Evaluating the demand patterns for irrigation water:
The case of western Macedonia

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Abstract

This article is concerned with the management of water resources in the region of Western Macedonia. Taking into account the great importance of agriculture as the principal consumer of water in the region, as well as the drastic increase in regional water consumption over the last decade, a related study evaluating the demand patterns for irrigated water can prove to be extremely valuable. This paper examines the demand patterns and probable trends for irrigated water using the Discrete Sequential Stohastic Programming (DSSP) Model for four agricultural products (apples, peaches, potatoes and tomatoes) and five specific subareas (the prefecture of Florina, the prefecture of Kastoria, the prefecture of Grevena, the city of Kozani and the city of Ptolemaida). Results clearly demonstrate that apples and potatoes are the only crops in the region that use water deficit irrigation strategies in short water years (representing a water deficit of 25%). In addition, results reveal that the most cost-effective solution would be to acquire water from the prefecture of Kastoria because the marginal value of run-off water in this area is lower compared to the other areas in question.

Introduction

An increased demand on water supplies generally originates from its use for recreational, industrial, municipal, environmental, or agricultural purposes. However, the construction of new water storage and conveyance facilities to meet these demands is no longer feasible on a general basis. Cost-effective sites have already been developed (Angelakis and Diamadopoulos, 1995) and recent environmental concerns effectively prohibit new construction. Consequently, the re-allocation of water from current users has been seen as the best alternative as it involves the lowest cost, if the emerging higher-valued water demands are to be met.

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Population growth can be held responsible for many of these increased demands, but it is the recent emergence of environmental needs that is having the greatest impact on current water users (Houk *et al*, 2000). In the Western Macedonian region, water for agricultural irrigation presently accounts for more than 83% of the total use of water resources (Greek Ministry of Agriculture, 2001). Agriculture is the largest and least-valued water user; Young (1984) observes that it would be generally less costly to transfer water from agriculture than to develop new water supplies.

The region of Western Macedonia mainly produces four irrigated agricultural crops (apples, peaches, potatoes and tomatoes) covering more than 90,000 hectares of irrigated land in total. Thus, it is critical to determine the value of water used for agriculture, so that the necessary information may be available for future decisions regarding water allocation. The efficient allocation of water resources should be organised in such a way so as to maximize social welfare. Gibbons (1987), states that social welfare is maximized when the marginal benefit of the resource is equal across all users. In the absence of working free markets for water, however, it is difficult to identify the value (or marginal benefit) that should be placed on this ever-changing resource.

The aim of this paper is to evaluate the demand for agricultural irrigation water in the region of Western Macedonia over a cross section of agriculturally distinct areas (reflecting various climatic, agronomic and crop market influences), during different periods of the growing season, where a variety of institutional arrangements for water transfer are utilized, and also in relation to the risk response related to fluctuating water supplies.

The results of this study can prove useful to both policy makers and individual farmers. Policy makers will be able to assess the feasibility of changing water rights to meet the demands of various water uses and the subsequent impact on farmers. On the other hand, farmers will be able to quantify the relationship between their water supply and their income, and have a clearer understanding of the consequences of any agreement that would affect the status of their current water supplies.

Methods

Field research was conducted, based upon interviews with producers and irrigation district employees, during May 2000. The region of Western Macedonia, which was chosen as the object of the research, was divided into five subareas (the prefecture of Florina, the prefecture of Kastoria, the prefecture of Grevena, the city of Kozani and the city of Ptolemaida). These subareas were selected due to their similar agricultural practices, water delivery systems, water institutions and climatic conditions. The prefecture of Kozani was split into two separate areas (the city of Kozani and the city of Ptolemaida) owing to the distinct characteristics of each specific area. Five representative farms were then constructed and simulated from survey and farm data based upon this division.

The representative farm framework in each area varies in farm size, crop production, crop rotation, types of irrigation used, amount of irrigation water available, precipitation, crop water requirements, cropping budgets, crop yields and crop prices. In the prefecture of Florina, agriculture is limited to wheat, potatoes and pasture. The area is characterized by high elevation, a short growing season and sufficiently secure water

supplies. The city of Kozani produces high yields of wheat, potatoes and peaches with limited water storage for late season irrigation. In the prefecture of Kastoria, agriculture mainly involves wheat, apples and pasture. The major irrigated crops in the other areas are potatoes, tomatoes and apples.

