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The impact of water-pricing policies on water productivity: Evidence of agriculture sector in Iran

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ABSTRACT

Water pricing and reducing the costs of the implementation and maintenance of irrigation systems have been a challenging topic for a long time. Water pricing issues combine two complex dimensions. The first dimension is the economy of the farm and its association with the broader economic system and farming practices. The second dimension is the hydrology and interconnection of the plot with the irrigation system, the river basin, and the underlying water policy framework. Accordingly, this study aimed to investigate how the institutionalization of water applied would affect water productivity through the implementation of a water-pricing policy. To this end, this study formulated a Positive Mathematical Programming (PMP) model with a gross margin maximizing objective function to assess the data collected from 213 farms in Hamadan-Bahar Plain, Iran. The results revealed that a water-pricing policy can change the cropping pattern and also irrigation system within the limitations of the case study. It can also be a driver to motivate farmers to use a modern and more efficient irrigation system. The potential environmental benefits from the improved on-farm irrigation efficiency depend on the government's ability to prevent the extension of the irrigated area. In absence of such controls, the aquifer depletion will be accelerated. Therefore, an appropriate water-pricing policy could improve water productivity and also reduce water applied.

1. Introduction

In semi-arid and arid regions, efficient water management is one of the key drivers in successful agricultural production. As many of these regions rely on slowly replenishing groundwater resources for supplying their water demands, water demand must be adjusted and institutionalized to guarantee the long-term stability of the socio-ecological system (Perry, 2007; Al-Rubaye, 2018). To assess water demand, various corporate, state, or community-led infrastructure networks have their temporary phases of institutionalization to continue operating within or outside their technological ambitions (Putri, 2016). Consequently, the institutionalization of water applied requires representation and negotiated decision-making to increase opportunities for community involvement (Jacob and Bernard, 2013).

Yet, in regions where no proper institutions are in place, coupled with inefficient irrigation technologies and a focus on crops with high water demand, fast groundwater depletion is a serious risk (Garrido and Calatrava, 2010; Al-Rubaye and Al-Ezzy, 2018). An example of such regions is Hamadan-Bahar Plain in Northwestern Iran. Fig. 1 shows the location of this plain. The region serves a strong agricultural sector, producing mainly alfalfa, maize, and rape, often for export. The dominant irrigation system is furrow irrigation (a form of surface irrigation), which causes high evaporation and loss of runoff. Therefore, the region shows very low water productivity (i.e., the efficiency of water applied

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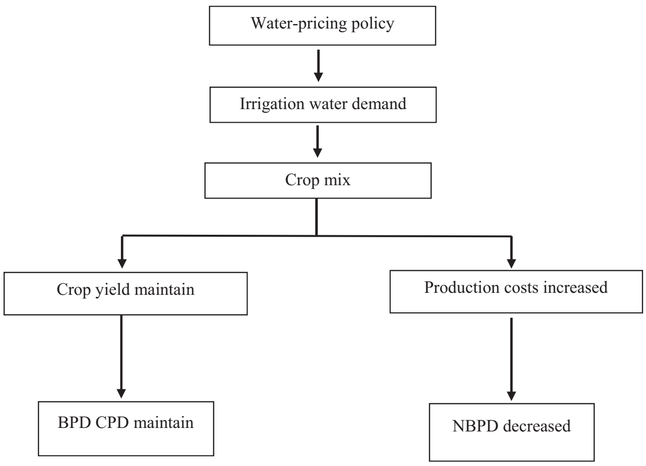

Fig. 1. The effect of water-pricing policy on water productivity.

as the input in relation to the products as the output). The water used for irrigation originates almost entirely from groundwater wells. While most of these wells are formally registered and licensed, the withdrawal of water is neither measured nor institutionally restricted. The current price of irrigation water in the study area is zero (Balali et al., 2011). However, farmers still need to pay the extraction costs. Due to the water crisis in Iran, the region is considered as a restricted plain in which the agricultural land extension is not allowed. Moreover, the height of the water table is more than 60 m deep on average, and even deeper than 100 m in some regions (Regional Water Company of Hamedan, 2017). Therefore, return flows may not be able to recharge the aquifer, or the impact is not considerable. In our analysis, we present water productivity indices at zero water price, which is referred to the current water productivity (i.e. status quo) (Table 1). To highlight other examples on water productivity in the case study, Seyedan and Ghadimi, (2019) and Mozaffari, (2020) calculated water productivity for different crops and different irrigation systems.

If the charged fees do not cover the irrigation costs, sustainability can be jeopardized without ongoing government subsidies (Al-Rubaye, 2018). Based on the allocation law of water equity, it is requested to calculate the water tariff by the quantity and quality of consumption in urban, rural, industrial, and other areas (Tahamipour et al., 2014; Nabavi, 2017). Moreover, water charges can be a financial instrument for recovering all or part of capital and recurring costs. National development reports in Iran focus on calculating the costs of building dams and water supply facilities and assessing irrigation water economically as an input to choose the best water sales tariffs for water supply costs in future years (Tahamipour et al., 2014). Water charging or disposal is not the ultimate objective. However, it is a tool for achieving one or more policy goals (Soto et al., 2018) in a way that, to save water and increase its productivity, the water price can be considered as an economic tool.

