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Evaluation of the Economic Impact of Climate Change on Egyptian Agriculture Using Ricardian Approach

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Abstract: This study employed the Ricardian approach to evaluate the economic impacts of climate change on farm net revenue in Egypt. A survey was done by interviewing 900 households from 20 governorates. The standard Ricardian model was applied, in addition to another three models each represent an adaptation option to be used to reduce the harm effect of temperature stress. Furthermore, the effects of two climate change scenarios (MAGICSENGEN and GCM's) were used. The empirical results from the standard Ricardian model (model 1) showed that temperature have a negative effects on farm net revenue in Egypt. Adding linear term of hydrology (model 2), linear and quadratic term of hydrology (model 3) and hydrology term and heavy machinery (model 4) to the analysis improve the adaptability of farm net revenue to high temperature. Marginal analysis indicated that harm effect of temperature was reduced by adding hydrology term and heavy machinery to the analysis. The marginal impact of temperature was $ -968.94, +26.17, +150.96 and -77.78 per hectare for the four models, respectively. Results from model (2) and (3) showed that irrigation could defeat the adverse effect of temperature and increase net revenue. Whereas, results from model (4) implied that using irrigation and expenditure on heavy machinery could reduce the harm effect of global warming and improve farm revenue. Results from the two climate change scenarios showed that high temperature will be a constrain to agricultural production in Egypt. Therefore, irrigation is the recommended adaptation option in addition to technology option. However, warming may also affect water resources and that would pose another problem for agricultural production. Thus, different adaptation policy should be developed to cope with the adverse impacts of climate change on agriculture.

Key words: Economic evaluation, Ricardian analysis, farm net revenue, adaptation option, climate change , MAGICSENGEN, GCM's

INTRODUCTION

The impacts of climate change on agricultural activities in term of yield losses and increasing of water needs have been studied for the last decade in Egypt. These results concluded that Egypt appears to be particularly vulnerable to climate change, because of its dependence on the Nile River as the primary water source. The damaged that climate change would do to agricultural productivity could be sever if no adaptation measures were taken[7]. Pervious research on the impact of climate change on agricultural sectors revealed that yields and water use efficiency will be decreased in comparison with current climate conditions, even when the beneficial effects of CO_2 were taken into account.

Climate change conditions could decrease national production of rice by 11%, soybeans by 28%, by the year of 2050, compared with their production under current conditions[2]. The impact of climate change on national maize production would be about 19% reduction in yield compared with its production under current climate[4]. Whereas, barley grain yield will be reduced by 20%[6]. Cotton seed yield would increase under warming climate by 17%, if temperature would increase by 2°C. Furthermore, cotton seed yield would increase by 31%, if temperature would increased by 4° C, in comparison with production under current climate conditions[4]. With respect to water needs, it will be increased up to 16 % for summer crops, compared to their current water needs under climate change conditions. Whereas, climate change conditions could decrease water demand for winter crops by up to 2 % by the year of 2050[3].

However, with all extensive research on the effect of climate change on crops production there was no research on the economic impacts of climate change on agricultural sector. Heavy economic dependence on agriculture in Egypt, imply that the effects of climate change is likely to threaten the welfare of the population and the economic development. The objectives of this study were: (i) To develop and estimate a Ricardian model to assess the potential impacts of climate change on Egyptian Agriculture; (ii) To use the estimated model

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to predict a range of impacts on the agricultural sector under various climate change scenarios; (iii) To evaluate alternative courses of action in terms of policies and strategies to help mitigate the likely climate change impacts on agriculture in Egypt.

