarios are computed in Deressa (2006).

increasing rate (except in case of PCM and HadCM3 in the B2 scenarios). However, for livestock, the three models predict an initial loss in 2050, but this loss eventually declines by 2100. The overall effect of the warming is a decline in net revenue from agriculture as a whole. However, the reduction of precipitation will lead to decreasing agricultural net revenue at a decreasing rate. It is especially worth mentioning the case of the impact of temperature change in different scenarios for agriculture as a whole. Most of the figures (percentage changes) of the losses are three digit numbers. From these results, we can clearly conclude that, unless appropriate adaptation options are adopted, climate change will have a negative impact on the Ethiopian economy.

Table 7. Impacts of specific scenarios on net revenue (based on coefficients from Tables 2, 3 and 4)

Model		**Crop**		**Livestock**		**Farm**	
		2050	2100	2050	2100	2050	2100
				A2 Scenarios			
PCM	**Temperature change (0C)**	-58%	-159%	26%	110%	-75%	-169%
HadCM3		-98%	-145%	149%	188%	-148%	-136%
CGCM2		-84%	-170%	102%	159%	-121%	-172%
				B2 Scenarios			
PCM		-58%	-106%	26%	53%	-75%	-117%
HadCM3		-98%	-208%	149%	168%	-148%	-217%
CGCM2		-73%	-144%	68%	93%	-101%	-154%
				A2 Scenarios			
CGCM2	**Precipitation change(%)**	-37%	73%	-157%	-78%	-64%	36%
PCM		-24%	-32%	-206%	-112%	-50%	-41%
HadCM3		-27%	-30%	-190%	-100%	-56%	-47%
				B2 Scenarios			
CGCM2		-32%	47%	-157%	-78%	-47%	-32%
PCM		-27%	-25%	-206%	-112%	-33%	-13%
HadCM3		-24%	-14%	-190%	-100%	-39%	-19%

Table 8. Effects of Climate Change on Net Revenue for Different Agroecological Zones using A1B Scenari

	Temperature effect								
	Crop			Livestock			Mixed		
Agro-ecological Zones	2030	2050	2080	2030	2050	2080	2030	2050	2080
Moisture Sufficient Highlands-Cereals based	-9%	-13%	-31%	124%	-47%	-48%	29%	-46%	-86%
Moisture Sufficient Highlands-Enset based	-19%	-32%	-58%	169%	-48%	-15%	77%	-83%	-102%
Pastoralist (Arid Lowland Plains)	-40%	-56%	-89%	145%	8%	93%	56%	-59%	-97%
Humid Low Lands Moisture Reliable	-97%	-134%	-145%	614%	279%	253%	43%	-47%	-85%

	Precipitation effect								
	Crop			Livestock			Mixed		
Agro-ecological Zones	2030	2050	2080	2030	2050	2080	2030	2050	2080
Moisture Sufficient Highlands-Cereals based	26%	47%	62%	26%	-79%	-153%	20%	33%	15%
Moisture Sufficient Highlands-Enset based	24%	-17%	13%	24%	-154%	-215%	-10%	-50%	-45%
Pastoralist (Arid Lowland Plains)	-8%	-26%	-35%	-8%	-240%	-206%	-61%	-64%	-65%
Humid Low Lands Moisture Reliable	-11%	-27%	-17%	-11%	-399%	-362%	-120%	-47%	-64%

The effect of climate change on net revenue for different agro-ecological zones using A1B scenarios is presented in Table 8. As can be seen from the table, there will be a decline in crop net revenue throughout the years in all agro-ecological zones, due to temperature increase. It will decrease at an increasing rate. For example, in the case of the moisture-reliable humid lowlands agro-ecological zone, the net revenue from crop agriculture will decrease by 97% in 2030, by 134% in 2050 and then by 145% in 2080. However, the result is completely different when it comes to the effect of temperature increment on livestock net revenue. Overall, net revenue will increase up to 2030 and then will decline for both the cereals-based and enset-based moisture sufficient zone, but will increase at a decreasing rate for the pastoralists and moisture-reliable humid lowlands. Similar to the result for livestock, the effect of climate change on net revenue of agriculture will be positive only up to 2030, but will decline at an increasing rate afterward.

