Changes in Rainfall-Distribution Patterns: The Impact on Agriculture in Israel

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I. Introduction

According to climate models, the steady accumulation of greenhouse gases in the atmosphere is expected to cause global warming and variations in precipitation distribution over the globe. Since 1750 the concentration of CO_2 has increased by 31%, with a current rising rate of about 0.4%/year. The Intergovernmental Panel for Climate Change (IPCC, 2001) estimates a consequential increase of 1.4-5.8℃ in the global average surface temperature during the period 1990-2100. The average precipitation is expected to increase during the 21st century in most of the world's areas; however, there is a fairly wide similarity among results of climate simulating models that in the Mediterranean basin rainfall is about to decline. Israel is located in the eastern part of the basin - an area with an extraordinary sensitivity to climate changes due to the impact of several different climates, particularly the cold-rainy European climate in the north and the sub-tropic African conditions in the south. Focusing on Israel, recent studies have identified an increase in the frequency of extreme temperatures (Ben-Gai et al. 1999a), as well as in extreme weather events (Alpert et al., 2002). Ben-Gai et al. (1999b) found considerable spatial variations in the annual precipitation distribution.

Such climate variation trends are expected to entail significant socio-economic implications through their impact on various factors; e.g., agronomic conditions, natural ecosystems, recreation patterns, seawater floods and intrusion into aquifers. Economic assessments of such impacts were carried out mostly on a larger scale; estimates frequently suffer from uncertainty and bias associated with aggregation over regions with different climate patterns (Tol et al., 2003)[1]. The intention of the present study is to provide a regional scale analysis of economic impacts on agricultural production in Israel that are related to climate-change.

This work is limited to the discussion of agricultural profitability in Israel. It does not pretend to cover all types of climate related impacts, nor the entire range of agricultural activities. The focus is on the impact of projected changes in the variations in annual rainfall distributions on the profitability of winter crop; this encompasses about 2 million dunams – nearly half of the state's cultivated lands. Winter is the only rainy season in this area and production during this period heavily relies on precipitations. Profitability of winter crops is therefore highly sensitive to variations in rainfall levels. We consider supplemental irrigation as a single adaptation instrument. To some extent, this puts the analysis in a shot-run perspective, since long-run factors, such as land allocation and surface-water-supply facilities are considered to be fixed. It should be acknowledged, however, that the impact of these factors on the production of winter-crops is quite limited. First, the principal purpose of surface-water infrastructures is to support summer-crops irrigation. Second, decisions on land-allocation among winter-crops are taken during fall, when the total water availability throughout the growing season is unknown. This sheds light on another character of winter-crops production relative to summer crops – the risk. The uncertainty associated with water availability at the planting stage increases the risk in the production decision since expenditures on land-preparation and planting may not be returned in drought years, even when supplemental irrigation is applied.

Our spatial-economic analysis utilizes a study of Ben-Gai et al. (1999), who have estimated probability distribution-functions for annual rainfall using data collected from sixty rainfall monitoring stations spread all over Israel. Although rather small, Israel is characterized by a sharp climate gradient, varying from arid conditions in the south to semi-arid in the north. Hence, this detailed spatial

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[1] Other evaluation studies focusing on climate impacts in the Mediterranean region are presented by Giupponi and Shechter (2003).

rainfall dataset enables us to pursue a high-resolution analysis, which accounts for the considerable spatial variability in production management and profitability throughout the country. Furthermore, referring to changes in precipitation-distribution functions rather than to variations in average-rainfall levels provides a unique opportunity to evaluate the economic aspects in terms of expected profitability and associated risks.

The economic evaluation is based on a pretty common methodology, known as the production-function approach: yield-response functions are used for simulating net-profits under projected scenarios of rainfall conditions. Examples for studies implementing this approach include Adams et al. (1990, 1999) and Rozenzweig and Parry (1994). Another analytical strategy is the Ricardian approach (Mendelsohn et al. 1994, 1996; Deschenes and Greenstone, 2004); it relies on the assumption that the market price of land is a reliable proxy to the land's present discounted value of future profits, which in turn are affected by climate features[2]. The preference of the production-function approach is attributed to the absence of a free market for agricultural lands in Israel. Since most lands are owned by the state, prices are significantly affected by administrative regulations and national policies.

This report is organized as follows. The next section presents the formal economic evaluation model. Section III describes the procedures for estimating rainfall-distribution functions and yield-response functions, as well as economic data used in the simulations. Section IV shows the simulation results for optimal surface-water applications under various levels of annual rainfall, expected net-profits under rainfall-distribution patterns in the past and according to a projected future scenario, aspects of profits' variation and risks and sensitivity to surface-water prices and salinity levels. Section V concludes.

II. General Model

Consider a geographic area with a semi-arid climate conditions. The area is divided into N regions, where in each region I types of winter crops are grown. Rain and supplemental surface-water irrigation constitute the potential water sources. In semi arid parts of the world winter is the rainy season. Land preparation for winter crops growing takes place during fall, implying decisions on land allocation among crops occur when farmers have no information about the rain available for the plants during winter. However, growers observe rainfall during the growing season, and select surface-water application accordingly. The nature of the decision making process is therefore recursive (McGuirk and Mundluck, 1992). That is, supplemental irrigation is considered as an adaptation strategy for intra-season changes in precipitations, whereas land allocation is not[3]. Hence, given the observed rainfall, r, for each crop i, $i = 1,\dots,I$, farmers select the optimal per-area-unit annual surface-water application $s^{*i}(r)$ by solving[4]:

$$s^{*i}(r) = \arg\max \pi^i(s^i, r) = p^{yi} y^i(s^i, r) - p^s s^i - \phi^i \quad (1)$$

π^i, $y^i(s^i, r)$ and ϕ^i are the crop-i's annual per-area-unit profit, yield, and non-water costs, respectively; p^{yi} denotes crop-i's output price, and p^s is the price of surface water[5].

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[2] Mendelsohn et al. (1999) provide a detailed comparison between the two .analytical approaches.