Water pricing was selected as a tool to decrease water demand (World Bank, 2003). This is expected that water pricing policies inculcate protection and stimulate a movement to higher-value crops (Venot and Molle, 2008). This price policy can encourage farmers to invest in technology, with the probability of increasing income rather than incurring higher costs (Expósito and Berbel, 2016). Farmers facing higher water prices might desire to intensify their production. Changes motivated by high water prices would therefore likely involve technological change and changes in crop patterns and lead to higher productivity of water (Molle et al., 2008). Water pricing policies are among various measures designed to improve the productivity and efficient use of water resources (Renzetti, 2000). From the correct assumption that low water prices provide a limited incentive to improve productivity, it can be seen that rising prices will improve productivity automatically and should be a prime objective for implementing improvements (Molle et al., 2008). From the right assumption that low water prices provide limited incentives to improve productivity, it can be seen that raising prices will automatically improve productivity and should be a prime target for implementing improvements (Molle et al., 2008).

Improving water productivity is among the top priorities for policymakers in the agricultural sector (Madani, 2014; Boazar et al., 2019). The economic role of water can be developed by pricing policies (Ehsani et al., 2012; Asaadi et al., 2019). Literature demonstrates that many countries are engaged in such pricing policies (Dinar, 2015). For example, Shi et al. (2014) used a bioeconomic model to analyze the

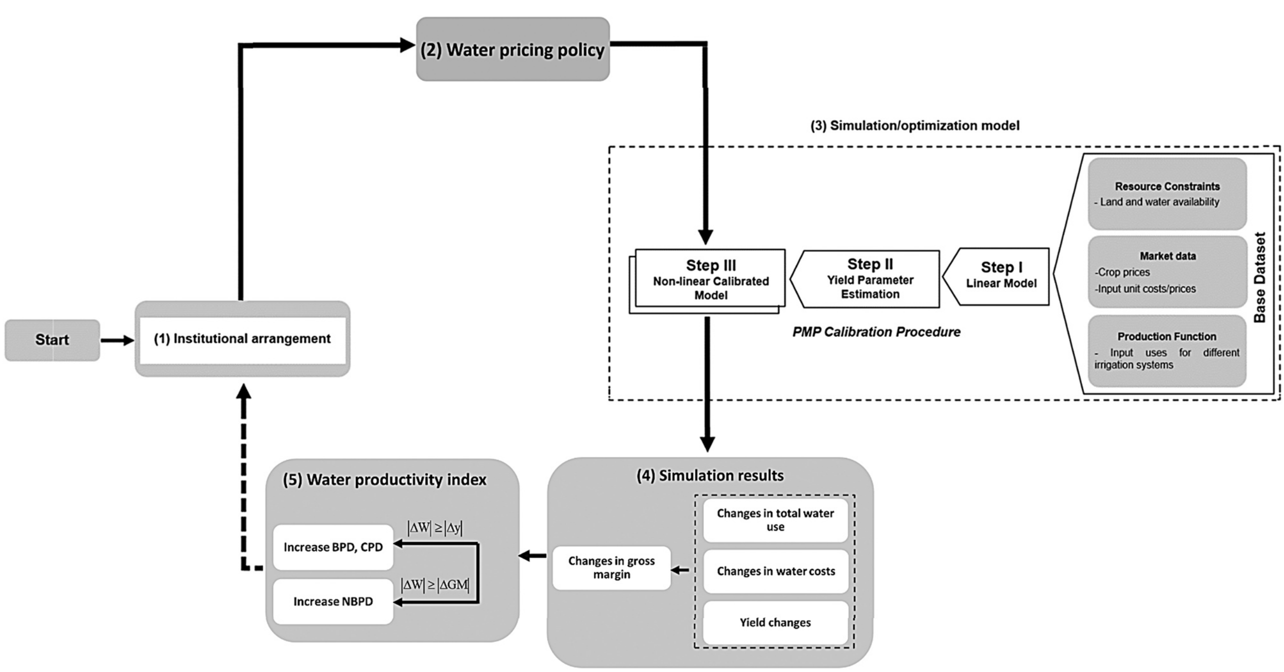

Fig. 2. Modelling framework of the study.

Table 1
Descriptive of input data and baseline.

Crop	Water applied (m^3/Ha)		Yield (Kg/Ha)		Variable costs (1000 Rial/Ha)		Revenue= Yield* Price (1000Rial/Ha)		Area (Ha)		Price (Rial/Kg)	NBPD (Rial/m^3)	
	Furrow	Modern	Furrow	Modern	Furrow	Modern	Furrow	Modern	furrow	Modern		furrow	Modern
Alfalfa	11,660	8341	12,690	13,622	10,283	12,152	22,347	23,988	1039	1015	1761	1.035	1.419
Forage Corn	8396	5500	50,805	53,800	18,517	17,954	22,862	24,210	231	186	4500	0.517	1.137
Rapeseed	3158	3000	2306	2719	10,427	7633	14,067	16,592	113	112	61,000	1.153	2.986

Note: All prices are IRR per Ha. [IRR: 0.00002 USD]
Source: Own calculation.

Table 2
Water productivity in “rapeseed” due to water-pricing policy.

