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Research Paper

Agricultural Economic and Environmental Impacts of Water Resources Management Scenarios of Agricultural Sector in Qazvin Plain

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Abstract

With the widening of the gap in water supply and demand in recent years and the schemes of the Ministry of Energy to restore and balance underground tables, the agricultural sector is projected to be under increasing pressure due to the rationing programs and the allocation of water resources to other sectors with higher economic efficiency in water use. We explored the economic impacts of non-pricing policy of limiting water supply and the policies of water pricing, taxing, and subsidization as per each m^3 water use over or below the average gross requirement of the planting pattern on the components of the agricultural sector in Qazvin Province using the data and statistics for the 2013-2014 growing season and the expansion of positive mathematical programming model with the maximum entropy approach. The results showed that the non-pricing policy of 50% limitation of water supply would have the highest economic return per m^3 water use. It is estimated to be $0.23. The highest reduction of chemical fertilizer use would be accomplished in the scenario of 50% limitation of water availability and the integrated scenario of 30% water availability limitation + 50% higher price for water. According to the comparison of employment per unit area vis-à-vis the reference year under different scenarios, the scenario of 50% limitation of water supply (20% increase per ha versus the reference year) would be the best for employment creation followed by the integrated scenario of 30% limitation of water availability. Since the non-pricing policy of limiting water availability would be more effective than the pricing policies in improving water use status and changing planting pattern, it is recommended to apply a combination of these policies in the studied region.

Keywords:
Positive mathematical programming, pricing and non-pricing policies, water economic return

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INTRODUCTION

Farmers' growing tendency to extend the planting area of the crops and the excessive exploitation of water resources have dramatically deepened the gap in demand and supply of this vital source, leading to its scarcity. In addition, the low price of agricultural water as compared to its real economic value has created the perception that this input is for gratis and has resulted in its excessive use. This is threatening the water resources and has had detrimental impacts on environment, erosion, and soil destruction of Qazvin Province, Iran (Anonymous, 2014).

In addition, the cheap price of water paid by farmers of this province, especially in recent years, has entailed excessive water use and the reduced water efficiency in arable lands (Ehsani et al., 2011; Parhizkari & Sabohi, 2014). The surface waters of this province are in the form of seasonal rivers (the Abharroud, Khorroud, and Hajji Arab rivers and some small streams in southern foothills) formed by rainfall. These rivers dry up in hot season because of the lack of rainfall. Then, farmers resort to groundwater resources to satisfy their irrigation requirements. Consequently, the water tables have been faced with fallen surface and the water budget has become negative in most parts of the province, particularly in southern parts of Qazvin Plain (Parhizkari & Sabohi, 2014).

These challenges have made the Ministry of Energy fulfill schemes to mitigate the pressure on water resources. Example includes the plan to revive and balance water tables. This plan has introduced some policies and technical and economic tools to accomplish the target – i.e. balancing local demand and supply of water. Non-pricing policies include less exploitation of water tables for agricultural uses, and economic policies include the pricing of water resources. Many argue that the low price of water is one of the major reasons for its excessive, inefficient use, particularly in the agricultural sector. They suggest that actual pricing of water resources on the basis of marginal cost is the way to overcome this challenge. Others challenge the efficiency of water pricing policies in reducing its use because of low elasticity of demand for water and its low tariff. They suggest that the policy of tax or subsidy for water and/or its complementary inputs would be highly motivating for consumers to optimally use water resources. Therefore, the question for the policymakers and the planners of water resources management is: 'Which price and non-price policies are of higher efficiency in accomplishing the goals of reducing the exploitation of water resources as set in official documents and Groundwater Resources Balancing Scheme, and what impacts do the scenarios have' The research is an attempt to answer this question.