MATERIALS AND METHODS

Generally, Ricardian approach is a cross-sectional model used to study agricultural production by measuring climate change damage as a reduction in net revenue or land value. In addition, it takes into account the cost and the benefits of different adaptation techniques that farmers do. Cross-sectional observation, where normal climate and soil factors vary, can be used to estimate farmer's adaptation to climate on crop productivity. The standard Ricardian model relies on a quadratic formulation of climate[1]:

[1] $NR/ha = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + u$

Where:

NR/ha = net revenue per hectare
F = vector of climate variables
Z = set of soil variables
G = set of socio-economic variables
u = error term

The earlier Ricardian studies have not included irrigation in the analysis. However, initial research on United States data by Mendelsohn and Dinar[8] suggests that water supply from runoff has an important effect on farms. Farms that can draw from runoff are more likely to use irrigation and earn higher net revenues. Under Egyptian conditions, irrigation is the main way for water application and it is also used as a relief factor to heat stress. Therefore, modeling runoff across Egypt could reveal how much runoff affects existing farms. Furthermore, it can explicitly capture how runoff changes would interact with direct climate changes and affect farms in the future. Therefore, two models were proposed: model (2), which included the linear hydrology variable and model (3), which included the linear and quadratic hydrology variables as follows:

[2] $Revenue/ha = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 H$

Where:
H = relevant hydrology variables

[3] $Revenue/ha = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 H + \beta_6 H^2$

Where:
H^2 = quadratic term of relevant hydrology variables

Furthermore, to test whether possession of new technology by the farmers could help in reducing the harm effect of heat stress on farm net revenue, model (4) was developed as follows:

[4] $Revenue/ha = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 H + \beta_4 T$

Where:
T = technology variables

Data for analysis: The data for the analysis was based on cross-sectional farm house hold survey at district level for several Governorates. The survey was done using a structured questionnaire. The survey was design to collect data, which reflected the substantial variation in the agro-ecological zones in Egypt. Moreover, the data reflected, as much as possible, all the major and minor crops. Small-scale and large-scale production, as well as traditional agriculture and agricultural production based on improved technology were also reflected in the survey.

The survey covered most of the country's governorates. Therefore, twenty governorates were selected to represent the whole country. The rest of the governorates have low contribution in the agricultural production in Egypt. Lower Egypt was represented by 12 governorates i.e. Alexandria, Behaira, Kafr-El Sheikh, Damietta, Dakahlia, Sharkia, Gharbia, Menoufia, Qalyoubia, Port Said, Ismailia and Noubaria. Middle Egypt was represented by 4 governorates i.e. Giza, Fayoum, Beni Suef and Menia. Upper Egypt was represented by 4 governorates i.e. Assuit, Suhag, Qena and Aswan. A sample of 45 house hold was collected from each governorate with a total of 900 house hold.

Farm household data: A farm household questionnaire was used to collect information from the selected household. The questionnaire attempted to capture information on pertinent variables required to calculate net farm revenues as well as to explain the variation in net farm revenues, land values and income across representative sample districts and agro-climatic regions in the country. The period of interest were the winter season of 2001/02 (October to April) and the summer season of 2002 (May to September). Some farmers plant crops in a third season, which called the Nili season. It starts from July or August to October or November. The questionnaire also aimed at capturing farmers' knowledge, attitudes and perception of climate variation and climate change. The questionnaire had two main parts and six sections. Part 1 focused mainly on crop production, whereas part 2 was on livestock production activities. Sections 1 and 2 focused on household characteristics and employment of the household head. The questions in section 3 were with respect to the household's land under farming activities (both crops and livestock) and farm labour used for different farm activities and respective costs. In section 4, detailed information were obtained on crop farming activities with respect to the type of crops grown, the size of land planted, amount harvested and sold and other crop farming related costs such as, seeds, fertilizer and pesticides and light, heavy and animal power and farming related buildings. Parts of section 4 requested information on the type of livestock, poultry and other farm animals, how many were purchased, lost and sold in the period of interest. It also required similar information on livestock and poultry products, such as milk, beef, eggs and wool. In section 5, the focus was on access to information for farming activities and the sources and cost of these information, while section 6 attempted to estimate the total income of the farm household (for both farming and non farming activities), taxes paid and subsidies received in the period of interest. The final section 7 consisted of eliciting information from farmers on their perception about short and long term climate change and their adaptation strategies in response to these perceived climate variation and climate change.