Model Structure

Agricultural production is sequential in nature, i.e. a lot of farm decisions are often influenced by earlier decisions and information that has become available only after earlier choices have been made (Anderson *et al.*, 1977). To account for the sequential nature of agricultural production, the Discrete Sequential Stohastic Programming (DSSP) model was used, which incorporates the risks of crop production into the objective function and allows for sequential decisions to be made. DSSP is a technique where decisions are optimized through multiple stages of expected occurrences (McCarl and Spreen, 1999). The DSSP model was developed by Cocks in 1968 and was later applied in 1971 by Rae to agriculture (Taylor and Young, 1995). Since then, however, it has been seldomly used (Kaiser and Apland, 1989).

The structure of the model can be viewed as a decision tree, where the decisions are linked in time sequence with their associated probabilities. As we move along the decision tree we are faced with forks representing possible outcomes or decisions, and if these event forks (state of natures) are not limited, then the problem can quickly become too large to work with. Anderson, Dillon and Hardaker (1977) recommend limiting stages of nature that are essentially continuous by approximating discrete distributions into two or three categories.

The model in this study simplifies the farm decision process by defining two sequential time periods during which irrigation water can become available to the farm. The stochastic variable is the quantity of irrigation water available during these two stages throughout the growing season.

During the first time period, the irrigation water available is limited to two states of nature, either full water or no water. The use of run-off water is restricted to the early production of apples (if apples are a possible crop choice for the area in question). Full water represents a sufficient supply to fully irrigate all available apples based upon regional apple rotations. The decision to be made at this time period specifies the amount of farmland that will be used to grow each crop. This decision limits future time periods because it causes less land to be available for other crops.

The second time period has three states of nature, identified as: full water, short water and very short water. This time period commences with the announcement of growing season storage water available for the irrigation district. Irrigation water available during this period will be used to grow all crops on the land available for the entire growing season, if the state of nature provides an adequate supply. Full water, short water and very short water supplies represent water deficits of 0%, 25% and 40% respectively (Houk *et al.*, 2000). The decisions to be made at this point concern the crop mix to be planted on the idle land available from the first time period, the irrigation strategy based on the water supply available, as well as various harvesting activities. Land can also be left idle, if it is found to maximize expected farm profits.

Quantities of water will be allocated per crop growing stages throughout the season, with the possibility of limiting the amount during individual or all stages of growth if conditions are optimal, based upon the water supply available. The model will then produce an optimal crop mix and optimal irrigation schedule based on the state of nature and period, by maximizing the total expected profit of each representative farm. The marginal value of water will be estimated for each time period and for each representative farm.

The DSSP model maximizes total expected profit over two sequential stages, subject to hectares of land, as well as agronomic and irrigation water constraints (Houk *et al.*, 2000):

$$Max \sum_{k=1}^{4}\sum_{i=1}^{11}\sum_{s1=1}^{2}\sum_{s2=1}^{3}\{HECT_{k,i,s1,s2}[Y_{ki}*(P_k - HC_k) - NC_{ki}] +$$

$$A_{s1}[(Ap - Ahc) - Anc] - (I_{k,i,s1,s2}*Ic)\}*P1_{s1}*P2_{s1,s2}$$

$$\text{s.t.:} \qquad HECT_{k,i,s1,s2} + I_{k,i,s1,s2} \leq Land\ Available$$
$$HECT_{k,i,s1,s2} \leq B_k$$
$$A_{s1}*Awreg \leq R1$$
$$HECT_{k,i,s1,s2}*(Wreg_4 - P_E) \leq R2$$
$$A_{s2} \leq A_{s1}$$