[3] This assumption does not hold for summer crops, since land allocation is decided upon when the total water availability is known.

[4] Note that the farmers in this work are assumed to adjust irrigation amount as a response to rainfall event without the need to commit for irrigation water quantity at the beginning of the season. Thus, their irrigation decision respond to rain fall events as they come. Hence the farmer does not optimize expected profit by choosing contracted amount of irrigation water based on the rain distribution, but rather adjust the irrigation as needed during the growing season.

[5] Note that is a result of a field-level decision making, which is not subject to constraints that may be set upon total regional surface-water consumption. Internalization of this aspect requires consideration of indirect impact of precipitation on regional water supply, as well as on water (and land) allocation between summer and winter crops; such an analysis is beyond the scope of this paper.

Spread over each region, n, are J^n rainfall monitoring stations; each of these stations represents a sub-region covering its surrounding area. In each sub-region j, the annual rainfall, r, is a random variable distributed according to a Gamma-distribution function:

$$f\left(r;\alpha_{nt}^{j},\beta_{nt}^{j}\right)=\left(\beta_{nt}^{j}\right)^{\alpha_{nt}^{j}}\left(r\right)^{\alpha_{nt}^{j}-1}e^{-\beta_{nt}^{j}r}\left[\Gamma\left(\alpha_{nt}^{j}\right)\right]^{-1} \quad (2)$$

$$r\geq 0\,,\quad \alpha_{nt}^{j},\beta_{nt}^{j}>0\;\forall\; j=1,\ldots,J^{n}$$

where α_{nt}^{j} and β_{nt}^{j} are the shape and scale parameters of the specific sub-region's Gamma-distribution function, respectively. The t index indicates that these parameters are related to a particular time period and may change due to global warming. $\bar{r}_{nt}^{j}=\alpha_{nt}^{j}\beta_{nt}^{j}$ and $v_{nt}^{j}=\alpha_{nt}^{j}\left(\beta_{nt}^{j}\right)^{2}$ are sub-region-j's rainfall expectation and rainfall variance, respectively. Let $G_{nt}^{j}\equiv\left\{\alpha_{nt}^{j},\beta_{nt}^{j}\right\}$ denote the pair of Gamma-distribution parameters during time-period t in sub-region j of region n; in time-period t the average annual net-profit expectation over region n with respect to crop i is:

$$\Pi_{nt}^{i}\left(G_{nt}\right)=\frac{x_{n}^{i}}{J^{n}}\sum_{j=1}^{J^{n}}\int_{0}^{\infty}\pi^{i}\left(s^{*i}\left(r\right),r\right)f\left(r;G_{nt}^{j}\right)dr \quad (3)$$

where x_{n}^{i} denotes the area allocated to crop i in region n, and $G_{nt}\equiv\left\{G_{nt}^{j},\ldots,G_{nt}^{J^{n}}\right\}$. Summation of (3) over regions and crops yields the annual net-profit expectation of the winter-crops production throughout the discussed area during period t:

$$\Pi_{t}\left(G_{t}\right)=\sum_{i=1}^{I}\sum_{n=1}^{N}\Pi_{nt}^{i}\left(G_{nt}\right), \quad (4)$$

where $G_{t}\equiv\left\{G_{nt},\ldots,G_{Nt}\right\}$. In the followings we analyze the impact of changes over time and space in the rainfall Gamma-distribution parameters, G_t, on the net-profit expectation associated with winter-crops growing $\Pi_{t}\left(G_{t}\right)$ and some other related aspects, such as risks, prices and water quality.

III. Data

3.1 Past and Future-Projected Annual Rainfall-Distribution Functions

As mentioned in the Introduction, the climate basis of the analysis is the spatial rainfall-distribution functions estimated by Ben-Gai et al. (1999) for sixty rainfall stations spread over the entire area of Israel. The data set of each station, consisting of 60 years record, was divided into two normal periods: Period I covers the winters from 1931/2 to 1960/1, and Period II, the winters from 1961/2 to 1990/1. For each meteorological station, two gamma-distribution functions were fitted to represent the distribution pattern in each period (see Ben-Gai et al., Table 1).

Ben-Gai et al. found that there are distinct three weather regions that are characterized by a different annual precipitation distribution, which we will refer to as the North, Center and South of Israel. Thus, in terms of the economic model this implies. Furthermore, each region exhibits a different variation-trend in the distribution-function parameters along the two normal periods.

In the North, the shape parameter decreases in Period II relative to Period I, while concomitantly the scale parameter increases. This increase in the distribution asymmetry implies an increase in the frequency of high rainfall events. An opposite development is seen in the South, where the average shape parameter increases by more than 60%, and the scale parameter declines by approximately 30%; these trends reveal a reduction in the aridity of the southern region of the country, and indicate a transition toward a normal distribution; Alpert (2001) attributes this variation in the South of Israel to local factors, particularly to the wide-spread and intensive agricultural activity that have started with the launch of the National Water Carrier in 1964. Directions of changes in the Center are similar to those found in the South, however, with a fairly moderate scale.

Substituting in (4), the aforementioned estimated distribution functions can be utilized for calculating profit expectations associated with rainfall patterns typical for the two normal periods. Our interest, however, is in analyzing projected future-rainfall patterns and their impacts on the profitability of winter-crops production throughout Israel. The next paragraphs describe a procedure used for calculating projected future rainfall-distribution functions.