Water Price (Rial/m^3)	Furrow irrigation			Modern irrigation		
	NBPD (Rial/m^3)	BPD (Rial/m^3)	CPD (Kg/m^3)	NBPD (Rial/m^3)	BPD (Rial/m^3)	CPD (Kg/m^3)
Zero	2037.22	4454.27	0.73	2054.95	5530.67	0.91
50	2123.48	4636.87	0.76	2138.62	5749.79	0.94
100	2215.06	4819.89	0.79	2227.05	5985.08	0.98
150	2312.68	4999.04	0.82	2320.88	6232.67	1.02
200	2417.23	5185.4	0.85	2420.84	6537.08	1.07
250	2529.77	5429.44	0.89	2527.82	6843.31	1.12
300	2651.54	5673.86	0.93	2642.83	7148.99	1.17
350	2783.77	5978.76	0.98	2766.74	7454.57	1.22
400	2928.88	6283.36	1.03	2901.76	7881.24	1.29
450	3089.35	6588.36	1.08	3049.9	8248.27	1.35
500	3268.33	6954.01	1.14	3213.64	8737.54	1.43
600	3639.44	7869.84	1.29	3501.58	9226.11	1.51
700	4153.97	9150.14	1.5	3904.39	10081.41	1.65

Note: Source: CDP, BPD and NBPD stand for Crop per Drop, Benefit per Drop, and Net Benefit per Drop respectively. [IRR: 0.00002 USD]
Source: Own calculation.

Table 3
Water productivity in “forage corn” due to water-pricing policy.

Water Price (Rial)	Furrow irrigation			Modern irrigation		
	NBPD (Rial/m^3)	BPD (Rial/m^3)	CPD (Kg/m^3)	NBPD (Rial/m^3)	BPD (Rial/m^3)	CPD (Kg/m^3)
Zero	584.58	2722.73	6.05	931.69	3962.36	8.8
50	697.41	3081.71	6.85	1005.55	4187.07	9.3
100	855.46	3612.18	8.03	1087.56	4444.61	9.88
150	1105.55	4491.62	9.98	1165.57	4689.89	10.42
200				1238.96	4922.45	10.94
250				1340.65	5264.86	11.7
300				1461.67	5683.67	12.63
350				1611.85	6205.65	13.79
400				1756.92	6719.85	14.93
450				1872.73	7143.52	15.87

Note: Source: CDP, BPD and NBPD stand for Crop per Drop, Benefit per Drop, and Net Benefit per Drop respectively. [IRR: 0.00002 USD]
Source: Own calculation.

Table 4
Water productivity in “alfalfa” due to water-pricing policy.

Water Price (Rial)	Furrow irrigation			Modern irrigation		
	NBPD (Rial/m^3)	BPD (Rial/m^3)	CPD (Kg/m^3)	NBPD (Rial/m^3)	BPD (Rial/m^3)	CPD (Kg/m^3)
Zero	1198.18	1916.56	1.088	1479.87	2875.95	1.633
50	1210.97	2003.93	1.138	1484.48	2897.11	1.645
100	1225.34	2104.13	1.195	1488.63	2918.03	1.657
150	1241.77	2221.22	1.261	1492.35	2938.26	1.669
200	1260.97	2360.94	1.341	1495.67	2957.8	1.68
250	1283.97	2531.94	1.438	1498.58	2976.63	1.69
300	1312.47	2747.92	1.56	1507.84	2994.75	1.701
350	1349.27	3031.98	1.722	1511.67	3012.14	1.71
400				1515.23	3028.79	1.72
450				1518.54	3044.69	1.729
500				1520.79	3059.82	1.738
600				1562.78	5244.53	1.842
700				1596.77	5302.6	1.875

Note: Source: CDP, BPD and NBPD stand for Crop per Drop, Benefit per Drop, and Net Benefit per Drop respectively. [IRR: 0.00002 USD]
Source: Own calculation.

shadow price of water resources and investigate the reaction of farmers to water pricing policies in northwestern China’s Heihe River Basin. Their findings suggest that farmers in most irrigation zones were not very sensitive to changes in water price since it was well below the shadow price of water supplies. A reduction in the demand for agricultural water could only take place with a large increase in the water price. Galioto et al. (2017) investigated the expected impact of changes in pricing policies applied to the use of water resources recently experienced in an agricultural area located in Northern Italy. The results highlight that the change in pricing criteria would not cause substantial variations in water uses. This was mainly due to the inelastic demand for water in agriculture. Water pricing represents a key issue both for developing and developed countries (Galioto et al., 2017). Nevertheless, outcomes from previous studies, comparing the performance of water pricing policies among different countries, confirm that there is no best practice that can be suggested to one country (Iglesias and Blanco, 2008). The reason is that optimal prices rely on the objectives of the water agency, as well as on the types of information available to it (Galioto et al., 2017).

In water demand management and its optimal allocation, pricing policies play an important role (Iglesias and Blanco, 2008; Asaadi et al., 2019). The determination of an appropriate water price leads to an optimal allocation of water only if there is a process such as a market to facilitate water reallocation from lower to higher value uses, particularly in agricultural consumption (Singh, 2016). The application of new subsidy legislation in Iran that insists on pricing water on the basis of its supply costs will have a significant impact on the management of water resources in the country’s agricultural sector (Nabavi, 2017; Tahamipour et al., 2014).