The Empirical model: Alternatives adaptation options for reducing the harm effect of heat stress on farm revenue were explored, by developing four Ricardian models. Model (1) is the standard Ricardian model, which include weather, soil and socio-economic variables. Model (2) contained weather, soil, socio-economic variables, in addition to relevant hydrology variable. Model (3) contained the previous variables, in addition to the quadratic term of relevant hydrology variable. The rationale for using quadratic term of hydrology variable is increasing irrigation amount might help in reducing heat stress on growing crops and consequently could increasing farm revenue. Model (4) contained the previous variables as model (2), in addition to technology variables. This model was developed to test whether access to more technology could increase farm revenue.

In addition to the above mentioned models, a comparison was made between small-scale farms and large-scale farms to assess its response to high temperature. However, the differences between them were found to be insignificant. Furthermore, Egypt was divided to three zones: Lower Egypt, Middle Egypt and Upper Egypt to also assess its response to high temperature. However, the differences between them were also found to be insignificant. This could be attributed to the important role that irrigation may play in agricultural production all over the country and also in the different types of farming activity.

Defining variables

1. Dependent variable: The absence of well functioning land market in Egypt made it difficult to climate response functions to reflect the adjustments made by farmers to normal climate conditions. Thus, net revenue[9] was selected to be the dependent variables for the analysis. Gross revenue, in addition to four measurements of net revenue was calculated from the house hold survey, with additional sets of costs been deducted from preceded net revenues. Gross crop revenue is the product of total harvest and price of the crop. The first one is nr1_3, which is gross revenue less the cost of fertilizer and pesticides per hectare of crop cropped area. The second one is nr2_3, where hired labour cost per hectare was deducted from nr1_3. The third one is nr3_3, where total machinery cost per hectare were also deducted from nr2_3. Whereas, other crop farming costs were deducted from nr3_3 to obtain the values of nr4_3. Table (l) showed summary statistics for these four variables.

Table 1: Estimated crop net revenues in Egypt (US$) for 2001/02

Variable	Observation	Mean	Standard deviation	Minimum	Maximum
nr1_3	689	1394.65	896.60	-118.61	5231.67
nr2_3	646	1233.80	880.73	-227.29	4890.69
nr3_3	646	1142.14	904.00	-1393.57	4889.09
nr4_3	617	1073.51	859.88	-1393.57	4654.94

Source: GEF Farm Household Survey Data (2001/02)

The mean value of nr1_3 was the highest compared with the other definition of net revenue. Furthermore, minimum value was negative because some households had higher relative costs and it was the lowest as additional costs were deducted. Therefore, to avoid having several negative data values for the dependent variable we decided to use nr1_3 as the dependent variable for the estimation of our empirical models.

2. Explanatory variables

2.1 Climate data: The climate set that gave the best results came from The Africa Rainfall and Temperature Evaluation System (ARTES), which is created by National Oceanic and Atmospheric Association (NOAA). These data were for temperature and precipitation.

The analysis showed that the temperature of consecutive months are highly correlated and performed poorly in the models. Therefore, season averages were used in the analysis. A season was defined as an average of three month. Winter is defined as December through February, spring is defined as March though May, summer is defined as June through August and fall is defined as September though November. In our analysis, the linear and quadratic terms of only temperature were included in the analysis. Seasonal witness index was excluded from the model because it violates the condition of the OLS models, which is to have a value for the F-stat to assure that the model is a full rank. Because precipitation is considerably low in Egypt, all the farmers are using irrigation for their cropping activities.

2.2 Soil data: Soil data for the twenty governorates under study was provided by the Food and Agricultural Organization (FAO). These data provides information on the major and the minor soil types. Similar soil types were grouped in twelve sets and used in the analysis to obtain the best results in term of significant and positive effect on revenue. Furthermore, insignificant soil types were excluded from the analysis. Only two soil types were used in the analysis: Soil_rc, which is calcaric regosols and Soil_z, which is solonchaks.

2.3 Socio-economic data: Socio-economic data were obtained from the survey, such as house hold size, farm size, distance to nearest marked to buy inputs, total cost for farm labor, amount of crops sold, amount of crops consumed by livestock, number of light machinery and control variable for livestock activity.

2.4 Hydrology data: Data for several runoff and flow terms were obtained from University of Colorado, Boulder and International Water Management Institute (IWMI). Each hydrological term was tested in the models. Flow sum gave the best results; therefore it was used in revenue calculations.