One may view the changes identified in the estimated rainfall-distribution functions as an evidence for the existence of a continuous curve of distribution variation. Under such a supposition, the analysis of Ben-Gai et al. can be considered as an estimation of two points on this curve. The median year of each period may represent its position in the time scale, i.e., 1945/6 stands for Period I and 1975/6 for Period II. This information can be used for estimating distribution parameters associated with other periods[6]. We use the following linear equation to calculate the shape and scale parameters of a certain station j, in region n and at some period t:

$$\alpha_{nt}^{j} = \alpha_{n1}^{j} + \psi(t)\left(\alpha_{n2}^{j} - \alpha_{n1}^{j}\right), \text{ and}$$

$$\beta_{nt}^{j} = \beta_{n1}^{j} + \psi(t)\left(\beta_{n2}^{j} - \beta_{n1}^{j}\right), \quad (5)$$

where t=1 stands for Period I, t=2 for Period II, and $\psi(t)$ is a factor indicating the portion of the parameters-variation between Period I and Period II added to the parameter-value in Period I. According to this specification $\psi(t)$ is a factor used for interpolation/extrapolation based on the variation-trend found between Periods I and II. To get the parameter values of Period I (t=1) one should substitute $\psi(t)=0$; similarly, substituting $\psi(2)=1$ returns the parameter values of period II. For periods in-between periods I and II (interpolation;$1<t<2$), there is $0<\psi<1$. Using equation (5) for estimating distribution-parameters in periods extraneous to periods I and II (extrapolation) should, however, be considered with much caution. In other words, attaching values to $\psi(t)$ for future periods (i.e., for $t>2$) should be done only if subject to the control of some additional information is available. To this end we utilize forecasts provided by climatologic studies with respect to expected future changes in the area's average annual precipitation. Let $R(t)$ be the percentage change in the area's average annual precipitation relative to the average rainfall in Period II:

$$R(t) = 100\frac{\bar{r}_t - \bar{r}_2}{\bar{r}_2} \quad (6)$$

where $\bar{r}_t$ is the average annual rainfall expectation over the whole area during period t:

$$\bar{r}_t = \frac{1}{N}\sum_{n=1}^{N}\sum_{j=1}^{J^n}\frac{\alpha_{nt}^{j}\beta_{nt}^{j}}{J^n}. \quad (7)$$

Using (5), (6) and (7) one can calculate the value of $\psi(t)$ that fits to any estimation of $R(t)$. Estimations for $R(t)$ are available from two studies of future climate scenarios. Based on runs of few general circulation models (GCM) the IPCC (2001) forecasts a reduction of 3-35% in the annual average-precipitation in the years 2070-2100 relative to the period 1960-1990. This is, however, a low-resolution estimation, referring to a large area, encompassing considerable parts of Asia, Africa and the Mediterranean Sea. A rainfall-change forecast more focused on Israel is provided by Dayan and Koch (1999), who estimate (based on a GCM developed by Palutikof et al., 1996) a reduction of 1-2%, 2-4% and 4-8% in the years 2020, 2050 and 2100, respectively. According to (5)-(7) there is ψ=1.24, 1.40, 1.65, for R= -2%, -4%, -8%, respectively. This provides a notion about the order of magnitude of the values one can attach to ψ for predicting distribution patterns in the 21st century.

Next, in the following economic analyses we calculate the impacts of changes in the parameters of the precipitation distribution-function that are parameters associated with various values of ψ on the farmers profits are calculated. That is, ψ serves as our indicator for the change in annual rainfall-distribution patterns, G_t. In terms of the formal general model, $G_t=G(\psi(t))$. We consider changes within the support $\psi\in[0,2]$; this entails a decrease of up to 16% in the area's average precipitation relative to Period II.

Figure 1 illustrates the association between ψ and the Gamma-distribution functions calculated for two stations typical to their regions: Kefar-Blum in the North, and Dorot in the South.

Three sets of parameters are presented for the distribution of precipitation at each station for

[6] Fitting distribution functions for periods of 30-years with a subsequent median year within the time interval 1945/6-1975/6 could have generate more points on the distribution-parameters curve.

Period I (ψ=0), Period II (ψ=1), and a prospective future Period III, for which ψ=1.75 (R=-10%). The change in the distribution at Kefar-Blum is characterized by a redaction in α and an increase in β; this causes a slight raise in rainfall variation from Period I to Period II, and an increase in the average annual precipitation from 524 mm/yr to 536 mm/yr. Assuming the continuation of this direction of change in the parameters from Period II to Period III yields an expansion of the left tail of the distribution and a reduction of 30 mm/yr in the average annual rainfall in the North. In Dorot the continual reduction in β reduces the variance, while the expected rainfall increases, first from 345 mm/yr in Period I to 367 mm/yr in Period II, and then sharply declines in Period III to 233 mm/yr.

Figure 2(a) plots versus ψ the average rainfall calculated for the three regions and for the entire area ($\bar{r}_t$). The average rain appears to have a maximum in ψ=0.75; i.e., within the time-interval analyzed by Ben-Gai et al. From that point and on there is a steady decline.

3.2 Production Functions

Three seasonal crops were selected to represent the major winter crop-groups: wheat for field crops, processing tomato[7] for vegetables and vetch for fodder. Production functions were generated for each crop through a two-stage meta-modeling procedure. This procedure is detailed in Kan et al. (2002); here we provide only a brief description.

In the first stage of the procedure, an agronomic model is run to create a data set - a matrix of yield and evapotranspiration (ET) levels associated with various combinations of applied water and applied-water's salinity; in the second stage, this data set is used for estimating response functions.

The agronomic model used in the first stage consists of two sub-models: plant level and field level. The plant-level model was developed by Letey et al. (1985) to predict yield and ET of crops irrigated with saline water; the approach is based on steady-state conditions in the root-zone among deep-percolations, soil salinity and plant-water uptake. Inputs to this model are five parameters: the maximum available yield (denoted y_{max}, ton/dun-yr[8]), maximum ET (e_{max}, mm/yr), minimal applied water required for yield production (w_{min}, mm/yr), a threshold salinity level above which yields decline, (C, dS/m), and the rate of crop reduction (B, ton-m/dS-dun-yr).

The translation from plant-level to field-level is required because spatial distribution of water is non-uniform, where the uniformity level is irrigation-system dependent. The ET and yield in the field-level are calculated based on the approach developed by Feinerman et al. (1983), using the lognormal-distribution function, as suggested by Knapp (1992). A sprinkler irrigation system is assumed; the standard deviation of the lognormal distribution associated with this system is 0.187, which fits a Christiansen Uniformity Coefficient (CUC) of 85.

