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ANALYSIS

Climate change, irrigation, and Israeli agriculture: Will warming be harmful?

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ARTICLE INFO

Article history:

Received 25 October 2006

Received in revised form 2 July 2007

Accepted 20 July 2007

Available online 6 September 2007

Keywords:

Climate change

Irrigation

Farm revenues

Ricardian model

ABSTRACT

This paper utilizes a Ricardian model to test the relationship between annual net revenues and climate across Israeli farms. The study finds that it is important to include the amount of irrigation water available to each farm in order to measure the response of farms to climate. With irrigation water omitted, the model predicts climate change is strictly beneficial. However, with water included, the model predicts that only modest climate changes are beneficial while drastic climate change in the long run will be harmful. Using the AOGCM Scenarios we show that farm net revenue is expected to increase. Although Israel has a relatively warm climate a mild increase in temperature is beneficial due to the ability to supply international markets with farm product early in the season.

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1. Introduction

The eastern Mediterranean region, like the rest of the world, is expected to undergo changes in rainfall patterns and temperature over the next several decades due to Global Climate Change (Houghton et al., 2001). Climate models for the region predict an increase in winter temperature combined with changes in rainfall amount and distribution (Ben-Gai et al., 1998). According to agronomic research, these climatic changes are likely to affect agricultural production (Gitay et al., 2001). This study evaluates the economic impact of climate change on Israeli agriculture.

There are different approaches in the literature to evaluate the impacts of climate conditions and agriculture. The agro-economic approach developed by Adams (1989), Adams et al. (1995) begins with agronomic models that predict how climate change will affect yields of specific crops. Mathematical programming is then used to predict which crops farmers will want to plant and what will happen to aggregate production and prices. This approach captures adaptation behaviors including

crop switching, but only in a partial fashion due to limited information. The modeler often does not know planting dates, plowing regimes, harvest dates, or crop varieties and how these may change with climate. If these adaptations are not explicitly built into the model, they are not taken into account. A production approach was implemented in Israel to evaluate the impact of changes in precipitation on net farm revenues (Rapaport-Rom, 2007). The decrease in net farm revenue from predicted reductions in precipitation by 2100 ranges between 1 and 8%. These changes are minor in comparison to the results in this study but it should be noted that the production study did not deal with temperature changes, only precipitation changes.

This study relies on the Ricardian method (Mendelsohn et al., 1994) (MNS) to measure the economic impacts of climate change on Israeli agriculture. Annual net revenues are regressed on climate, soils, and other socio-economic control variables. By using net revenues and not individual crop yields, we allow farmers to adapt to climate change by choosing different crops, crop mixes, technologies and management practices under

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different climate conditions. One of the advantages of the Ricardian approach is that it fully captures long term adaptation. We utilize the empirical results from the Ricardian study to examine the combined effects of possible future changes in both precipitation and temperature.

Previous work on adaptation to climate change in agriculture suggests that there are a variety of adaptation measures that can be initiated at the private and public levels (see review of literature in [Kurukulasuriya and Rosenthal, 2003](#)). In order to address the complicated nature of climate change impacts on the agricultural sector, a joint private–public and dynamic adaptation model is needed ([Mendelsohn, 1999](#)). Technological development and measures of know-how related to various aspects of the production process, including irrigation, where water is available, need to be considered.

A major criticism of early Ricardian method applications is that it did not address irrigation water ([Cline, 1996](#)). [Mendelsohn and Dinar \(2003\)](#) tried to address this criticism by using surface water withdrawal data in their re-estimation of the Ricardian model but actual withdrawals are endogenous. [Mendelsohn and Dinar \(2003\)](#), [Schlenker et al. \(2005\)](#), and [Kurukulasuriya et al. \(2006\)](#) also address the irrigation issue by estimating Ricardian models for dryland separately from irrigated land. In Israel, water supplies are determined exogenously by administrative and historic mechanisms. This specific situation allows us to explore what difference exogenous flows of irrigation water have on farm performance and on its climate sensitivity. Using diversified water availability levels across the country, the paper offers a unique opportunity to investigate the role of irrigation water as an adaptation strategy of farmers to climate change in Israel.