Numerous studies have been conducted in Iran and in other countries to find solutions for these challenges. Huang et al. (2006) used Positive Mathematical Programming (PMP) model for irrigation water pricing in China. They reported that if a right price was set for water, farmers would be sensitive to it and that pricing policy should be supplemented with policies to support farmers and compensate the lost income. He et al. (2006) used PMP model to analyze the alternative policies for the improvement of irrigation water allocation efficiency in Egypt and Morocco. They found that tax on water complementary inputs like fertilizers and tax on water-intensive crop production were more effective on optimum use of water resources than pricing. Cortigani and Severini (2009) explored the impacts of increasing irrigation water costs, decreasing water quantity, and changing crop price on the adoption of deficit irrigation techniques in a Mediterranean region by PMP model. They found that increasing water costs to adopt deficit irrigation techniques motivated farmers and made them save water by the shift from full irrigation to deficit irrigation techniques when available water was limited and/or the irrigated crop prices were higher. In a research by linear programming model in a part of Jordan, Salman and Al-Karablieh (2004) examined a set of optimum activities to maximize farmers' net income. They estimated water shadow price for the crop production in the best planting model in terms of net income in one area and calculated water price elasticities. They concluded that local farmers responded to the changes in water price. Howitt et al. (2012) assessed the impacts of water transfer under drought conditions in California by PMP model and constant elasticity of substitution production function and reported that higher flexibility of water allocation market can reduce drought-related income losses by as high as 30%. In Iran, Zamanian et al. (2015) used maximum entropy-based PMP method to explore the effect of environmental stress and higher prices of agricultural inputs on planting pattern in Khomein Plain. They revealed that the estimated PMP model could well reproduce the values of base year and that the policy of increasing prices of water and fertilizer decreased the diversity of planting pattern. Mousavi and Banaei (2015) examined the sustainability of water resources and planting pattern as affected by water management policies in Fars Province, Iran using PMP model and data for 2015-2014 growing season. The study focused on two scenarios of increasing irrigation water price and decreasing irrigation water use. They revealed that the increasing price had a mild impact on planting pattern and reduced farmers' profit, but it had a slight effect on water use. In a study on the effect of removing diesel fuel subsidy on planting pattern in Rey County using PMP model and maximum entropy approach, Shirmahi et al. (2014) found that the removal of fuel subsidy decreased the planting area of all crops except wheat and cauliflower and that the use of inputs and the return in different groups were decreased remarkably. Overall, they concluded that the policy of removal of diesel fuel subsidy was not expedient to farmers in Rey County. Parhizkari and Sabohi (2014) used PMP model to simulate farmers' response to the policy of reducing available irrigation water in Alamut region of Qazvin Province. They found significant difference between water economic value and water price paid by farmers in Roudbar Distrcit of Alamut. Also, they reported that the reduction of available irrigation water increased its economic value in the studied regions and directed the planting pattern towards crops that would generate fixed income as per lower quantity of water.

As the review of literature shows, most studies in Iran have focused on simulating the impacts of one of the policies considered in our study, and a few studies have simultaneously analyzed and compared the consequences of different water resources management policies for the components of the agricultural sector. Accordingly, we try to develop an economic modeling system in order to introduce an optimum approach for the exploitation management of surface and ground waters in Qazvin Province under various pricing and non-pricing policies. The policies explored in the study site include the reduction of available water, subsidy to crops with low water requirement, tax on water-intensive crops, and water pricing under different scenarios. These policies are analyzed and their impacts are examined on planting pattern, farmer gross income, and the amount of water use in optimum patterns. Finally, the optimum approach is recognized by "profit: consumed water" ratio.

METHODOLOGY

When simulating the impacts of a policy or environmental change, the policy-maker seeks to compare the present conditions (reference conditions) and the conditions after the change. To have a valid analysis, the policy analysis model should be able to simulate the levels observed in the reference year as much as possible. In Normative Mathematical Programming (NMP) models, it is difficult to reproduce or replicate the levels observed in the base year of decision variables due to the lack of a calibration mechanism and it is likely for some crops not to be included in the planting pattern (this phenomenon is due to the hidden marginal costs) whereas this would not be observed in real world even if other crops are highly profitable. Positive Mathematical Programming (PMP) model has been introduced by Howitt (1995) to overcome this normative feature. PMP model is composed of three following steps in a broad sense.