Positive Mathematical Programming (PMP) is particularly useful in situations where there are only short time series data available, such as in sectoral analyses of developing countries (e.g., Iran) and environmental economic analyses (e.g., water scarcities) (Hashemy Shahdany et al., 2017). The PMP is a policy-oriented approach to formulate policy recommendations (Kahil et al., 2016). Therefore, given the growing problems with the water sector in most parts of Iran and the need for correcting water prices (Madani et al., 2016), PMP will help policy-makers resolve the water issue and improve the productivity of water resources. We need a model to “simulate” the dynamics of water productivity and water pricing policy. Due to data limitations, mathematical programming-based models, including normative and positive models, are considered as appropriate options. As discussed earlier, positive mathematical programming allows us to calibrate the model according to the base year. Therefore, this model is generally suitable for the current study analysis. So far, different PMP type models have been applied in the literature (Graveline, 2016). These models are calibrated based on either a non-linear yield function or a non-linear cost function. Our model is based on non-linear yield function, which allows us to capture the changes in yield in response to water pricing (Gómez-Limón et al., 2016; Lee et al., 2019). The current study can contribute to both thematic and methodological aspects as follows:

i) Focusing on the thematic aspect, institutionalization of water applied has been considered in this study. The institutionalization of water applied would affect water productivity by using a water pricing tool. According to high water applied in arid and semi-arid regions, the contribution of institutionalized water to improving water productivity is significant in these areas.
ii) Focusing on the methodological aspect, this study applied the positive mathematical programming (PMP) method to analyze water pricing policies' implementations. Using this innovative approach of the PMP, the methodology can contribute to improving productivity by applying an appropriate pricing scenario. Moreover, the current study aims at:

  i) The assessment of current water management strategies with regard to water pricing scenarios in Hamadan–Bahar basin. Considering the site of the study, it should be noted that the Hamadan–Bahar basin climate is semi-arid with mean annual precipitation of 324.5 mm and average annual temperature of 11.3 °C. Groundwater is the only source of drinking water available in the region and is widely used by rural and urban communities, especially for irrigation (Balali And Viaggi, 2015; Talebmorad et al., 2018).
  ii) The identification of low-water cultivation techniques by comparing furrow irrigation system with modern irrigation.
  iii) The proposal of water redistribution programs for high-value agricultural sectors.

This study hypothesizes that the implementation of such a water-pricing policy would have an impact on:

H1: the cropping pattern (i.e., a shift to more water-efficient crops);

H2: use of irrigation system (i.e., a shift from furrow to modern irrigation (e.g., sprinkler));

H3: water productivity (i.e., it will increase); and

H4: total water applied (i.e., restricting water applied).

2. Literature review

2.1. Water resource management in Iran

Approximately 70% of Iran's territory is located in arid and semi-arid regions and is currently facing a severe water crisis (Gorjian and Ghobadian, 2015). By 2021, the country's total annual renewable water per capita is projected to reach only about 800 m^3 (Gorjian and Ghobadian, 2015). In this context, seawater desalination has been seen as a possible solution and has been used for a long time. However, it is argued that this method is no longer feasible and sustainable since it depends on fossil fuels. In Iran, the main freshwater consumer is the agricultural sector (90–93%) compared to the domestic and hygiene sector (5–6%) and the industrial sector (~1%) (Yazdanpanah et al., 2014). However, since the beginning of 1990, water has become very scarce in Iran. According to Yazdanpanah et al. (2014), the water crises have been exacerbated by severe droughts which have affected nearly all sectors in Iran, leading to large economic losses, the collapse of water bodies, and relocation of numerous villages.

2.2. Water productivity

In the Iranian context, water constraints can be more perceptible in agriculture than in industry (Faramarzi et al., 2010). To address current sustainability needs, water productivity of agriculture becomes an important index to assess the effect of saving water and irrigation water management. Kijne et al. (2003) developed an approach according to which the productivity of crop water should be assessed in terms of both kilograms of crops per cubic meter of water applied (Kg/m^3) and the net or gross value of crops produced per cubic meter of water. In general, water productivity includes total precipitation, the higher utilization ratio of precipitation, higher water productivity, and at the same time, the higher repetitive utilization ratio of water in a region.

There are a number of researchers (Faramarzi et al., 2010; Kijne et al., 2003; Perry, 2007; Xu et al., 2010) who have summarized the factors affecting water productivity. These factors are crop variety, irrigation water applied (irrigation technique), carbon remobilization, grain filling rate, soil texture, soil nutrient, and agronomic management. There are generally two distinct perspectives regarding water productivity. In the agronomy literature (see e.g., Molden, 1997; Perry, 2007), it is mainly emphasized on the technical aspects of irrigation water efficiency with a focus on the water consumed by a single crop. Although this concept could provide precise information on the water used by each crop individually, it ignores the interaction between different crops at farm level. From an economic perspective, it is crucial to find how efficient farmers distribute water between different crops to achieve their productivity at farm level, considering their water applied. Based on the above-mentioned studies, the main aim of the current study is to find out whether the government can encourage farmers to achieve higher water productivity through the implementation of a water-pricing policy.