Due to the fact that Israeli agriculture depends heavily on water, there have been significant efforts by the public sector to provide incentives to farmers to use water efficiently. Israeli agriculture is unique in its investment in capital to substitute for water and land. Farmers use combinations of advanced irrigation technologies, such as drip irrigation and cover technology in order to adapt specialized farming techniques to local climate. Israeli farmers have consequently been able to shape their agricultural system to the climate of their country and take advantage of heat rather than be a victim of it. We consequently anticipate that Israeli agriculture may be relatively more heat tolerant than, for example, American agriculture ([Mendelsohn and Dinar, 2003](#)).

The next section will provide the background information on climate and water quotas in Israel—two essential resources that shape the nature of Israeli agriculture. Section 3 of the paper spells out the applied model. The data sources and data preparation procedures are described in Section 4. The results of the sensitivity surface estimates are presented and discussed in Section 5. A set of forecasts of impacts is detailed in Section 6, followed by a conclusion section on possible extensions and policy implications.

2. Israeli climate conditions and water quotas

Israel's total area is about 22 thousands square kilometers. The northern part is characterized by a Mediterranean climate while the southern part is a hot desert. In between, there is a

narrow transitional strip of land that has a semi-arid climate. The rainy season extends from around mid-October to early May, with the rainfall peaking from December through February. Rainfall varies considerably from the north to the south. The highest rainfall is observed in the North and center parts of the country and the lowest in the southern part. The average annual precipitation range is between 151.94 mm and 772.6 mm and the average annual temperature ranges between 15.92 °C and 23.91 °C. A more detailed classification of the climatic zones in Israel can be delineated by 12 geo-climatic zones ([Goldreich, 2003](#)). This classification is based on comprehensive climatic data and adjustment for physiographic conditions. This classification expresses the synthesis between regional similarity by climatic parameters and the special physiographic characteristics of the various regions. We base our data sampling on the geo-climatic zones since they reflect better the climate zones relevant for agriculture.

Israel's agricultural sector is characterized by an intensive system of production stemming from the need to overcome a scarcity in natural resources, particularly water and arable land. The country's varied climate and seasonal temperatures have stimulated the development of unique agro-technological solutions. The climate conditions enable especially the warmer regions to produce vegetables, fruits and flowers during the winter off-season, particularly for export markets in Europe ([Sheskin and Regev, 2001](#)). This ability to be the first to the market affords them high prices in the European markets as well as in the local market. In this case warm temperatures are an advantage.

About half of the 282 thousands hectares of crop area are allocated for growing field crops. On about a quarter of this area farmers grow vegetables, potatoes and melons. About 16% of the cropland is used for fruit orchards, 7% for citrus orchards and 2% for flowers and other garden plants ([Israel Central Bureau of Statistics, 2005](#)). Almost all the crops excluding field crops are irrigated. Field crops are grown on large plots of marginal lands and depend partially on rainfall. The agricultural sector is the main water user in Israel. About 60% of the water supply (from wells, reservoirs, effluent water, etc.) is used for irrigation.

Underground and surface water are state property by the Israel water law. Each year the Israel water commissioner allocates for each village an annual water quota for irrigation. Historical initial quotas were determined according to factors such as: total land suitable for irrigation, soil type, population size, location, water usage prior to 1959 and political affiliation of the village. Water quotas are adjusted periodically in order to take into consideration new water sources and new villages. The price of water is determined by the commissioner using a three-tier price system. These price levels are determined according to historical quotas ([Bar-shira et al., 2006](#)). Thus, the allotment of irrigation water and water prices are assumed to be exogenous to the farmers. Although prices potentially could be a limiting factor for farmers, in practice, water use is limited by the quotas.

3. Model

A production function of a farm can be expressed as a function of exogenous and endogenous inputs and managerial skills

variables. The exogenous input variables include climate and soils conditions and, in the Israeli case, the irrigation water quota. The endogenous variables include labor, capital, seeds and fertilizers and other inputs. The characteristics of the farmers may also have an important contribution to the production process.

The profit function for a farmer growing n crops is of the following form:

$$\pi = \sum_{j=1}^n [p_j Q_j(z, m, x_j) - w x_j], \quad j = 1, 2, \dots, n \text{ crops} \quad (1)$$

where: p_j are crop prices, Q_j production functions, z is a vector of climate variables, m is a vector of exogenous farm characteristics, x_j is a vector of crop's j inputs and w is a vector of input prices.