2.5 Technology data: Technology data was obtained also from the survey. It represents the number of heavy machinery that the farmers used in their farms.

Statistical analysis: OLS estimation procedure using "Stata" Statistical and Econometric software were used to fit the above mentioned models. To overcome the problem of heteroscedastity, a robust estimation of the standard errors was undertaking. Moreover, to overcome the problem of multicolinearity, identified correlated variables were dropped from the model.

Several runs were done with different explanatory variables. Most of these variables were dropped from the model because of their low significance level and their low contribution in improving upon the overall significance of the estimated models.

Marginal impact of seasonal temperature was estimated for each of the four proposed models.

Furthermore, two climate change scenarios were used to assess the impact of heat stress on farm revenue. These two scenarios were MAGICC/SCENGEN results, which propose 1.5° C raise in temperature and General Circulation Models results, which propose 3.6° C rise in temperature. The expected reduction in farm revenue as a result of these two scenarios was then calculated.

RESULTS AND DISCUSSIONS

1. Farm net revenue determination: Farm net revenue is defined in the model as house hold crop gross revenue less fertilizers and pesticide costs per hectare of total cropped area. Four models were developed to assess the impact of high temperature on farm net revenue and to explore different adaptation options to reduce the harm effect of high temperature.

Table 2: Regression coefficients obtained for net revenue/ha based on cropped area using ARTES temperature (Model 1 and 2)

Net revenue	Model (1)	Model (2)
Winter mean temperature	-18857.84	-20633.74
Winter mean temperature squared	580.94	638.25
Spring mean temperature	42317.62	36562.31
Spring mean temperature squared	-915.34	-791.58
Summer mean temperature	-47320.17	-43483.39
Summer mean temperature squared	808.60	744.34
Fall mean temperature	32765.83	34690.04
Fall mean temperature squared	-673.94	-719.22
Soil_rc	1411.33	1597.48
Soil_z	364.56	---
House hold size	85.18***	85.89***
Farm size	68.77	65.85
Distance to market (hours)	5.18	8.03
Total cost for farm labour	-0.01	-0.01
Amount of crop sold	0.002***	0.002***
Amount of crop consumed by livestock	-0.01	-0.01
Number of light machinery	16.31	15.30
Flow sum	---	0.003*
Constant	-40871.3	-37695.76
R2	0.2258	0.2251
N	140	140
F	33.97	33.48

*Significant at 10%; *** significant at 1%

1.1 Net revenue determination using model (1): Model (1) is the standard Ricardian model, which include weather, soil, socio-economic variables. Results in Table (2) showed that linear and quadratic term of both spring and fall temperatures have a U-shape relationship with farm net revenue. Spring is the time that winter crops developed their seeds, where any rise in temperature could reduce seed development phase and consequently reduce yield. Similarly, the temperature in the fall is still relatively high specially, in September and October, which is the time that summer crops developed their seeds. Therefore, any increase in it could result in reduction in the revenue. Furthermore, results also showed that winter and summer temperatures have an inverse U-shape relationship with crop area net revenue. The inverse U-shape relationship between summer temperatures and net revenue was not expected, given that summer temperature is already hot. The results also showed that the linear term of winter and summer temperature is negatively affecting net revenue. The quadratic term of spring and fall temperature are negatively affecting net revenue.

The two types of soils that were found to be relevant in the model were not significant, probably because their formulation in the model was not accurately done.

Farm size, house hold size, distance to nearest market to buy input, amount of crops sold and number of light machinery were positively affecting net revenue. Whereas, total cost for labor per farm and amount of crop consumed by livestock were negatively affecting net revenue.

Table 3: Regression coefficients obtained for net revenue/ha based on cropped area using ARTES temperature (Model 3 and 4).