Step 1: Calculating shadow price of crops using a linear programming model

The first stage of a PMP model can be presented as below using a simple linear programming model designed to maximize gross returns:

$$Max \quad Z = GM\,X \tag{1}$$

subject to:

$$AX \leq b \qquad [\pi] \tag{2}$$

$$X \leq (X^0 + e) \qquad [\lambda] \tag{3}$$

$$X \geq 0 \tag{4}$$

where, Z is the value of objective function (should be maximized), X is the vector of activities, and GM is the vector of crop gross return (the product of price in crop yield minus production variable costs) that is derived by

$$GM = (YP) - C \tag{5}$$

where, p denotes the crop price, Y represents the crop yield, and C shows the total costs of the variable. A is the matrix of technical factors, b and π represent the vector of existing resources and their dual variables (or shadow prices), respectively, e and λ denote a vector of small positive numbers and the dual variable of calibration constraint, and x^0 shows the level of activity observed in base year (Howitt, 2005). Equation (2) is called resources constraint and Equation (3) is called calibration constraint. The resources constraint for the study region (Qazvin Plain) was considered to include two inputs, i.e., land and water (seasonally including spring, summer, autumn, and winter). When calibration constraints are added, the optimum answer of mathematical programming gives the planting levels of the activities observed in the base year exactly (Howitt, 1995; Howitt et al., 2012).

Step 2: Estimating the parameters of nonlinear cost function of crops

The second step uses the values of λ, derived in the first step, to estimate the nonlinear variable cost functions of the crops. For simplicity and the lack of strong reasons to select other functions, the following quadratic variable cost function is usually applied (Heckelei, 2002):

$$C^V = d'x + \frac{1}{2}x'Qx \tag{6}$$

where, C^v is the variable cost, d is a vector (n × 1) of parameters pertaining to the linear component of the cost function, and Q is a certain, positive, symmetric matrix (n × n) of parameters pertaining to the quadratic component of the cost function. This function is derived provided that the final variable cost of the activities is equal to total accounting cost of the activities (c) and the dual variable of calibration constraint (λ). Therefore, the parameters of the cost function should be calculated under the following condition:

$$MC^v = \frac{\partial C^v(x^0)}{\partial x} = d + Qx^0 = c + \lambda \tag{7}$$

The nonlinear cost function is estimated by maximum entropy introduced by Paris and Howitt (1998) to estimate all parameters of the vector d and the matrix Q. These models allow the fitting of production or cost functions by econometrics and mathematical programming methods. The maximum entropy to estimate the parameters of the model is formulated as below (Heckelei & Britz, 2001):

$$\text{Max}\; H(p) = -\sum_{k=1}^{K}\sum_{i=1}^{n} pd_{k,i}\ln pd_{k,i} - \sum_{k=1}^{K}\sum_{i=1}^{n}\sum_{j=1}^{n} pq_{k,i,j}\ln pq_{k,i,j} \quad (8)$$

subject to:

$$d_i + \sum_{j=1}^{n} q_{i,j}x_j^* = c_i + p_i \forall_{i,j} \qquad i = 1,\dots,n \qquad j = 1,\dots,n \quad (9)$$

$$d_i + \sum_{k=1}^{K} pd_{k,i}zd_{k,i} \forall_j \qquad i = 1,\dots,n \qquad k = 1,\dots,k \quad (10)$$

$$q_{i,j} + \sum_{k=1}^{K} pq_{k,i,j}zq_{k,i,j} \forall_{i,j} \qquad i,j = 1,\dots,n \qquad k = 1,\dots,k \quad (11)$$

$$\sum_{k=1}^{K} pd_{k,i} = 1 \qquad \forall_j \qquad i = 1,\dots,n \qquad k = 1,\dots,k \quad (12)$$

$$\sum_{k=1}^{K} pq_{k,i,j} = 1 \qquad \forall_{i,j} \qquad i,j = 1,\dots,n \qquad k = 1,\dots,k \quad (13)$$

$$q_{i,j} = q_{j,j} \forall_{i,j} \qquad i = 1,\dots,n \qquad j = 1,\dots,n \quad (14)$$

Equation 9 expresses the first constraint to estimate the coefficients of the variable cost function as described above. The second and third constraints (Equations 10 and 11) introduce the parameters of the vector d and the matrix Q that are the fixed component and the slope of the nonlinear variable cost function, respectively. The fourth and fifth constraints (Equations 12 and 13) express the probability sets for d and Q, respectively. Finally, the sixth constraint (Equation 14) assures the asymmetry condition of the elements of the matrix Q.