A profit maximizing farmer will choose vector x satisfying the following condition for all the endogenous inputs:

$$p_j \frac{\partial Q}{\partial x_j} = w \quad j = 1, \dots, n \quad (2)$$

Optimal x_j can be denoted as follows: $x_j = x_j(z, m)$. Following MNS (1994) it is assumed that the climatic variables enter in a quadratic functional form in z . We can also assume that p and w are uniform across the country. Under these assumptions and by substituting $x_j = x_j(z, m)$ in Eq. (1) the farm profit function can be expressed as a function of C climate conditions and L farm characteristics:

$$\pi = \alpha_0 + \sum_{i=1}^C \alpha_i z_i + \sum_{i=1}^C \beta_i z_i^2 + \sum_{l=1}^L \gamma_l m_l + u \quad (3)$$

$$i = 1, 2, \dots, C \quad l = 1, 2, \dots, L$$

where: α , β , and γ are coefficients of the climate and exogenous variables respectively and u is an error term $u \sim N(0, 1)$.

One of the exogenous variables under the prevailing conditions in Israel is the allotted irrigation water. We hypothesize that a larger supply of water leads to increased farm revenue. Due to the extensive use of technology and access to early markets our

hypothesis is that the response of farm net revenue to annual temperature should be u-shaped (convex).

4. Data

Most of the farmland in Israel is publicly owned by the Land Authority. The land is leased on a long term basis and its price is not determined in the free market. Thus, the prices of agricultural land in Israel cannot be used for the Ricardian approach. In order to conduct the analysis linking profits to climate conditions, we rely on annual net farm income and not land values as in MNS (1994).

Farm data were collected in 2003 by conducting a face-to-face survey among a representative sample of farmers (Table 1). The sampled farmers were chosen according to their location in the geo-climatic zones and type of village. Rural communities vary in their organization. There are 863 rural villages. They can be subdivided to 3 types: kibbutz (collective communities, 36%), moshav (cooperative communities, 47%) and other private villages (17%). The kibbutz and moshav today account for 80% of the country's fresh agricultural produce. The kibbutz being collective communities are much larger farms than the moshav farms whose ownership is on a per family basis. Thus we account for the size of the farm in the analysis.

The different types of rural villages define three strata, which were represented proportionally in the sample. Three maps were created, each showing the geoclimatic zones of Israel: the first one denotes the location of each kibbutz, the second one the location of each moshav, and the third one the location of the other types of villages. The dispersion of each type of village in the different geoclimatic zones can be observed using these maps.

In the next stage we ordered the villages in each map from north to south in strata of 4 km each. All the villages in such a stratum received a number identifying the stratum and were ordered according to their stratum number from north to south. The most northern stratum received number 1, the one south of it number 2, and so on. Systematic sampling was done

Table 1 – Variable description and descriptive statistics

Name	Description	Mean	SD	Minimum	Maximum
Age	Age of farmer or farm manager (years)	52.8	10.61	27	76
Hectare	Size of farm in hectares	81.2	206.78	0.2	1490
Irrigation water quota	Yearly average quantity of irrigation water quota per hectare (in thousands m ³)	5.59	2.95	0	14.46
Profit	Gross revenue per hectare minus variable costs and capital cost (7% of investment) (\$)	1874	25,024	-133,727	186,501
Latitude	Latitude	32.3	0.56	30.91	33.24
Longitude	Longitude	35.1	0.32	34.39	35.77
Altitude	Altitude (meters)	113.6	160.7	-326	857
Lat*long	Latitude*longitude				
Lat*alt	Latitude*altitude				
Long*alt	Longitude*altitude				
Tan	Average annual temperature (C°) 1965–1979	19.4	0.85	15.92	23.91
Pan	Average annual precipitation (mm) 1961–1990	526.3	129.5	152.23	772.71
Sand2	Sand with granule size 0.2–2 mm (% in soil)	4.3	2.54	1.05	12.55
Sand1	Sand with granule size 0.02–0.2 mm (% in soil)	37.1	25.01	10.96	86.12
Salinity	Dummy=1 if soil is not salt free	0.22		0	1

Table 2 – Regression of average annual temperature and precipitation over latitude, longitude and altitude data