Net revenue	Model (3)	Model (4)
Winter mean temperature	-20310.80	-21587.33
Winter mean temperature squared	629.79	666.06
Spring mean temperature	35346.82	38128.71
Spring mean temperature squared	-765.59	-823.34
Summer mean temperature	-42126.67	-46485.62
Summer mean temperature squared	721.58	795.03
Fall mean temperature	34208.47	37142.48
Fall mean temperature squared	-710.43	-770.62
Soil_rc	1641.89	1584.76
House Hold size	85.57***	81.33***
Farm size	66.07	45.88
Distance to market (hours)	7.94	6.38
Total cost for farm labour	-0.01	-0.01
Amount of crop sold	0.002***	-0.002***
Amount of crop consumed by livestock	-0.01	0.01
Number of light machinery	15.33	21.57*
Flow sum	-0.0002	0.004
Flow sum squared	2E-07	---
Constant	-40213.2	-33603.74
R2	0.2251	0.2141
N	140	140
F	33.67	29.79

* Significant at 10%; *** significant at 1%

1.2. Net revenue determination using model (2): Model (2) is the standard Ricardian model, which include weather, soil and socio-economic variables, in addition to hydrology term. This model intended to test the effect of irrigation on reducing the harm effect of high temperature. Results in Table (2) indicated that all the independent variables behave the same as in model (1). Flow sum was found to be positively and significantly correlated with net revenue, which prove that irrigation plays an important role in heat stress tolerance.

1.3 Net revenue determination using Model (3): Model (3) included weather, soil and socio-economic variables, in addition to linear and quadratic term flow sum. Results in Table (3) showed that all the independent variables behave the same as in model (1). The results also showed that flow and its quadratic term have a U-shape relationship with net revenue. With respect to the first case, the U-shape can be attributed to applying more irrigation water might be harmful to the crop and might reduce net revenue, but as heat stress prevails applying more irrigation could increase net revenue.

1.4 Net revenue determination using Model (4): Model (4) included weather, soil and socio-economic variables, flow sum, in addition to number of farm heavy machinery. Model (4) was developed to assess the effect of using heavy machinery in the farm as an adaptation option to help in tolerating the harm effect of climate change. Number of heavy machinery was found to be positively and s ignificantly affecting net revenue (Table 3). This is an indication that the more money that farmers can spend on farm equipments, the more revenue they can gain.

Table 4: Marginal impact of temperature on net revenue/ha based on cropped area obtained from models (1 and 2).

Net revenue (US$/ha)	Model (1)	Model (2)
Winter temperature	3554.69	3989.85
Spring temperature	-190.74	-189.88
Summer temperature	-7229.5	-6579.25
Fall temperature	2896	2814.33
Annual temperature	-968.94	26.17***

*** Significant at 1%

Table 5: Marginal impact of temperature on net revenue/ha based on cropped area obtained from models (3 and 4)

Net revenue (US$/ha)	Model (3)	Model (4)
Winter temperature	3986.61	4109.17
Spring temperature	-207.04	-107.32
Summer temperature	-6350.65	-7068.05
Fall temperature	2722.04	2988.43
Annual temperature	150.96*	-77.78***

* Significant at 10%; *** significant at 1%

2. Marginal impacts of temperature on farm net revenue: The critical value for marginal impacts is the annual temperature because the season's alternate signs offset each other throughout the year. With respect to the standard Ricardian model (model 1), results in Table (4) implied that one degree increase in temperature would reduce net revenue by $968.94. Furthermore, including irrigation in the analysis (model 2) reduced the harm effect of high temperature and increase net revenue by $26.17 per hectare.

Similarly, including the linear and quadratic term of flow in the analysis (model 3), reduced the harm effect of high temperature and increased net revenue by $150.96 per hectare. Moreover, including the number of heavy machinery per hectare in the analysis reduced the harm effect of high temperature to $77.78 per hectare (Table 5).

3. Effect of climate change on farm net revenue: Two climate change scenarios were used in the analysis to predict the reduction in farm net revenue by the year of 2050. These two scenarios were MAGICC/SCENGEN results, which propose 1.5° C raise in temperature and General Circulation Models results, which propose 3.6° C raise in temperature by the year of 2050. Results from model (1) and (4) indicted that warming will reduce net revenue (Table 4 and 5). However, results from model (2) and (3) showed that warming will increase net revenue (Table 4 and 5). Results in Table (6) implied that temperature increase by 1.5º C or 3.6°C will greatly reduce farm net revenue per hectare calculated from model (1). The reduction in net revenue was $1453.41 and 3488.18 per hectare under 1.5 and 3.6°C increase, respectively; if no adaptation options were taken into consideration (model 1). However, these reductions in net revenue could be lowered if farmers used more heavy machinery in their farms (model 4). Reduction in net revenue was $116.67 and 280.01 per hectare under 1.5