Two response functions are estimated in the second stage of the meta-modeling procedure. First, ET, e (mm/yr), is described as a function of the applied water, w (mm/yr), and the applied-water salt concentration, c (dS/m). Let $w = s + r$ (all in mm/yr) and $c = \frac{sc^s}{w}$, where c^s (dS/m) is the salinity level of the surface water; note that rain water have zero salinity. The functional form is borrowed from Kan et al. (2002):

$$e(w,c) = \frac{e_{max}}{1+\gamma_1\left(c+\gamma_2 w^{\gamma_3}\right)^{\gamma_4}}, \tag{8}$$

where γ_1- γ_4 are crop and irrigation-system specific coefficients to be estimated. Second, a function describing the relationship between the annual yield, y (ton/dun-yr), and e is estimated. Here we find that a power function with coefficients δ_1 δ_2, is found to provide the best matching[9]:

$$y(e) = \delta_1 e^{\delta_2}. \tag{9}$$

Note that (8) enables calculating volumes of deep-percolations, d (mm/yr), according to the identity $d = w - e$; also, based on the assumed steady-state conditions in the root-zone, we get

[7] Open-field production.

[8] Metric tons.

[9] Kan et al. (2002) used a linear function, which appears suitable for the plant-level relationship rather than the field-level.

$\chi = \frac{sc^s}{d}$, were χ (dS/m) is the salinity of the deep percolation flows. These measures are utilized later in an analysis of the external impacts of agriculture production on the quality of groundwater.

Table 1 presents the parameters used for the plant-level model and the estimations for the field-level-function coefficients for each of the three crops.

Most of the parameters used in this study are taken from Letey and Dinar (1986), Mass and Hoffman (1977) and Mass (1990); y_{max} values (representing the maximum yield available under no water and salinity stresses), however, were selected as to calibrate the output calculated by equation (9) to average yields that were observed in Israel during the years 2000-2002. Figure 3 illustrates the functions $e(w,c)$ and $y(e)$ estimated for wheat and tomato; these are examples for salinity tolerant and salinity sensitive crops, respectively.

3.3 Economic Data

The economic analysis is based on 2003 economic parameters that were observed for the Israeli agricultural sector. Output prices, as well as production costs, were collected from various reports and growing-cost studies published by the Israeli Ministry of Agriculture, and by an agro-economic consulting company (Tzmudot 2003). Data and sources are presented in Table 1. Also reported are 2002 crop-production areas in the three regions under consideration, as detailed by the Israeli Central Bureau of Statistics. Monetary values are in 2003 US dollars[10]. Surface water salinity (c^s) equals 0.75 dS/m, according to the average salinity of fresh water supplied by Mecorot, the Israeli national water company. The average price of surface water for agricultural use (p^s) is subsidized and stands on about $0.24/m^3. (Impacts of changes in policies affecting the levels of c^s and p^s are presented bellow.)

IV. Results

4.1 Optimal Surface-Water Applications

Given the observed annual rainfall, r, farmers are assumed to select the optimal per-area-unit surface-water application for each crop, $s^{*i}(r)$; i.e., they solve equation (1). Based on the corresponding functions and economic parameters, Figure 4(a1)-4(a2) present the variation in the optimal surface-water application levels, s^*, for wheat and tomatoes with the annual precipitations, r. Also presented are the associated changes in applied water, w, changes in ET, e, and in deep percolations, d. Figures 4(b1)-4(b2) show the corresponding variations in the per-unit-area net-profits, π, and yields, y.

When there is no rainfall, r = 0, surface water constitutes the single plant intake water source. As precipitations increase there are two phases of change. First there is a linear reduction in the optimal surface-water application, s^*, which reflects the substitution between the two water sources. Note that the substitution is imperfect due to the difference in the sources' salinity levels. This is exhibited by the slight decrease in the total applied water, w, as rain increases – the increase in rainfall reduces the salinity of the applied water and thereby reduces the optimal water application; i.e., less water intake is required to compensate for the negative effect of salinity on yields. The combination of the two water sources maintains ET almost constant, which implies that the yield does not change significantly. This management regime maintains the equality between the price of surface water and its value of marginal production (VMP). Because of the reduction in surface-water purchasing costs profits increase linearly with rainfall.

The second phase of variation starts at the rainfall level under which s^* attains zero – from this point on surface-water's VMP is lower than its price. Thus, precipitations constitute the single water source, and w increases according to the 45° line. Concurrently, ET climbs up; however, as seen in the variation of d, as rain continues to increase, the fraction of rain penetrating down as deep-percolations grows almost in a 1:1 ratio - approximately parallel to the 45° line. Profits in this phase increase according to the response of yields to the additional rainwater.

Note that in wheat (and vetch, not shown)

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[10] The exchange rate is 4.5 New Israeli Shekel per $.

production carries on also under negative profits, since as aforementioned, land preparation and planting is accomplished before the rainfall level is known; hence, the non-water cost, ϕ^i, can be viewed as a lost expenditure.

4.2 Economic Impacts of Rainfall-Distribution Changes

Having the optimal surface-water management for various rainfall levels, we use equation (3) to calculate for each region and crop-group the regional average annual net-profit expectation; this expectation is associated with a specific annual rainfall-distribution pattern, determined according to $G_t=G(\psi(t))$. Figure 5 presents the response of the profit expectations to the rainfall-distribution changes, as indicated by the value of ψ.

The evaluated changes in accumulated profit associated with all crops are shown in Figure 5(a) for each region, as well as for the entire area (as depicted by equation (4)). Apparently, the total annual net-profit increases first from $93.0 million at ψ=0 (Period I) to $102.8 million at ψ=0.75; then it declines to $101.7 million at ψ=1 (Period II), and to $67.1 million at ψ=2. This illustration indicates a positive impact of the distributions-change on the profitability of the agricultural sector between Period I and II; however, this trend is reversed and profitability is expected to decline with the prospective increase in ψ. Considering the aforementioned forecasts provided by Dayan and Koch (1999), the overall annual net-profit expectations in 2020, 2050 and 2100 are evaluated to be $100.1-98.5 million, $98.5-94.8 million and $94.8-86.1 million, respectively. Relative to Period II these are reductions of 1.6-3.2%, 3.2-6.9% and 6.9-15.4%, respectively.