where $HECT_{k,i,s1,s2}$ is the amount of hectares planted for each crop $k(k=1, ... , 4)$ across all irrigation strategies $i(i=1, ... , 11)$, for both time periods and all possible states of nature $s1(s1=1, 2)$ and $s2(s2=1, 2, 3)$. The amount of hectares is multiplied by the difference in crop price P_k and the cost per unit of harvesting HC_k to get a per hectare value of production that then has the per hectare non-harvest costs subtracted NC_{ki}. The value of non-harvest costs is dependent upon the crop (k) and the irrigation strategy (i). The value related to the first harvest of apples is then added to the value of all other crops. A_{s1} represents the hectares of apples irrigated with run-off water and then harvested, which is multiplied by the difference in the apples' price (Ap) and the apples' per unit cost of harvesting (Ahc), and then has the apples' non-harvest costs (Anc) subtracted. The cost of maintaining idle land is then subtracted from the total value of all crop production. The quantity of idle land $(I_{k, i, s1, s2})$ is a function of all crops produced, irrigation strategies used and all time periods and is multiplied by the cost of the idle land (Ic). The last step of the objective function is to include the probabilities ($P1_{s1}$, $P2_{s1,s2}$) of each state of nature into each of the two time periods. The objective function is subject to many constraints, the first of which is to make the total number of hectares used by crops plus the idle land equal the total land available. B is the minimum rotational requirement for each of the crops. The quantity of water used by apples in the first harvest ($Awreg$) must be less than the amount of run-off water available ($R1$). The second water constraint requires that the total water required for each crop ($Wreg_4$) minus the area's effective precipitation (P_E), be less than the total quantity of water available during the second time period ($R2$). The last constraint links the quantity of apples from the first period (A_{s1}) to the quantity of apples from the second time period (A_{s2}).

Objective Function, Costs of Production, and Crop Prices

The objective function maximizes the total expected profit in relation to all possible states of nature. It is a summation of all activities for each time period in the model, calculated by the value of crop sales minus the per unit costs of harvesting and the non-harvest hectares' costs accrued throughout the growing season. The value of the crop sales will reflect the regional crop prices and non-harvesting hectares costs will vary according to the different irrigation strategies and crop mixes.

States of Nature

It was assumed that the beliefs and perceptions of decision makers regarding an uncertain event would serve to dictate their behaviour in the long run. Probabilities for each state of nature and for each time period were identified. Producers and irrigation district employees were consulted as to the likelihood of receiving run-off water and of having full, short or very short water supply in specified irrigation districts. Probabilities were based on historical data for each area.

Agronomic and Water Constraints

Possible crops can be listed as: apples, peaches, potatoes and tomatoes. Rotational practices for each area were determined following interviews with relevant producers. Water restraints were constructed using the evapotranspiration requirements for each crop per area. In addition to irrigation water fulfilling these evapotranspiration requirements, the average effective precipitation during the growing season for each area was estimated (Houk *et al.*, 2000).

Crop-Water Production Functions and Crop Yields

The generalized production function used in this study was taken from Doorenbos and Kassam (1979) and quantifies the relationship between relative yield decrease (*1-Ya/Ym*) and relative evapotranspiration deficit (*1-ETa/ETm*):

$$1\text{-}Ya/Ym = Ky\,(1\text{-}ETa/ETm)$$

Where: *Ya* = *Actual Yield*
  Ym = *Maximum Yield*
  Ky = *Yield Response Factor*
  ETa = *Actual Evapotranspiration*
  ETm = *Maximum Evapotranspiration*

The yield response factor (*Ky*) is dependent upon crop types, magnitude of water stress and timing. Values of the yield response factor (*Ky*) were used as estimated according to Doorenbos and Kassam (1979). Evapotranspiration (*ET*) represents the actual quantity of water used by the soil plant system and was used because it has been found to be a better predictor of yield than applied water (Vaux and Pruitt, 1983). When actual evapotranspiration is less than the maximum evapotranspiration required, a relative evapotranspiration deficit occurs resulting in decreased yields. The use of

relative evapotranspiration allows the model to have site transferability so that it can be used in different parts of the same region (Vaux and Pruitt, 1983). The quantity of water that is actually applied for crop production will then be adjusted to represent the quantity of water available for evapotranspiration through the use of area-specific irrigation efficiencies.

Currently the most common plan for acquiring water from agriculture is the use of short-term water "leases" during low water years. The DSSP model can be used as a deterministic linear programming model that will calculate the value water during short year periods only. To do so it is necessary to change the probabilities for each state of nature, so that the model is forced to offer a solution when it is a short water year, in other words when the probability of a short water year is equal to 1 (Houk *et al.*, 2000).

Results

Incentive based techniques such as early spring run-off water transfers, long term growing season transfers, and dry year "leases" are analysed in the following sections by identifying the marginal value of irrigation water under these possible conditions.