Variable	Temperature	Precipitation
Latitude	90.07* (35.82)	-1662.37 (5248.78)
Latitude sq.	0.55* (0.18)	13.53 (25.45)
Longitude	-262.22* (118.5)	26,304.12 (16,763)
Longitude sq.	5.43* (2.19)	-392.8 (311.73)
Altitude	0.18* (0.07)	-14.08 (10.02)
Altitude sq.	-0.000002** (0.000001)	-0.00004 (0.0002)
Lat*long	-3.60* (1.27)	29.59 (182.55)
Lat*alt	0.002* (0.001)	0.12 (0.09)
Long*alt	-0.007* (0.002)	0.30 (0.35)
constant	3140** (1652)	-432,779.4** (231,051.8)
N	38	32
R ²	0.95	0.92

Note: Standard deviations are in parenthesis, and *, ** denote significant at 5%, 10% respectively.

within each stratum. A number between 1 and 10 was chosen randomly. Each village receiving this chosen number was included in the sample, as was every 10th village thereafter.

A total of 86 rural villages out of 863 potential villages were sampled: 41 moshavs, 31 kibbutzes, and 14 other villages. Five farmers were chosen randomly and interviewed from each moshav and “other village” for the sample. In each kibbutz, we analyzed five questionnaires, one from each agricultural branch. These branches were randomly selected and the manager for that activity was interviewed for the survey.

A total of 381 farmers were interviewed out of which 230 grow crops and the rest have animal husbandry farms. In this paper, we concentrated on crop farms only and thus most of the analysis is conducted on the 230 crop farms observations. It should be noted that 95% of the farmers in our sample irrigate at least part of their land.

Two methods were used to obtain net farm income from farmers. In the first approach, the farmers are simply asked about their net income. The second method asked detailed questions about farm revenue and costs. Net farm income was calculated from these detailed responses. These two estimates were compared. When there was a discrepancy, we used the norms used in the Ministry of Agriculture in order to decide which data were more reliable.

Climate data on temperature and precipitation were taken from Bitan and Rubin (2000). Average annual temperature calculations are based on data collected in 38 meteorological stations over the period 1965–1979 while average annual precipitation were calculated on data collected from 32 meteorological stations over the years 1961–1990. The periods and the stations for the temperature and precipitation calculations are slightly different because precipitation were not measured in all of the 38 stations and in some stations data for temperature were not available for all the years.

Following MNS (1994) we used an extrapolation of physical data of each village location to predict climate data for 230 farms based on data from 32 meteorological stations. Annual average temperature and precipitation were described by a polynomial function of the altitude, longitude, and latitude of each village. The models’ OLS coefficients appear in Table 2. The R² values are high in both models: 95% for temperature and 92% for precipitation. This means that the model can

predict quite accurately the variation in climate data and thus predictions of these models can be used for climate data at the village level.

Unlike similar studies we use annual climate data only and not monthly or seasonal data. The main reason for this is the small size and geographical location of the country in our study and thus the lack of significant variation in climate conditions over the year. The use of monthly or seasonal climate data led to high multicollinearity in the regression analysis. As a result almost all the monthly or seasonal climate variables were not found to be significantly different than zero.

Data for water quotas were obtained from the annual water consumption report of the Water Commissioner 2001 (Israel Water Commissioner, 2001).

5. Results

Table 3 presents the results of the two models. In the first model, linking farm profits to farm exogenous variables, the irrigation water quota was omitted. The second model in Table 3 includes irrigation water in a linear form. A third model was also estimated that included irrigation water in a quadratic form but it was not significant and so it is not shown. All models were estimated using heteroskedasticity-robust standard errors.

Comparing the Israeli results to MNS reveals that the value of R² is low. There are several reasons for this: 1) farm profits for one year tend to fluctuate more than farmland value, 2) the Israeli data set has individual farms as observations whereas MNS relied on county averages for observations and 3) Israel is a small country relative to the US. For example, the range of temperature in the Israeli sample is from 16 to 24 °C whereas the range of temperature in the MNS sample is from -12 to +34 °C.