Table 6: Impact of two climate change scenarios on farm net revenue

Net revenue	Model (1)	Model (2)	Model (3)	Model (4)
Under current temperature	-968.94	+26.17	+150.96	-77.78
Under current temperature +1.5º C	-1453.41	+39.26	+226.44	-116.67
Under current temperature +3.6º C	-3488.18	+94.21	+543.46	-280.01

and 3.6 °C increase, respectively. This would prove that expenditure on farm machinery could reduce the harm effect of temperature increase. With respect to model (2) and (3), results implied that irrigation is expected to increase farm net revenue by $39.26 and 94.21 per hectare under 1.5 and 3.6° C increase, respectively for model (2). Whereas, for model (3) net revenue is expected to increase by $226.44 and 543.46 per hectare under 1.5 and 3.6° C increase, respectively.

Conclusion and Policy Implications: The Ricardian approach was applied in this study to help to understand the effect of climate change on farm revenue because it takes into account farmer’s adaptation to climate implicitly. The standard Ricardian model was applied (model 1), in addition to another three models each represent an adaptation option to be used to reduce the harm effect of temperature stress. Model (2) examined the role of linear term of hydrology. Model (3) examined the role linear and quadratic term of hydrology. Model (4) examined the role of linear hydrology term and expenditure on heavy machinery.

Empirical results implied that irrigation is one of the most important adaptation option used to overcome heat stress, either the linear term (model 2), the linear and quadratic terms (model 3) or the linear term and technology term (model 4). Irrigation could alter the relation between farm revenue and climate, because it could help crops to grow well under warmer temperature. The marginal impact of temperature was improved from $ -968.94 per hectare for model (1) to $ +26.17 per hectare for model (2) and to $ +150.96 per hectare for model (3). Whereas, results from model (4) implied that using irrigation and expenditure on heavy machinery could reduce the harm effect of global warming from $ -968.94 per hectare to $ -77.78 per hectare. Therefore, irrigation is the recommended adaptation option. The results suggested that using irrigation to reduce the harm effects of heat stress could increase farm revenue (model 2 and 3). Another alternative could be use if warming affected water resources and water scarcity occurred, which is expenditure on heavy machinery.

Unfortunately, warming may also affect water resources and that would pose another problem for agricultural production. Therefore, adaptation policy should be developed to cope with the adverse impacts of climate change. This policy should include three directions: crop management, water management and land management.

The first direction is a careful selection and/or breeding for heat-tolerant, salinity tolerant and water conserving cultivars. Furthermore, changing crop rotations to use high revenue crop with low water needs, such as all-season vegetables and fruits could increase farmer's revenue. Another alternative is to plant tomato, onion or potato as winter crops before cotton in the rotation instead of wheat, which could conserve irrigation water and increase cash return. In addition, efforts should be made to promote the preferential adoption of high-return and water-conserving crops, such as sugar beet instead of the presently grown water-profligate crops such as rice.

The second direction is the appropriate management of water resources. This could be done by improving both technical water application efficiency and agronomic water use efficiency. This involves revamping the entire system of water delivery and control with effective monitoring and regulation to avoid water losses.

The last direction is land management, where a further set of measures should be taken into consideration involving the management of low-lying lands at the northern fringe of the Delta, where the consequences of sea-level rise cause submergence and increase salinity of these soils. Some of those lands must be retired from agriculture and the amount of water that was assigned to it should be made available to be assigned to irrigate new lands outside the New Valley and Delta.

The current study managed to quantify the economic impacts of climate change on farm revenue using the Ricardian approach. Moreover, it took into consideration two adaptation options i.e. irrigation and expenditure on heavy machinery. However, different adaptation practices done by individual farmers should be explore too, such as using high-yielding varieties. Therefore, it is important that future research consider micro-level analysis of adaptation strategies, using farmer's behavioural models to capture farmer behaviour in choosing among various adaptation options.

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