Step 3: Calibration of mathematical programming model

This step uses the nonlinear cost functions calibrated for various crops as well as the resource constraints to build a nonlinear programming model as below given the calibration constraints:

$$MaxZ = GM'x - d'x - x'Qx/2 \quad (15)$$

subject to:

$$Ax \leq b \quad (16)$$

$$x \geq 0 \quad (17)$$

In this model, the non-linear cost functions of the alternative crops become their mean costs in linear programming model and the model is re-run under the constraints of production resources and in the absence of calibration constraints. The output of this calibrated model under base year conditions would be exactly the levels of base year activities. In this state, the policies can be analyzed in the model by altering the conditions and the definition of different scenarios. The data of the present study are documents registered in governmental agencies. They were collected directly from the relevant agencies (Jahad-e Agriculture Organization and Regional Water Organization) in Qazvin Province. The mathematical programming model of the study was coded and run in GAMS.24 Software Package.

RESULT AND DISCUSSION

Qazvin Province that covers an area of 15821 km^2 in central Iran is apt to crop production because of its unique location (Mozaffari et al., 2015; Nasseri et al., 2012; Parhizkari, 2013). The surface water of the province mainly flows in the Sefidroud and Roudshour watersheds. The total water that can be planned for the agriculture sector is 1531 million m^3, out of which 653 million m3 is related to the water extracted from the surface resources. Also, about 878 million m^3 water is annually extracted from the water tables for agriculture use. There are 9268 wells, 368 Qanats, and 18724 springs throughout this province (Anonymous, 2014).

Irrigated wheat with the planting area of 48,000 ha has the highest share in the current planting pattern of the province. Alfalfa has the second rank with 22,000 ha of planting area. The main reasons for more development of wheat and barley planting area than other crops (grain corn, sugar beet, tomato, and canola) in Qazvin Plain are the lower risk of their production in terms of natural risks and market conditions (the guaranteed purchase price) and also, their lower water requirements.

Comparison of economic parameters under different scenarios

Economic return per m^3 consumed water and reserved water rate (1000 m^3)

Table 1 presents the economic return per m^3 water under different policy scenarios. It shows that the non-pricing policy of the supply of 50% of water would have the highest economic return per m3 consumed water as estimated at \$0.23 The second highest economic return of \$0.19 is related to the integrated policy of 50% increase in water price and 30% lower supply of water. The policy of 30% reduction of water supply would generate the third highest economic return of \$0.19. The economic return of \$0.18 is related to a combination of the pricing policy of \$0.01 subsidy and tax and non-pricing policy of 30% lower supply. It was ranked the fourth. Also, Table 1 shows that the amount of reserved water would be the highest under the limited water supply policies and the integrated policies and would be the lowest under higher water pricing scenarios. Since water is a cheap input, farmers use it as long as it is economically profitable and overlook its optimum use or the conservation of water resources. Thus, as long as the cost of the consumed water would not be higher than the value of final product of this input, water use would follow the conventional pattern and the planting area and pattern would not change remarkably. In this respect, higher gross return would be the only benchmark of the production.