Table 3 – Regression models explaining farm profit level

Variable	Profits per hectare (w/o water quota)	Profits per hectare (with water quota)
Annual temperature	-60,010* (18886)	-41,650** (22224)
Temperature squared	1559* (524)	1040** (621)
Annual precipitation	342* (105)	361* (105)
Precipitation squared	-0.30* (0.09)	-0.33* (0.1)
Sand1	74.2 (89)	-42.7 (121)
Sand2	3539* (1404)	3863* (1448)
Salinity	6503 (5085)	7242 (4940)
Hectare	2.21 (4.33)	7.68 (5.1)
Age	483* (189)	457* (182)
Water quota	-	1541* (743)
Constant	442,507* (149,033)	274,606 (184955)
N	230	230
R ²	0.19	0.21

Note: Standard deviations are in parenthesis, and *, ** denote significant at 5%, 10% respectively.

Examining the significant coefficients of the control variables in Table 3 reveals that they have the expected sign. Soil type Sand1 has a positive significant effect on farm profit level. Profits increase with the age of the farmer. Age reflects experience and thus managerial skills of farmers. It should be noted that we tried to include the age variable in a squared form but it was not significant.

Soil type ‘Sand2’ and level of salinity do not have a significant effect on the profit level of farmers. The variable ‘hectare’ (farm size) which is considered in the regression in order to account for economies to scale and the farm system is also not significant. The reason that a variable reflecting farm type does not appear separately in the regression analysis is the high correlation it has with farm size. Collective farms, Kibbutz, are much larger than private farms. Adding a dummy variable for the Kibbutz farm is not significant.

The estimated second order climate coefficients in Table 3 imply that the farm profit function is u-shaped (convex) in temperature and hill-shaped (concave) in precipitation. The coefficient of the water quota variable is positive and significant. This means that an increase in yearly water quota to the farmer leads to an increase in the annual profits per hectare. The assumption that the water quota is exogenous to the farmer was tested by running a regression of the water quota on the climate variables, i.e., annual temperature, annual temperature squared, annual precipitation and annual precipitation squared. The R^2 was found to be 0.08 and all the coefficients were not significant. These results confirm our assumption that the water quota does not depend strongly on climate conditions and thus can be considered exogenous.

Comparing the two models in Table 3 reveals that including the availability of irrigation water affects the climate coefficients. Consequently, Ricardian models of regions with irrigation that fail to include water availability may be biased. Based on our data the bias was not found to be significant. Including the water quota variable in the second model led to a decrease in the level of significance and magnitude of the two temperature coefficients. The temperature coefficients, which were significant at the 5% level in the first model, are significant only at the 10% level in the second model. It also should be noted that the optimal temperature is higher in the model with a water quota than without the water quota. There was little effect on the precipitation coefficients.

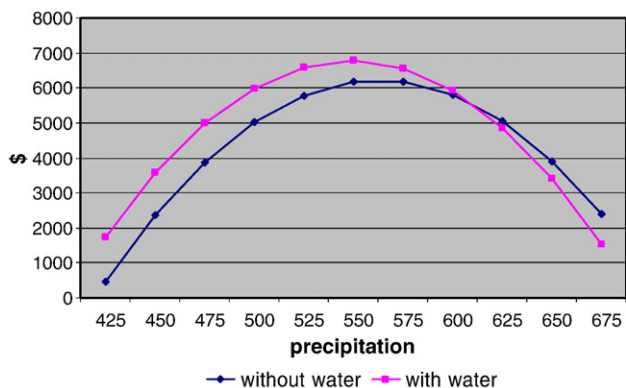


Fig. 1 – Predicted profit (\$) per hectare as a function of precipitation (mm) with and without water quota.

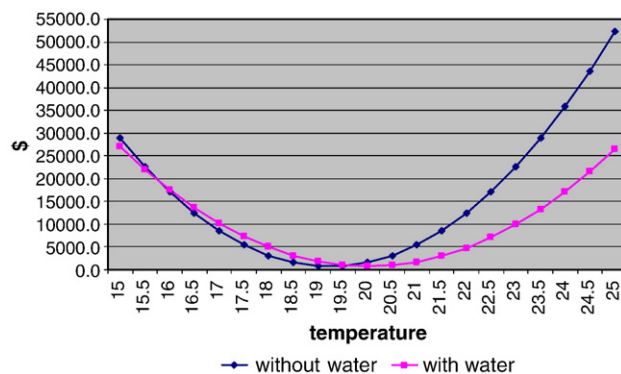


Fig. 2 – Predicted profit (\$) per hectare as a function of temperature (°C) with and without water quota.