Value of Spring Run-off

The first and largest harvest of apples among the irrigated cultivations of the Western Macedonian region is secured by spring run-off diversions. The expected marginal value of run-off water is thus related to this first harvest of apples and ranged from 3.43 euros per hectare in the prefecture of Kastoria to 6.47 euros per hectare in the prefecture of Florina. The only other area that was using spring run-off to irrigate apples was the city of Kozani, where the value was 6.43 euros per hectare (*Figure* 1). The difference in value between these areas could be related to the lower price of apples in the prefecture of Kastoria as well as the lower percentage of apples grown there. The values in the other areas are almost equal because the crop budgets and percentage of apples grown on any representative farm are similar.
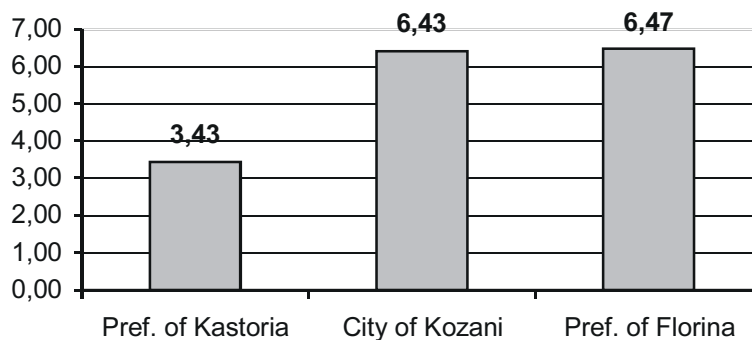

Figure 1. Expected Marginal Value of run-off Water (euro/hectare)

Value of Water in the Second Time Period

The second time period concerns the water available from irrigation districts for the entire growing season excluding the first harvest of apples. The expected marginal value of water during this time period ranged from 1.76 euros per hectare in the prefecture of Grevena to 6.40 euros per hectare in the prefecture of Florina (*Figure* 2). These values of water represent the long-run value at this margin; during most years these farms expect to have abundant water supplies, which would cause the marginal value to be zero at that time. This value depicts the amount of compensation a producer would be willing to accept for the water per hectare on a long-term water "lease" regardless of the current year's water conditions. In water short years this value would be lower than the actual amount and in a wet year it would be higher.
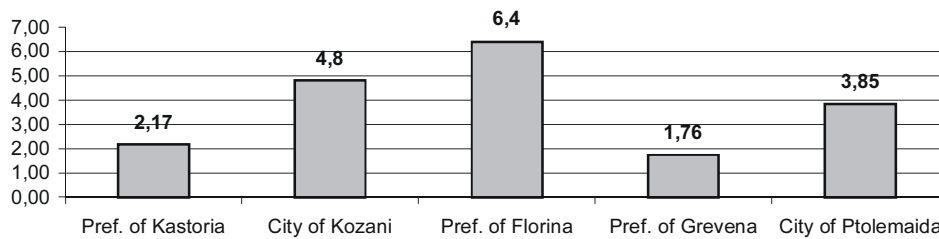

Figure 2. Expected Marginal Value of Water in the second time period (euro/hectare)

The prefecture of Grevena, characterized by the shortest growing season and limited crop choice, had the lowest value of water in the Western Macedonian region. This result was expected due to the much lower yields and efficiency observed in this area. The prefecture of Florina had the highest value of water in the region; this was most likely related to the higher production of profitable crops, like peaches and potatoes.
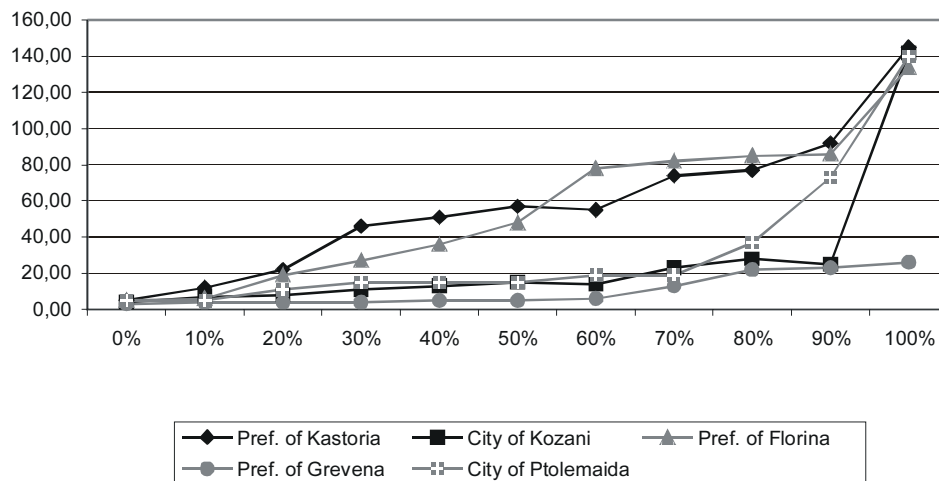