2.3. Water-pricing policy

Water used for irrigation shall be managed as an economic commodity that has immense social and environmental values. It may be quantified through basic resource availability to ensure sustainable harvesting (Banihabib et al., 2016; Habibi Davijani et al., 2016). Water pricing objectives go beyond economic efficiency, including sustainability and equity, among many other goals (Al-Saidi and Dehnavi, 2019). Water prices should also be transparent, legitimate, easy to administer, fair, etc. (Rogers et al., 2002). The water-pricing policy is a major water-managing topic to be discussed in countries that are faced with the problem of water scarcity and have a clear understanding that water is a kind of strategical resource with a significant influence on sustainable ecological development which should be allocated reasonably and effectively. A way to reduce water demand is to adopt transparent and clear allocation rules (Ray, 2007). Compensation for environmental and management costs should be considered when formulating water-pricing policies and also deciding within social and national policies (Pulido-Velazquez et al., 2012). A marginal cost water pricing system is the most efficient option. However, water rights need to be well defined, and water governance issues need to be addressed in technical, organizational, and political terms.

Fragoso and Marques (2013) considered the important role of irrigation in socioeconomic development and aimed to assess the economic impact of water allocation and cost recovery on cropping patterns. Reduction in water applied is done by changing cropping patterns and introducing less profitable crops that have low water requirements to reduce the use of fertilizers. However, improved agricultural practices could significantly reduce the environmental impact of fertilizers, making it difficult to determine the direct environmental benefits of water pricing (Julio and Jose, 2000).

A number of researchers (Mobin-ud-Din et al., 2009; Jens Erik Ørum, 2010; Fragoso and Marques, 2013) focused on the irrigation water applied and farmers' response to water-pricing policy and tried to find the relationship between irrigation water demand and water price. According to a simple profit maximization problem, as farmers cannot reduce costs, abandoning unprofitable crops or raising production prices will be the key to get more benefits. It means that the farmers will increase the benefit of water used per cubic meter by increasing production prices, instead of reducing the demand for water (Mobin-ud-Din et al., 2009). Ørum (2010) conducted a study on incentives for farmers to save water by taxing water and concluded that, instead of stimulating a shift in water-saving technologies and strategies, the regulation could lead farmers to pick other crops or stop irrigation entirely. By raising the tax on water, the cultivation pattern goes to rain-fed, less water-requiring crops such as grass or cereals, instead of valuable water-requiring crops such as potatoes (Ørum et al., 2010).

2.4. The effect of water-pricing policies on water productivity

According to the definition of water productivity, it is obvious that factors influencing crop yield, gross margin (numerator of the productivity equation), and water used (denominator of the productivity equation) may affect the water productivity, e.g., crop cultivar type, water applied, soil factor, and so on (Ali et al., 2008). How would water-pricing influence water applied and crop production? A water pricing policy would have an impact on water applied by changing the irrigation pattern of a single crop and/or changing the crop pattern. In the presence of a water pricing policy, farmers may intend to use less water for a single crop, which could lead to lower yields.

The cropping pattern change would further influence crop production and gross margin. This is an effect that a large number of researchers have confirmed (Varela-Ortega, 1998; Chebil et al., 2010; de Fraiture and Perry, 2002). Furthermore, the research results also indicate that by using water-pricing as a single strategy, water applied does not significantly decrease until the price of the water reaches a certain level that negatively affects the income of the farmers. Chebil (2010) used the PMP model to assess the effects of three scenarios on the agricultural production system. The results show that the reduction of water applied happens when the price of water reaches a certain level and the farm income reduction reaches 20% of the current observed income. A study by Varela-Ortega (1998) used a dynamic mathematical programming model to analyze the effect of different water-pricing policies on water demand, and the results show the effect of alternative pricing based on regional and water districts. Due to the research topic and location and structural and institutional conditions, the water demand curve against increasing water prices makes a slight difference (Fragoso and Marques, 2013). However, the trend of water demand curve against increasing water-pricing in most cases is similar, which can be summarized in three stages. In the first stage, the farmers respond only slightly and maintain their crop distribution and demand for water. Within the second stage, the farmers change cropping patterns and reduce their water applied. For the third phase, if the water price rises to a significantly high level, the demand becomes relatively inelastic again, and there is no response to a further price increase.

3. Theoretical background

3.1. Water productivity indices

Water productivity has been defined in diverse ways (Kijne et al., 2003). In the crop production sector, water productivity means the relationship between the crop produced and the amount of water used, which can be expressed as crop production per unit volume of water, or when dealing with different crops, the yield can be transformed into monetary units such as gross margin or net benefit.

In this paper, we will use CPD (Kg/m^3), BPD (Rial/m^3), and NBPD (Rial/m^3) indices to assess water productivity. The formulas are as follows:

$$CPD_{s,i} = Y_{s,i} / W_{s,i} \tag{1}$$

$$BPD_{s,i} = (P_i \times Y_{s,i}) / W_{s,i} \tag{2}$$

$$NBPD_{s,i} = (P_i \times Y_{s,i} - VC_{s,i}) / W_{s,i} \tag{3}$$

where P_i and $Y_{s,i}$ denote the price (Rial) and yield (Kg), $W_{s,i}$ means water applied (m^3), and $VC_{s,i}$ means the total cost of the crop (Rial) I under irrigation type of s, respectively.