Figs. 1 and 2 illustrate how the predicted climate sensitivities of the two models differ. The predicted values of profits with and without the water quota were calculated at the average values of all the variables except for precipitation in Fig. 1 and temperature in Fig. 2. The inclusion of the water quota variable in Fig. 1 shifts the profit curve with respect to precipitation to the left and in Fig. 2, with respect to temperature, to the right. One possible interpretation of these results is that a unit of water causes a larger increase in net revenue in cooler and wetter locations in Israel. In warmer and dryer settings, it takes more water to have the same effect on crops. Alternatively, farmers might have to engage in more water saving activity in hotter and dryer locations given the available water quota.

The marginal effects of climate predicted by both models are calculated in Table 4. The marginal effects of temperature are negative up to about the current average annual temperature for Israel. As expected in a relatively warm region, an

Table 4 – Marginal effects of range of precipitation and temperature in Israel

Average annual temperature	Marginal effect without water quota	Marginal effect with water quota
16	-10129*	-8378*
17	-7012*	-6298*
18	-3894*	-4219*
19	-776	-2139
20	2341	-60
21	5459	2020
22	8576*	4099
23	11694*	6179
24	14811*	8258
Average annual precipitation		
175	235.6*	245.6*
275	174.8*	179.9*
375	114.1*	114.2*
475	53.3*	48.5
575	-7.5	-17.3
675	-68.2*	-83.0*
775	-129.0*	-148.7*

* Significant at 5%.

Table 5 – Forecasts of average net profits per hectare according to AOGCM scenarios

Climate scenario	Change in temperature °C	% Change in precipitation	Change in welfare effect w/o water quota	Change in welfare effect with water quota
PCM 2020	0.8	11	9	-108
PCM 2060	1.6	-4	219	20
PCM 2100	3.2	11	762	205
CCSR 2020	1.4	-2	201	15
CCSR 2060	3.9	-23	965	270
CCSR 2100	5.8	-23	2580	1176
CCC 2020	1.2	10	80	-85
CCC 2060	2.8	-2	633	199
CCC 2100	5.6	1	2733	1337

increase in temperatures leads to a decrease in profits. However, at high temperatures, profits rise. The region that is mostly characterized by these high temperature levels is the Jordan valley where it is warm all year round. Irrigation, cover, and other technologies enable farmers in the region to adjust to the high temperatures. Moreover, they are the first to bring their produce to both the local and European markets and thus enjoy high prices before their competitor's outputs reach the markets.

In the case of precipitation the inverse is true, up to about the average precipitation level in Israel, the marginal effect of more rainfall is positive (Table 4). For Mediterranean and Arid climates, where almost all the crops are irrigated, it is expected that profits will increase with precipitation. However, more rain above the average reduces profits. The significant negative marginal effects in the high precipitation levels indicate that too much rain reduces net income. For example, too much rain prevents farmers from working the fields, reduces sunlight to crops, and may cause crop diseases.

The marginal effects differ between the models with and without the water quotas. Including the water quotas increases the absolute values of all the significant marginal effects of precipitation in the model. The reverse is true for almost all the absolute values of the temperature marginal effects. Including the water quota increases the sensitivity of farm profits to precipitation but lowers the sensitivity to temperature. Similar results were found in the USA (Mendelsohn and Dinar, 2003).

6. Forecasts

We then apply three climate scenarios from Atmospheric Oceanic Global Circulation Models (AOGCM) for Israel (Mendelsohn and Williams, 2004). We use the 2020, 2060, and 2100 forecasts of the Parallel Climate Model (PCM) (Washington et al., 2000), Center for Climate System Research (CCSR) (Emori et al., 1999), and Canadian Climate Centre Model (CCC) (Boer et al., 2000) to forecast percent changes in average annual farm profits in each of those decades. The forecasts are calculated

for each farmer separately and then the aggregate profit is calculated and compared to the aggregate profit in the base year. The models predict an absolute change in temperature and a percentage change in precipitation for the country, which was then applied to each farm. The climate coefficients in Table 3 are then used to predict the change in net income per hectare for each new climate. The forecasts in Table 5 demonstrate the importance of specifying the model correctly. The two models, with and without irrigation water, show different results. The forecasts with irrigation water quota in the model show lower absolute welfare effects. That is, by omitting water quota, the Ricardian model overstates gains from climate change scenarios.