Figure 3. Expected Marginal Value of Water in the second time period for incremental increases in water shortages (euro/hectare)

Although the prefecture of Kastoria had a similar crop rotation to the prefecture of Florina, the value of water was lower in the former because the crop budgets reflected a higher cost of production in that area.

This model was also used to estimate the marginal value for water reductions of up to 100% in 5% increments. These values represent a demand schedule for irrigation water for each of the areas. The highest expected marginal value of water, when all water was diverted away from the farm, was in the area of Kozani at a value of 145.33 euros per hectare (*Figure* 3).

Value of Water in Short Years

The results from this procedure (*Figure* 4) indicate that the marginal value of water increases approximately by 370% during a short water year (40% reduction in water).
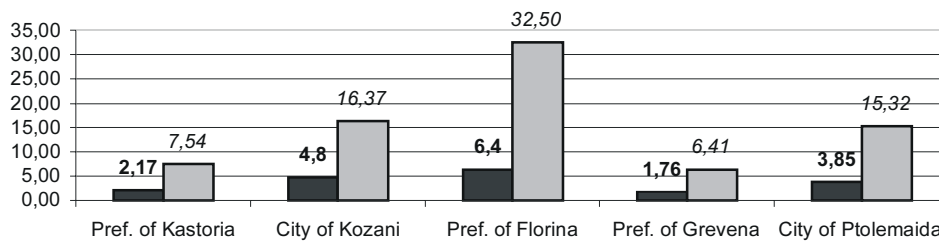

Figure 4.   Marginal Value of Water in a 40% Short Water Year Versus All Years (euro/hectare)

The value of water in a short water year is directly linked to the severity of the water shortage. These values ranging between 7.54 euros per hectare and 32.50 euros per hectare represent what the farmers in these areas would be willing to accept in relation to the consumption of water per hectare when water supplies are 40% less than required.

Conclusions

The value of irrigation water within the region of Western Macedonia is dependent upon water supplies available to farms and the way producers respond to changing conditions. The DSSP model indicated that apples and potatoes were the only crops that made use of water deficit irrigation strategies during short water years. The other crops were not irrigated with water deficit irrigation strategies during short water years because of their relatively high negative response to the water deficit. It was therefore proven more profitable for the model to reduce the quantity of irrigated land and fully irrigate the crops mentioned above rather than water-stress all possible hectares of land. Results also revealed that apples were deficit irrigated during short water years, a fact also supported by the producers' own behaviour, according to the interviews, as apples were the first crop to be water stressed.

At present, current supplies of irrigation water in the Western Macedonian region are sufficiently secure with relatively high allocations. The fact that these conditions are expected to remain unchanged in the future, causes the expected values of water in the

long-run to be considerably lower than some other studies have found. If the likelihood of receiving full water supplies were to decrease in the region, the expected marginal value of water would increase. Optimal crop hectares of land and irrigation strategies produced from the DSSP model were found to be similar to the present situation observed in these areas of the Western Macedonian region. Consequently, these results give us greater confidence in the accuracy of the values of water produced.

If water was to be diverted from agriculture to crop recovery at this time, assuming the cost of water transport to the critical areas was low or non-existent, the most efficient solution would be to re-allocate water from its lowest-valued current use in agriculture. If water were to be targeted early in the year, it would be most efficient to transfer spring run-off water from the prefecture of Kastoria. It would be much less costly to acquire water from the prefecture of Kastoria because the marginal value of run-off water in this area is lower than in the other areas. The producers in this area should also be willing to be compensated for their water supplies at a much lower rate than the producers in the other areas. Reducing the water supply to these areas would increase the efficiency of water use and cause their expected marginal values to increase. And if it were necessary to continue reallocating water from agriculture, the most efficient step would be to continue doing so by moving on to the next lowest-valued water user, until all of the water users in the region were receiving the same marginal benefits from their water supplies.

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