The CPD expresses the crop production obtained by water applied per m^3 which, from an agricultural viewpoint, serves to evaluate the physical productivity of water. The higher the index, the more efficient the use of water. However, this index cannot express economic benefits. The BPD and NBPD indices measure the economic productivity of water from an economic and monetary viewpoint. The indices show the created monetary value of water applied per m^3. The NBPD shows that products which have a higher net earning with lower water applied will have higher economic productivity (Ehsani and Khaledi, 2003; Henry et al., 2006; Liu et al., 2007).

Compared with CPD and BPD, NBPD is considered to be a net benefit. Therefore, if the research purpose is to analyze the efficiency of agricultural water from an economic perspective, the NBPD index is more suitable than other indices. This is because by using less water, which results in lower production costs, the NBPD index can provide additional benefit.

These indices can be used to compare a certain type of crop in different regions or a specific region over time, which means that these indices can be applied for an external comparison, e.g., water-pricing under water scare condition, and also for an internal comparison (Ehsani and Khaledi, 2003).

Fig. 1 shows the effect of a water-pricing policy on production per cubic meter given the first reaction, where farmers show only a slight or no response at all to rising water prices. In the first stage, CPD and BPD would not change a lot, while the decrease in NBPD would be significant. Since in this stage crop patterns are not modified significantly, and water demand remained unchanged, the net benefit decreases due to the increasing water-pricing.

In the second reaction, substitutions in crop plans take place as an adaption to further increase the water-pricing. Water applied and water cost are both decreased. The crop yield is also decreased. This means that if the decrease unit of water applied is higher than the decrease unit of crop yield, the BPD and CPD will increase; otherwise, the BPD and CPD will decrease. If the decrease unit of water applied is higher than the decrease unit of net benefit, the NBPD would increase; otherwise, the NBPD would decrease. For the third stage, the change in CPD, BPD, and NBPD indices would be similar to the first stage. Since the water demand is relatively inelastic again, water applied remained unchanged, and crop patterns would not change significantly.

However, the water-pricing has risen beyond the economic viability of the agricultural system, and the water applied would fall very fast in the end. Therefore, we are not going to discuss its effect on water productivity since pricing would not be suggested as a proper policy in this stage.

In addition, most studies indicate that the increase in water-pricing would negatively affect the welfare of farmers and agricultural employment. However, in the case of Iran, where water is extremely scarce, the water-pricing policy could have a positive effect on water saving and environment, and fertilizer use might also decrease.

4. Methodology

During the last decades, PMP has been implemented frequently for analyzing policies in the agricultural sector and simulating the external effects of such policies on other sectors (Cortignani and Severini, 2011; Graveline, 2016; Gómez-Limón et al., 2016; Lee et al., 2019). The original motivation of PMP is to increase the liability and simulation power of a constrained optimization model by using the observed information in the specification phase. The PMP has two distinct advantages: firstly, the ability to deal with limited and incomplete information; secondly, the ability to calibrate the farm-level model and approximate even roughly implemented farm production plans (Gómez-Limón et al., 2016; Lee et al., 2019).

In the context of the newly developed Farm Systems SIMulator (FSSIM), Kanellopoulos et al. (2010) introduced a modified PMP calibration approach. Mérel and Bucaram (2010) argued that most studies use prior information on supply elasticity, which appears to be the most frequently used calibration approach based on our review of the model presented below (Fig. 2).

As shown in Fig. 2, the policy analysis in the current study is formulated through five consecutive steps: (1) first, decisions on water irrigation pricing policies are taken and proposed by government institutions; (2) second, the scenarios are designed to reflect common policy decisions on water pricing policies; (3) third, farmers' reactions to water pricing scenarios are simulated using the PMP model, and non-linear yield functions are estimated for each crop through calibration procedure; (4) fourth, the scenarios are modeled based on the simulation results for the land use, variables cost, yield, and gross margin; and (5) fifth, changes in water productivity indices are estimated at the end. Continuing the loop, demand-side information on the estimated water productivity indices provides policymakers with a basis for re-adjusting the water pricing policy for the following periods. The empirical model of the study consists of the non-linear objective function and the constraints including water and land. Following Mérel and Howitt (2014) and Zamani et al. (2019), each PMP model is calibrated in three stages: (1) a linear base model, (2) a maximum entropy yield parameter estimation, and (3) a non-linear calibrated model. Based on a study by Zamani et al. (2019), the model is calibrated on the basis of non-linear yield function using generalized maximum entropy (GME). For the sake of simplicity, only the final calibrated PMP model that maximizes the non-linear gross margin (equation 4) subject to water and land constraints (Eq. 5) is presented in this section as follows:

$$\max_{NX_{s,i,j}} NLZ = \sum_{s}\sum_{i}\left[\sum_{j} P_i\left(\alpha_{s,i,j}NX_{s,i,j} - \beta_{s,i,j}NX^2_{s,i,j}\right)\right] - \sum_{s}\sum_{i}\sum_{j} C_{s,i,j}NX_{s,i,j} \text{(nonlinear objective function)} \tag{4}$$

$$\sum_{s}\sum_{i} a_{s,i,j}NX_{s,i,j} \le b_{j\text{land and water}} \text{(land and water constraint)} \tag{5}$$