Winter agriculture in the South is found to be the most sensitive to rainfall-distribution changes; the net-profit of all crops increases from $16.6 million in Period I to $24.8 million in Period II, but then falls and even turns negative at ψ=2 (Figure 5(a)). This outcome is attributed mainly to the effect on field crops, for which the average net-profit expectations in the South becomes negative at $\psi>1.6$. In the North rainfall patterns affect profitability of field crops and fodders, while vegetables show almost no response to the changes in precipitation distribution. Changes in the Center are minor for all types of crops.

4.3 Variation and Risks

Risk-aversion farmers care not only for annual net-profit expectations, but also for the variation in annual profits. Increase in rainfall instability due to a larger variation in the annual rainfall distribution imposes additional costs that are attributed to the need for inter-annual water storage and conveyance of larger amounts of surface-water. Moreover, the associated increase in profits instability may motivate farmers to seek for more secure income sources. In fact, since the mid 1980th there is a continuous worsening in the terms of trade of the agricultural sector in Israel. This has driven many farmers out of business and increase the sensitivity to income fluctuation for the ones that remained in the agriculture sector.

To examine the impact of changes in rainfall patterns on farmers risk considerations, we calculate regional average coefficient-of-variations (CV = standard-deviation/average, expressed in percents) of net-profits. The computation is as follows: first, net-profit expectation and standard deviation associated with production of a weighted average winter crop are calculated for each sub region, where crops' profits are weighted according to the regional land allocation; second, the sub-region CVs are calculated and averaged over regions. Figure 6 presents the variations of the regional CVs with ψ.

In the North and the Center CVs are quite stable on approximately 50% for $\psi<1.5$. In higher ψ levels CV increases in the North. In the Center, at $\psi>1.5$ there is an increase in CV followed by a reduction. In the South, CV is reduced from 100% in Period I (ψ=0) to about 60% in period II (ψ=1), and then there is a wide fluctuation at ψ>1.5; this is attributed to the low (and some times negative) profits in this region at high ψ levels (Figure 5(a)). These findings indicate that trends in rainfall patterns are expected to increase agricultural risks in Israel toward the second half of the 21st century.

4.4 Sensitivity to Water Price and Salinity

The net profit expectation estimations presented in Figure 5 are based on 2003 observation of prices, technologies, quality of inputs, etc. Some of these factors are expected to vary in time, and few of these changes may be stimulated by the variations in rainfall patterns. The increasing demand for domestic-water use due to population growth and the incessantly increase in per-capita water consumption, together with the increase in surface-water scarcity in Israel, are already affecting water pricing and water allocation to the agricultural sector. Currently, historical grandfather seniority user-rights fresh-water allocations are sharply cut, and replaced by allotments of treated wastewater. This policy is expected to reduce yields due to increase in soil salinity. In the long run the use of treated water would depreciate groundwater sources, thereby escalating water scarcity. Furthermore, a plan to construct seawater-desalination plants for water provision to urban uses puts the current subsidies of agricultural-water under an intensifying criticism and calls for a dramatic price increase are often debated in the political arena. In this subsection we analyze the impacts of such trends by reevaluating the economic effect of changes in rainfall-distribution patterns under various surface-water prices and qualities. For each exogenous change in these parameters, the area's average net-profit under various rainfall-distribution patterns, $G_t=G(\psi(t))$, is calculated by solving equation (1) to find the appropriate $s^*(r)$, and substituting the resultant in (3).

Table 2 summarizes the results of the sensitivity analyses, based on the scenario given in Dayan and Koch (1999) for average-rainfall reductions relative to Period II (with the median year 1975) of 1.5%, 3.0% and 6.0%, for 2020, 2050 and 2100, respectively. The second column in the table presents net-profit expectations according to the reference scenario, where surface water price and salinity are those observed in 2003 – $0.24/m^3 and 0.75 dS/m, respectively. Columns three and four present the effects of higher surface-water price and higher salinity on the profit expectations. The higher price was selected to equal the marginal cost of seawater desalination - $0.56/m^3, and the higher salinity is that of treated waste water – about 2.0 dS/m. Columns five and six express these impacts as percentage rates relative to the reference case.

The simulated increase in surface-water price imposes a considerable reduction in profitability – for Period II rainfall distributions there is a decline of 41.5% for the entire area. Moreover, the prospective changes in rainfall increase this loss up to 52% in 2100. As expected, this impact increases along Israel's climate gradient from the North to the South; in fact, without any supplementary policy, such as provision of a non water-related subsidy, production of field crops and vegetables in the South becomes unprofitable at all periods. As the highest water consumption crops (Figure 4(a2)), vegetables are the most sensitive crops-group for water prices, with a profit reduction of 82.2% and 95.1% in 1975 and 2100, respectively (not shown). Field crops are ranked second in the sensitivity to water-price, although the higher water consumption relative to fodders – this is attributed to the steeper response of profits to water applications (not-shown).

The "higher-salinity" scenario shows similar patterns in its impact on profitability, but of a lower magnitude. Nation-wide profits are reduced by 7.8% and 9.7% in 1975 and 2100, respectively; impacts are the largest in the South. Represented by tomato, a relatively salt-sensitive crop, vegetables are the most sensitive group with a reduction of about 15% throughout the entire state. Fodders are second with nearly 6%, and wheat for field crops exhibits a reduction of about 3%. Rainfall-distribution changes along periods enlarge salinity's negative impact by approximately 2%.

V. Concluding Remarks

Variations in rainfall-distribution patterns are projected to impose significant damage to winter-crops production in Israel. On average, net-profits are expected to decline by about 11% by the year 2100 relative to the latter part of the 20th century. Though, impacts vary considerably in space. The semi-arid southern region is the most sensitive to the projected climate change, with a 35% decline in profit, whereas in the Center and the North of the country reductions in profitability amount to 5% and 8%, respectively. Also risks, as measured by the coefficient of variation, are in general lower in these two latter regions; this is attributed to the fact that a more dramatic rainfall reduction is projected in the South.