Table 1

Comparison of Economic Return per M^3 Water (\$) And Reserved Water Amount (000 M^3) Under Different Scenarios

Scenario	Economic return per m^3 water (\$)	Reserved water amount (000 m^2)
Base year	0.150147	0
25% more expensive water price	0.160941	0.1
50% more expensive water price	0.187853	908.3
75% more expensive water price	0.226824	1362.5
150 IRR tax and exemption	0.150147	3381.9
300 IRR tax and exemption	0.150235	6908.6
500 IRR tax and exemption	0.150265	14956.1
10% lower water supply	0.187882	153526
30% lower water supply + 150 IRR tax and exemption	0.150441	471562.6
30% lower water supply	0.150618	470965.9
30% lower water supply + 50% more expensive water price	0.150794	3176.3
50% lower water supply	0.187353	780240.6

Land use

Table 2 compares the planting area and profit per ha under the studied scenarios. The highest reduction of planting area would be 49% under the scenario of 50% reduction of available water. This scenario would decrease the planting area from 142,860 ha to 72,670 ha. The pricing policies of higher water price and tax for water-intensive crops and subsidy for crops with lower water requirement would not change the total planting area. The scenarios of lower water supply show the highest decrease in planting area and gross return. Planting area would be decreased under the integrations of pricing policies and non-pricing policies of water supply reduction, too. Table 2 compares the profit per ha under different scenarios, too. Accordingly, the highest profit would be gained from 50% reduction of water supply and then, from the integrated scenarios. The lowest profit is related to higher water pricing scenarios. It implies that farmers resort to adaptive approach when they are faced with the scarcity of the resources. In other words, as water resources are decreased, the shadow value of water that shows the resource scarcity value increases and it directs farmers towards crops with higher economical value and lower water requirement.

Table 2
Comparison of Land Use Amount (Ha) And Profit Per Ha (000 $)

Scenario	Land use amount (ha)	Profit per ha (000 $)
Base year	142860	1.613529
25% more expensive water price	142860	1.730882
50% more expensive water price	142860	2.014118
75% more expensive water price	142860	2.356765
150 IRR tax and exemption	142860	1.561706
300 IRR tax and exemption	142860	1.509706
500 IRR tax and exemption	142860	1.457941
10% lower water supply	128479	1.824412
30% lower water supply + 150 IRR tax and exemption	101768	1.614118
30% lower water supply	99269	1.615882
30% lower water supply + 50% more expensive water price	99104	1.604706
50% lower water supply	72670	1.958529

Fertilizer use

Table 3 shows the fertilizer application under different scenarios. As is evident, the policy of 50% reduction of water supply would reduce fertilizer application versus the base year remarkably. Interestingly, the combination of water supply reduction with other pricing policies shows a considerable decrease in fertilizer use. It demonstrates the environmental impact of these policies and lower rates of fertilization. The application of only pricing policies would not only have no effect on directing the planting pattern towards lower rates of fertilizer use, but it would also result in considerably higher fertilizer use than the base year. This finding should guide the policy-makers who set environmental targets for their plans.

Employment amount

The pricing policies, including water pricing and tax and subsidy on each m^3 consumed water, do not change employment amount as compared to the base year. In addition, the employment amount would be reduced to a greater extent under tax and subsidy scenarios. The non-pricing policy of water supply reduction would influence total employment because it would decrease the planting area considerably so that the highest loss of employment would be observed when available water is reduced by 50%. The next highest employment losses would be associated with the integrated scenario of 30% reduction of available water + 50% higher water price and then, with the integrated scenario of 30% lower water supply + 150 IRR subsidy and tax. Table 4 compares the employment amount per unit area versus the base year under different scenarios. It shows that the highest employment amount would be gained from the scenario of 50% lower available water supply. The next highest employment amounts would be observed under the integrated scenario of 30% reduction of water supply + 150 IRR subsidy and tax, 30% lower water supply, and 30% lower water supply + 50% higher water price.