where $NX_{s,i,j}$ is the decision variable indicating the amount of input j which is used for crop i and irrigation system s. P_i and C_{sij} respectively show the price and the unit cost of input j (land, irrigation, labor, machinery, fertilizers), crop i, and irrigation systems. $a_{s,i,j}$ is Leontief coefficients (technical coefficient) indicating the amount of input j used to produce a unit of crop i. The right-hand side of equation, i.e., $b_{j\text{land and water}}$, presents the maximum available water and agricultural land in the case study. The parameters of non-linear yield function, including $\alpha_{s,i,j}$ and $\beta_{s,i,j}$, are estimated (re-produced) by GME.[1] The calibrated nonlinear model presented by Eq. 4, 5 is able to reproduce the base-year information without imposing additional calibration constraints. A highlighted feature of the final model's quadratic objective function is to prevent over-specialization or so-called corner solutions (Mérel and Howitt, 2014). Accordingly, the final calibrated model in the last stage of PMP is more flexible to simulate policy changes including water pricing scenarios (Lee et al., 2019).

In order to simulate the impacts of policies more precisely, we divided the costs of irrigation into the price of water and variable cost of groundwater extraction per cubic meter, respectively. The variable cost of irrigation for crop i and irrigation s, i.e., $CW_{i,s}$, is presented by Eq. 6. In this equation, $cwe_{i,s}$ indicates the unit cost of groundwater extraction, and wp is the price of water which is zero at status quo[2].

$$CW_{i,s} = (cwe_{i,s} + wp)w_{i,s} \tag{6}$$

Another part of the cost function includes the costs related to fertilizer, labor, machinery, pesticides, and manure.

As mentioned before, we focus on Hamadan-Bahar plain located in Northwestern Iran. Fig. 3 shows the location of this plain. We randomly collected our data sample from 213 farms in the study region, for three different crop types, including rapeseed, forage corn, and alfalfa, and two different irrigation systems. Table 1 describes the input data for the sample farms. We took the average of data over different farm types (in terms of irrigation system and crop choice). Thus, the presented data are for one hectare. The data on the applied water for individual crops have been extracted from a survey. Thus, for each farmer/irrigation system/crop we calculated applied water as shown in Table 1. Water applied for crops decreases as irrigation technology improves. This fact goes back to the higher efficiency in water deliveries in the farm. Additionally, the average yield is higher as irrigation technology improves due to a better irrigation management (Balali et al., 2011; Barati et al., 2019). In the model above, the applied water data are presented by technical coefficients (i.e., a_(s,i,j)), while the total available water at farm level is included in the right-hand side of the water resource equation (i.e., Eq. 5).

5. Results

5.1. Baseline

To analyze the impact and the changes resulting from the implementation of the water pricing policy, this study first assessed the current situation. To do so, this study focused on the water productivity of the two irrigation systems and analyzed the current crop pattern of the case study. As shown in Table 1, the average yield of crops under the furrow irrigation system is lower compared to the modern (conventional) system. In fact, we can easily assume that losses due to the use of furrow irrigation are important in terms of infiltration along the furrows. These losses contribute to the reduction of overall water efficiency of applied water. As Perry and Steduto (2017) and Balali et al. (2011) stated in their study, water applied for crops decreases as irrigation technology improves. Moreover, average yield is higher as irrigation technology improves due to a better irrigation management. In this line, Table 1 shows the higher financial productivity of water for crops with conventional irrigation systems.

According to the baseline, alfalfa has a major share of land use, followed only by forage corn. This pattern could be due to a higher gross margin (defined as "revenue-variable costs") of this crop compared to forage corn and rapeseed. Although forage corn has higher productivity of water, it has a lower share of land use. This pattern could be explained by the zero price of irrigation water in the case study.

5.2. Impact of water-pricing on cropping pattern

Although the value of water (or shadow price) can be a benchmark for pricing, it is normally higher than irrigation water price, due to social and economic constraints in the agricultural sector (Barker et al., 2003). In other words, "water rates for irrigating crops paid by farmers do not reflect the actual value of water that can be expressed solely as a shadow price" (Ziolkowska, 2015; page 20). In our analysis, we defined different scenarios to assess the effects of water pricing policy. By imposing this policy, first of all, according to microeconomic theory, water applied would decrease. Considering current constraints in the area, such as the restriction of expanding agricultural land, two possible reactions would be expected, including changing cropping patterns and replacing the

[1] For more detail please check Mérel and Howitt (2014)