The above findings signify a growing threat to the agricultural sector in the southern part of Israel. Farmers' incentive to depart the agricultural livelihood in favor of some more secure income sources is expected to rise dramatically. Simultaneously, pressures for designating agricultural lands to alternative uses, particularly to urban areas, would grow, and may entail changes in the landscape and a reduction in the availability of open-spaces.

Nevertheless, some exogenous factors such as increases in food demands and supportive governmental intervention may balance these negative effects of climate change. Moreover, internalization of additional adaptation options into the analysis is expected to lessen the estimated economical impacts; particularly the allowance for variations in land allocation among crops. On the other hand, constraints associated with surface-water provision were ignored, and may increase the evaluated damage if introduced. Further research avenues include bringing in such aspects; this entails development of more sophisticated models, involving regional scale calibration procedures with respect to land allocation, and analyzing efficient surface-water distribution among regions.

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Table 1 Model's parameters, production-function coefficients and economic data.

Description	Wheat (Field crops)	Tomato (Vegetables)	Vetch (Fodders)
Plant-level coefficients[a]			
y_{max} (ton/dun-yr)[a]	0.75	12	11
w_{min} (mm/yr)	469	420	260
e_{max} (mm/yr)	261	820	800
C (dS/m)	6.0	2.5	3.0
B (ton-m/dun-yr-dS)	7.1	9.9	11.0
Field-level coefficients			
γ_1	1.343×10^{-2}	1.742×10^{-2}	5.836×10^{-4}
γ_2	6.666×10^{13}	2.690×10^{10}	21,931
γ_3	-4.910	-3.420	-1.181
γ_4	1.130	1.453	2.556
δ_1	2.488×10^{-6}	1.696×10^{-6}	7.237×10^{-6}
δ_2	2.055	2.360	1.796
Prices and costs[b]			
p^y (\$/ton)	157.8	48.9	170.7
ϕ (\$/dun)	69.8	316.0	43.1
p^s (\$/m^3)	0.24	0.24	0.24
Production areas (dun)[c]			
North	346,791	96,433	290,377
Center	95,723	55,173	63,758
South	130,316	128,163	744,054

a Data are from Letey and Dinar (1986), Mass (1990) and Asher Izenkot from the Israeli Ministry of Agriculture and Rural Development (personal communication).

b From sample cost studies of the Israeli Ministry of Agriculture and Rural Development, and Tzmudot company (2003). Output price is net of yield-related costs, as harvesting.

c Source is the Israeli Central Bureau of Statistics for 2002; the areas are for total winter field crops, vegetables and fodder crops, represented for the economic analyses by wheat, tomato and vetch, respectively.

Table 2 Sensitivity of net-profit expectations under rainfall patterns in 1975 (Period II), 2020, 2050 and 2100 (Dayan and Koch (1999)) to an increase in surface-water price up to the level of seawater-desalination cost, 0.56 $/m^3, and to a rise in surface-water salinity toward the level of treated waste water, 2.00 dS/m.

	Net-profit expectations (million $/yr)			Change relative to "Reference" (%)	
	Reference	Higher Price	Higher Salinity	Higher Price	Higher Salinity
p^s ($/m^3)	0.24	0.56	0.24	0.56	0.24
c^s (dS/m)	0.75	0.75	2.00	0.75	2.00
1975 (Period II, ψ = 1, R = 0)					
Entire area	101.8	59.5	93.8	-41.5	-7.8
North	47.4	33.9	44.7	-28.5	-5.6
Center	17.1	10.8	15.9	-36.7	-7.1
South	24.8	-3.0	20.0	-112.0	-19.2
2020 (ψ = 1.19, R = -1.5%)					
Entire area	99.3	56.0	91.2	-43.7	-8.2
North	46.5	32.7	43.8	-29.8	-5.9
Center	16.9	10.5	15.7	-37.8	-7.3
South	23.0	-5.6	18.1	-124.4	-21.2
2050 (ψ = 1.33, R = -3%)					
Entire area	96.5	51.8	88.2	-46.4	-8.6
North	45.6	31.3	42.8	-31.4	-6.2
Center	16.7	10.2	15.4	-39.0	-7.5
South	20.8	-8.9	15.8	-142.6	-24.2
2100 (ψ = 1.53, R = -6%)					
Entire area	90.7	43.1	81.9	-52.5	-9.7
North	43.6	28.4	40.6	-34.8	-6.8
Center	16.2	9.5	14.9	-41.5	-8.0
South	16.2	-15.8	10.9	-197.6	-33.0

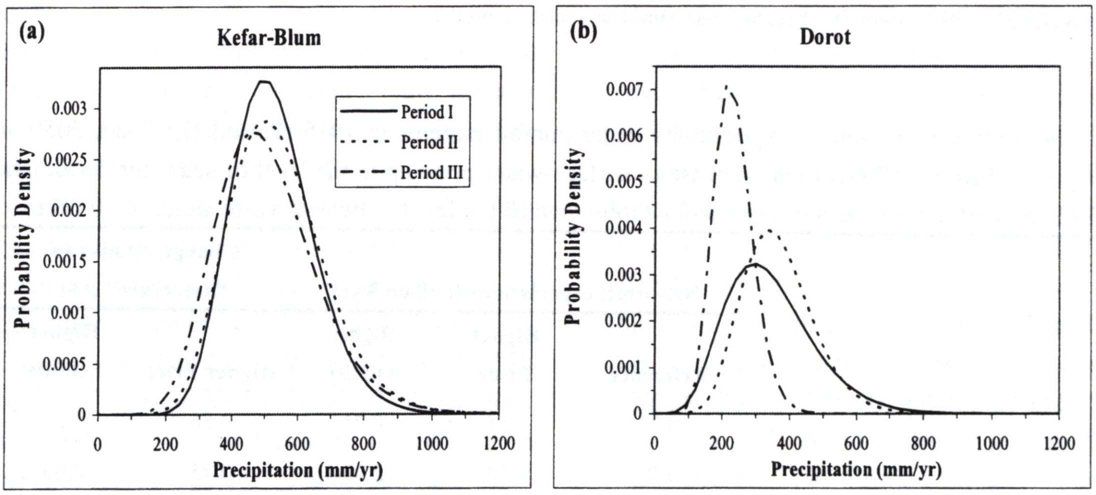

Figure 1 Annual rainfall-distribution functions for (a) Kefar-Blum station in the North and (b) Dorot