Likewise, the effect of precipitation decline on crop net revenue for different agro-ecological zones is mixed. For instance, whereas crop net revenue will increase at an increasing rate for the cereal-based moisture sufficient highlands, it will decrease throughout the years in the case of pastoralist and moisture-reliable humid lowlands. Unlike the result for the temperature effects on different agro-ecological zones, a decline in precipitation results in a huge and continuous loss of livestock net revenue, with most of the figures being three digit numbers. The effect of precipitation on agriculture net revenue of the cereals-based moisture-sufficient highlands will be positive. However, decreased precipitation will lead to a decline in net revenue at an increasing rate in both the moisture sufficient *enset*-based highlands and the arid lowland plains.

Conclusions and Policy Implications

This study is an attempt to assess the economic impact of climate change on crop production, livestock production and agriculture as a whole, inclusive of livestock, in the context of Ethiopia using the Ricardian model. Annual net revenue was regressed on climate, socio-economic and soil variables. The regression results were then applied to possible future climate scenarios.

The effects of soil characteristics and socio-economic variables varied across the regressions. The effects of the seasonal climate variables also varied across the three models.

Results also suggest that climate has a nonlinear effect on net revenues from crop, livestock and agriculture as a whole.

The results of marginal impact, uniform climate scenarios and specific climate change scenarios from AOGCMs show that the magnitude and direction of climate change impacts crop production, livestock production and agriculture as a whole.

Annual marginal impact analysis of increasing temperature and precipitation also indicate that a unit increase in temperature would reduce crop net revenue per hectare, unlike the effect on livestock revenue. On the other hand, marginal increase in precipitation would enhance crop net revenue. On the contrary, a marginal warming temperature leads to increased revenue from livestock. Though rainfall generally increases crop and pasture productivity, the result of this study reveals that precipitation reduces net income from livestock. The explanation of this result may lie in three possible reasons. First, farmers shift to crops as rainfall increases. Second, grassland shifts to forests as rain increases. This reduces the quality of natural grazing for most animals. Third, increases in precipitation increase the incidence of certain animal diseases.

Uniform climate scenarios are also used to analyze the likely impacts of climate change on net revenues from crops, livestock and total agriculture. The results of these scenarios indicate that increasing temperature, as well as reducing precipitation, reduces crop revenue very substantially in magnitude. A warming of temperature by 2.5^{o}C and a decline of rainfall by 7% and 14% result in a remarkable decline in net revenue from livestock. The 5^{o}C increase in temperature decreases crop net revenue. By contrast, it increases livestock and agricultural net revenue, perhaps because crops have very limited optimal temperature range as compared to livestock, and a 5^{o}C increase is beyond the tolerable limit for crop growth.

Forecasts from three different climate models (PCM, HadCM3 and CGCM2) are also considered in this study to examine the impacts of climate change on net revenue from crop, livestock and total agriculture. The results depict that, in all scenarios, warming temperature is beneficial for net revenue from livestock over the years 2050 and 2100. However, for the rest of the scenarios, future climate change would damage the agriculture sector of the Ethiopian economy. Results from different agro-ecological zones using A1B scenarios also support the previous results. Due to temperature increase, there will be a decline in crop net revenue throughout the years. When we come to the effect of temperature increment on livestock net revenue, the result is completely different. On the other hand, the effect of precipitation decline on crop net revenue for different agro-ecological zone is mixed. Unlike the effect of temperature on different agro-ecological zones, the effect of a decline of precipitation on net revenue of livestock results in a huge and continuous loss, with most of the figures three digit numbers.

Therefore, the following recommendations and policy implications are drawn in relation to crop, livestock and agriculture as a whole in Ethiopia. Concerning crop agriculture, recommendations include: enhancing R & D and introduction of new crops/varieties that are more appropriate to hot and dry conditions and that will give farmers a hand in adapting to harsh climatic conditions; encouraging profitable micro-irrigation systems that will lessen the effects of climate change; providing meteorological information, which will also likely help farmers to adapt; and finding ways to make credit work better for farmers. Regarding livestock agriculture, important issues of policy consideration are: encouraging production and use of local breeds which are adapted to local climatic stress and feed sources; improving local genetics via cross breeding with heat and disease tolerant breeds; improved animal health; and improved water and soil management.

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