Table 3

Chemical Fertilizer Use Per Ha and Total Fertilizer Use (Kg) In One Growing Season

Scenario	Fertilizer use (kg ha^{-1})	Total fertilizer use (kg)
Base year	448.677	64098000
25% more expensive water price	447.722	57522950
50% more expensive water price	434.532	43135600
75% more expensive water price	538.148	31840250
150 IRR tax and exemption	453.880	64841350
300 IRR tax and exemption	454.170	64882750
500 IRR tax and exemption	454.477	64926700
10% lower water supply	429.913	42606150
30% lower water supply + 150 IRR tax and exemption	455.554	65080550
30% lower water supply	457.447	65350950
30% lower water supply + 50% more expensive water price	460.388	65771150
50% lower water supply	446.201	45409050

Table 4

Created Employment Per Ha and Total Created Employment under Different Scenarios in Qazvin Plain (Person-Day)

Scenario	Employment rate per ha	Total employment rate
Base year	33.737	4819797
25% more expensive water price	34.649	4451708
50% more expensive water price	37.505	3723084
75% more expensive water price	40.713	2958615
150 IRR tax and exemption	33.782	4826120
300 IRR tax and exemption	33.786	4826786
500 IRR tax and exemption	33.793	4827675
10% lower water supply	37.317	3698286
30% lower water supply + 150 IRR tax and exemption	33.867	4838258
30% lower water supply	33.882	4840440
30% lower water supply + 50% more expensive water price	33.133	4733494
50% lower water supply	38.069	3874288

In all studies in Qazvin Plain including Parhizkari and Sabohi (2014), the positive mathematical programming model has been used to simulate the response of farmers in Alamut area of Qazvin Province, Iran to the policy of limiting irrigation water availability. They estimated the economic value of each m^3 of irrigation water in the studied region over the reference year of 2011-2012. The results showed that the economic value of irrigation water has increased in the studied region with the reduction of available irrigation water. Pahizkari and Mozafari (2015) investigated using a positive math planning model and regional production functions of agricultural products to simulate the water market and analyze the effects of irrigation water sharing policy on cropping patterns in underwater conditions in the Shahroud basin. The results showed that with the formation of local water market, the economic interests of farmers in Shahrood basin will increase.

The present study is the first work that explores several policies – some conventional and others proposed – simultaneously. In addition to measuring the impacts of these policies on the gross profit of the users, this study addresses the variations of planting pattern and economic return per m^3 water consumption, employment, environmental impacts, and fertilizer use. Results of previous studies in different regions of Qazvin Province including Alamut have also indicated that the policy of limiting water availability is one of the most effective policies for the management of available water resources.

The results of the model and the comparison of different scenarios in Qazvin Province lead us to the conclusion that despite the fact that policies on water supply control and pricing would reduce the planting area and would alter the planting pattern, they would direct farmers towards more applicable crops, would increase employment and would mitigate policy-makers' concern about water resources management and the social consequences of employment loss. Furthermore, given the lower fertilizer use under these scenarios, they would be expedient to the environment, too.

CONCLUSIONS AND RECOMMENDATIONS

Given the results of the study, the importance of water for the agricultural sector and water deficiency in the region, the following recommendations are put forth:

• Given the fact that the impact of non-pricing policy of reducing available water resources was stronger on the alteration of planting pattern and saving of water use than the pricing policies, it is recommended to apply a mixture of the policies in the region. It was revealed that when irrigation water is cheap, the inelasticity of water demand of the agricultural sector renders the application of just economical tools, e.g. the increase in water price, inefficient in accomplishing the efficiency and water saving targets.

• With respect to the challenges of water resources deficiency and the policy orientation of the Ministry of Energy to rehabilitate and balance the water resources, it seems likely in future to ration water resources and reduce their supply. Accordingly, it is necessary for the agricultural sector to get prepared and to figure out approaches to adapt with these conditions and to avoid the pertaining costs given the economic consequences of these policies and the climate change.

• Lower planting area implies lower employment capacity of the agricultural sector. Thus, in addition to its economic consequences, the policy of reducing available water would entail social consequences as more unemployment in rural areas of the province. Therefore, a priority for the planners would be to seek strategies to deal with it via resorting to the capacity of the alternative industries in job creation through less water use, especially the development of supporting industries for the agricultural sector.

• Since water is supplied to farmers with low price, the producers would keep using water as long as it is economically profitable without considering its optimum use or the conservation of the water resources. It is recommended to approach and apply actual water price by resorting to short-term tools for water supply control like blocking unauthorized wells and mounting contour on authorized wells and the long-term tool of enforcing pressurized irrigation for water-intensive crops.

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