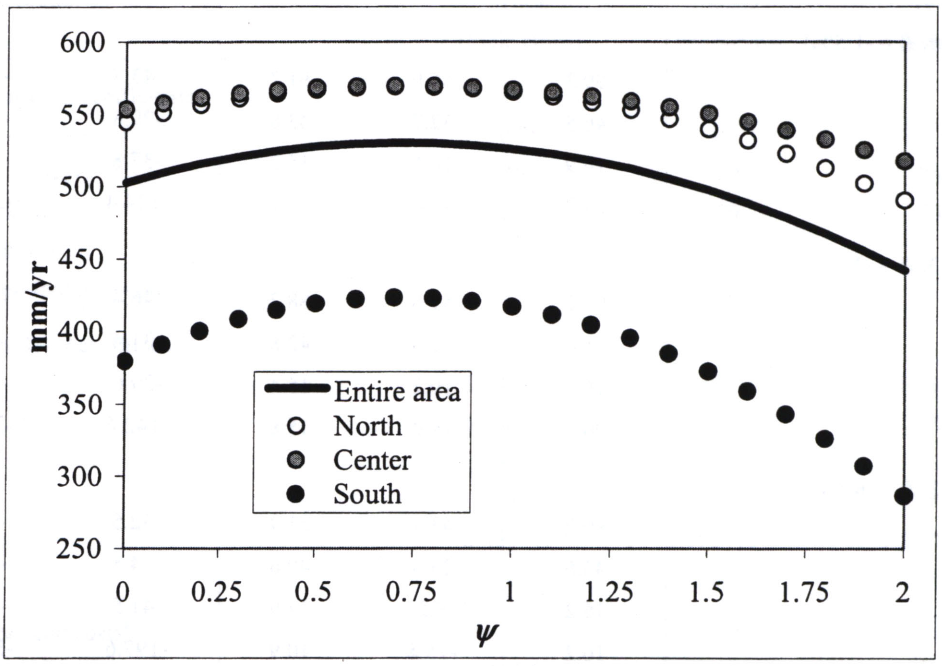

Figure 2 Regional average rainfall expectations plotted versus ψ for the North, Center and the South regions, and for the entire area of Israel.

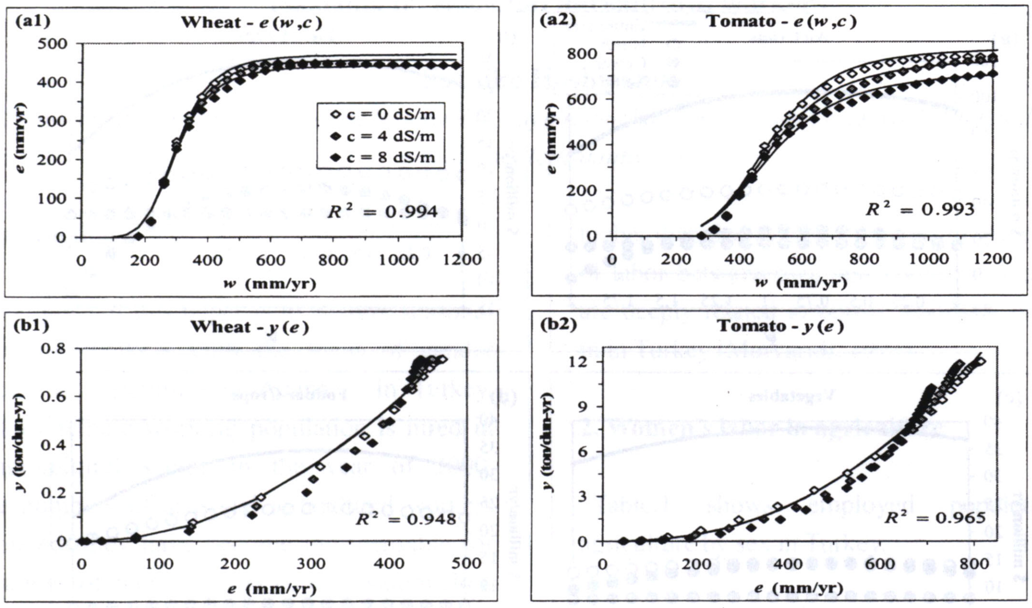

Figure 3 Response functions of (a1, a2) ET versus quantity and salinity of applied water, and (b1, b2) yield versus ET, for wheat and tomato; symbols are field-level-model outputs and lines are drawn according to the fitted functions.