Comparing scenarios over time reveals that the models are highly sensitive to temperature. According to the model with irrigation water quota, farm profits tend to decrease at first with small changes in temperature across in two climate scenarios and increase in the CCSR scenario. Over time, as temperatures climb even higher, farm profits increase in all three climate scenarios. A different picture, however, emerges with the model that omitted irrigation water quota. In this case, higher temperatures lead to increasing farm profits over time. Farms in warmer locations have higher allocations of water per hectare fooling this biased model into thinking that warming is beneficial. The biased model predicts that global warming is strictly beneficial to Israeli agriculture.

7. Conclusions and policy implications

This paper estimates the economic effect of climate on Israeli agriculture using the Ricardian technique. An economic survey of farms throughout Israel was conducted for this study. Net annual income is regressed on climate and other control variables across farms. Because this region depends heavily on irrigation, the study examines the importance of water supply on the Ricardian results by comparing regressions with and without irrigation water quotas. Higher allotments of irrigation water clearly increase profits (\$1500/m³). However, including irrigation water quotas also affects the estimated climate coefficients. The study finds that including irrigation water quotas reduces the marginal impact of the temperature variables. In other words, Ricardian models that omit irrigation water (or quotas) in regions with irrigation, as in the MNS (1994) paper, will tend to over predict the benefits and losses of warming.

Despite the fact that Israel has a relatively warm climate, the study found that farms with temperatures above 20 °C have higher net income per hectare. The level of technology plays an important role in Israeli farms and affects the impact of climate on farmers' profits. Israeli farmers use irrigation, cover, and their warmer climate to export to Europe. The Israeli first fruits reach the European market first. The Israeli farmers thus turn hot climates into an advantage that yields them additional profit. Of course, these results may not continue to apply if other hot regions duplicate the Israeli investments in technology. Increased supply early in the season would reduce prices and thus profits.

Examining alternative climate scenarios suggests that the marginal changes in climate that one might see over the next

twenty years are likely to be beneficial to Israeli agriculture. The existing technology including irrigation, cover, and early market products will likely cope with small warming. However, according to the model with water quotas included, climate change scenarios are less beneficial than the model that did not include water allotments. The difference in these results demonstrates the importance of including irrigation water allotments in models of farms that depend on irrigation.

An important caveat to the results concerns the assumption that water supply would not change with climate change. In practice, higher temperatures would reduce flows and increases/decreases in precipitation would increase/decrease flows. A complete model would treat these hydrological changes endogenously. As climate changes, the model would predict changes in available aggregate water supply. The water should then be reallocated to the farms with the greatest marginal productivity for water. The change in net productivity of each farm can then be calculated given the change in irrigation water as well as climate that it faces. For example, an endogenous hydrologic-agriculture model was recently constructed for California (Lund et al., 2006; Howitt and Pienaar, 2006). The use of technology such as irrigation and cover are also a function of climate conditions and needs to be investigated further.

Climate change is likely to affect agriculture in many countries. The impact depends on the location, level of development, technological advancement, and the institutional setting in the countries. Approaches to adapt to climate change may also differ based on the same set of variables. Whether or not the findings from one country may be applicable to other countries is not easy to determine. Probably some findings could be adapted in part to other countries. In that respect we would like to particularly touch upon several issues that are more relevant for such extrapolation.

Water quotas (rights) are a guarantee for farmers and secure their enterprises. How can water rights help in adaptation to climate change in developing countries? Having a secured resource allows farmers to invest in other water-related technologies and leads to stability and lower vulnerability to climate. Introducing water rights is a relatively simple institutional reform that has been adopted in many countries. Therefore, recognizing the importance of secured water rights should become a policy intervention where water is available.

Acknowledgement

We would like to thank Dubi Wolfson from the Israel Ministry of Agriculture for sharing his knowledge with us. The work leading to this paper was funded in part by the German Federal Ministry of Education and Research (BMBF) in collaboration with the Israeli Ministry of Science and Technology (MOST) in the framework of the project GLOWA Jordan River and by the Research Committee of the World Bank under the study 'Climate Change and Rural Development' that was tasked managed in the Agriculture and Rural Development Department of the World Bank by Ariel Dinar. The views expressed in this paper are those of the authors and should not be attributed to the World Bank.

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