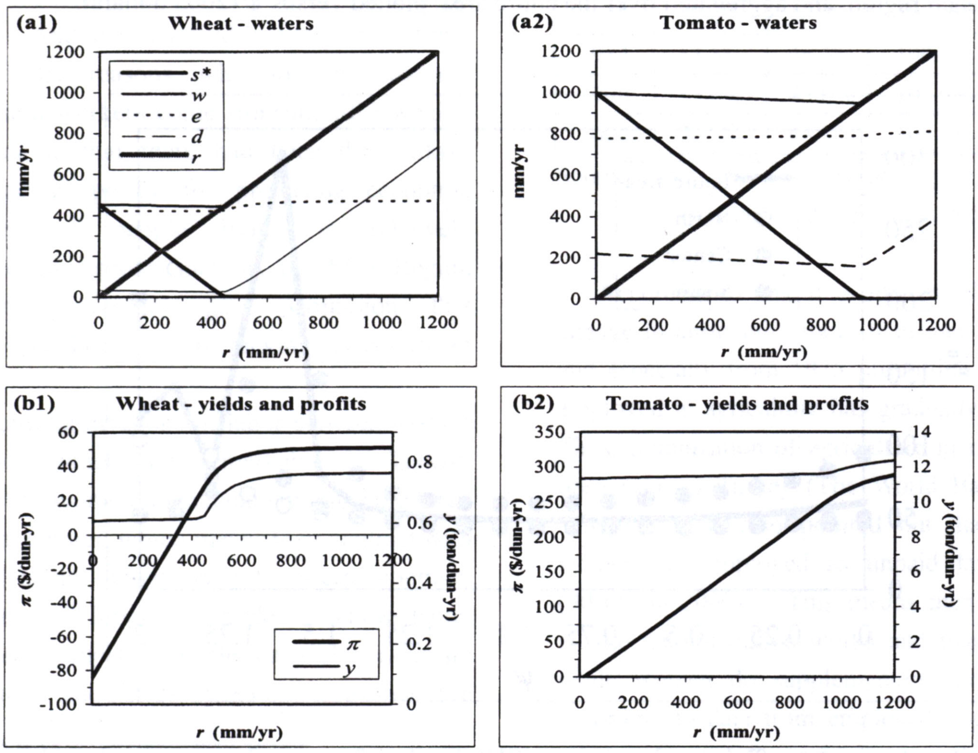

Figure 4 (a) Optimal annual surface-water applications, s^*, ploted versus annual rain, r, for wheat and tomato, and the associated applied water - w, evapotranspiration - e, deep-percolations – d, and (b) yields - y, and net-profits - π.

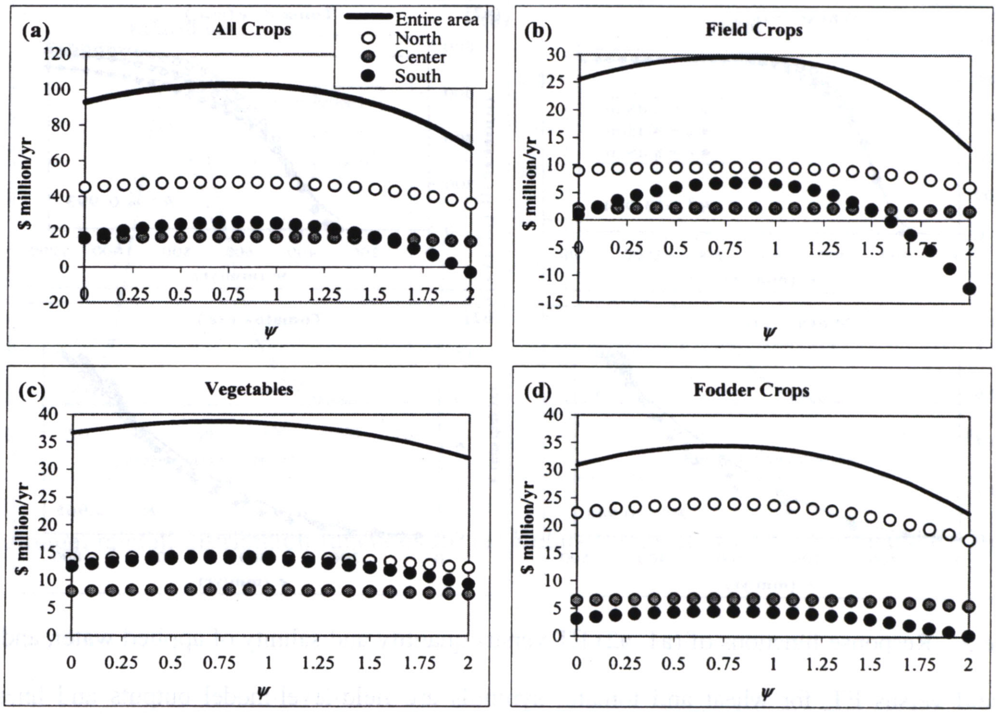

Figure 5 Average net-profit expectations of (a) all crops, (b) field crops, (c) vegetables and (d) fod crops, in each region, and aggregated over the entire area, plotted versus ψ (2003 dollars).

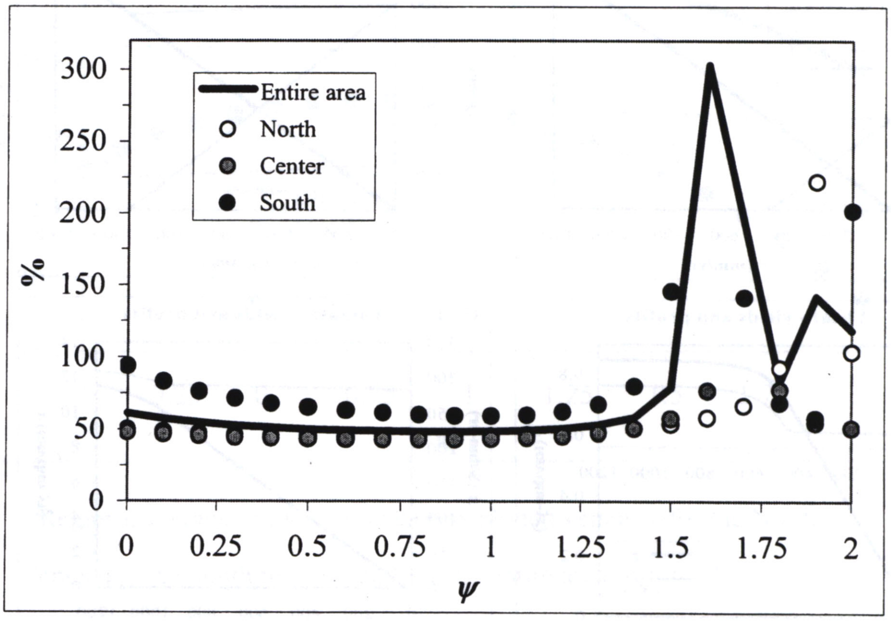

Figure 6 Average coefficient-of-variation (CV) levels of net-profits associated with production of an average crop in each region and in the entire area, plotted versus ψ.