[2] which is a stream of scenarios imposed to the mode

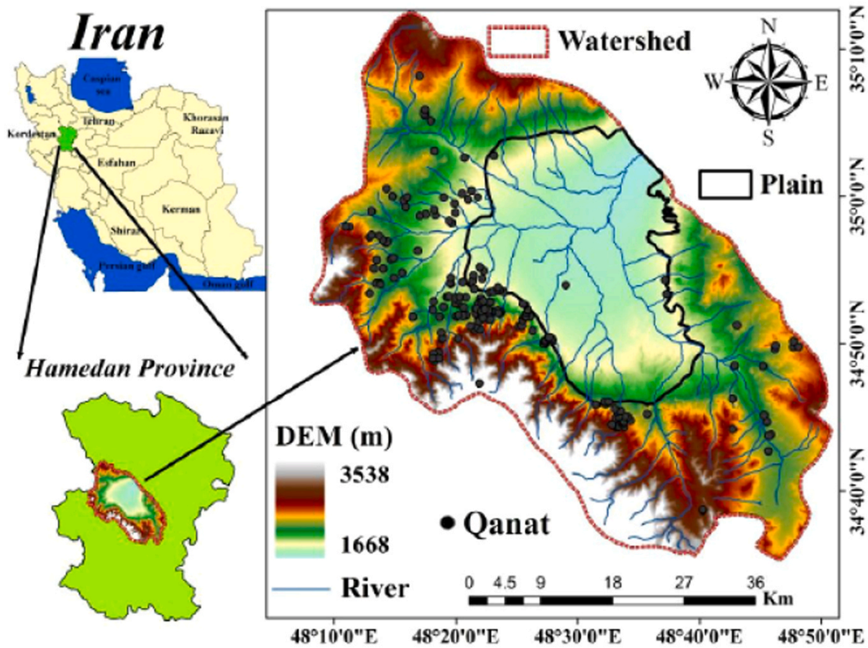

Fig. 3. Location of Hamedan-Bahar Plain, Hamedan Province, Iran.
(Source: Farokhzadeh et al., 2015).

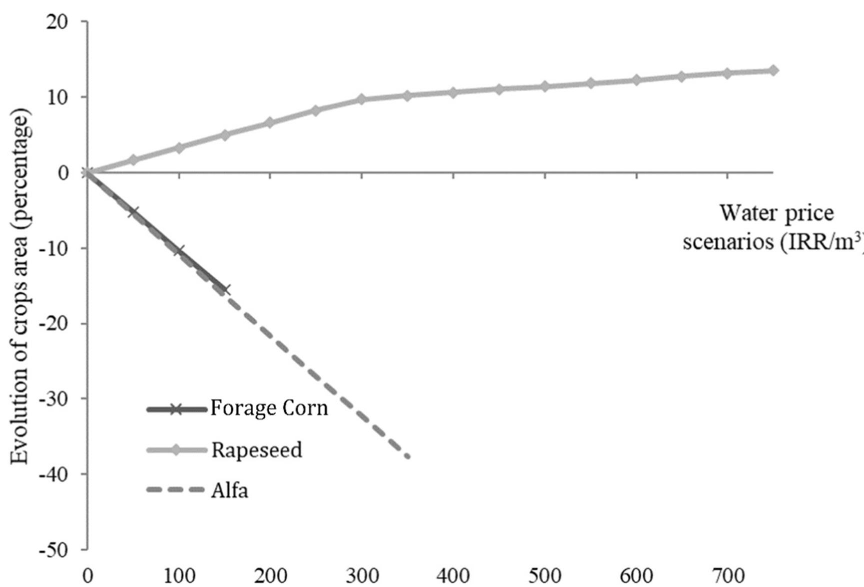

Fig. 4. Changes in cropping pattern due to different water price scenarios (in case of furrow system).
Note: [IRR: 0.00002 USD].
Source: Own calculation.

furrow irrigation system with a modern irrigation system. The results of the change in cropping pattern under two irrigation systems are shown in Figs. 4 and 5. By increasing the water price, farmers try to replace crops with a lower NBPD with those that produce more net benefit per water applied. Under furrow irrigation, alfalfa shows an immediate decline and after a price of more than 350 IRR/m^3, it is completely eliminated. Moreover, rapeseed, as a high NBPD crop, has been expanded. It should be mentioned that generally, changing cropping patterns under furrow irrigation is more effective compared with the modern one. Another interesting fact is that in case of modern irrigation, the farmers increase the surface of alfalfa before a drastic decrease, and also increase the surface of rapeseed more (water applied), compared with the furrow area (up to +13,5% in the furrow irrigation system and up to +20,6% in modern irrigation system). This represents the change of price elasticity in different crops regarding the relation of NBPD and water price with a drastic change at the turning point of economic feasibility.

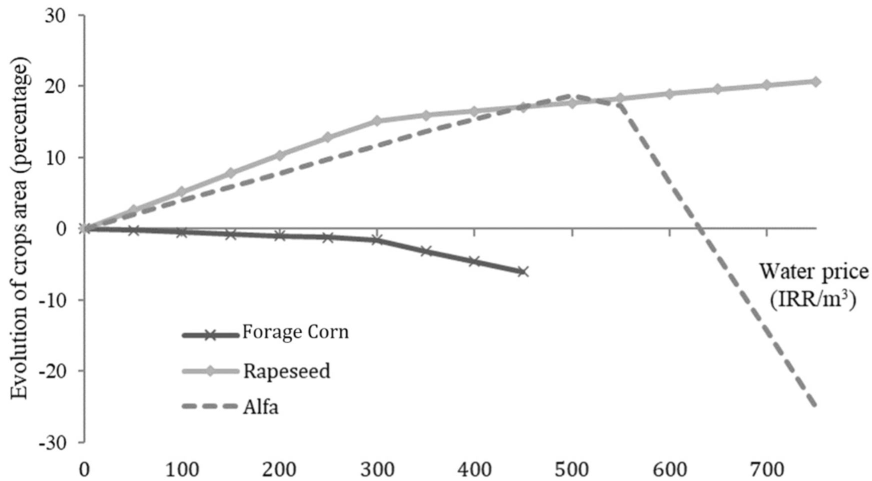

Fig. 5. Changes in cropping pattern due to different water price scenarios (in case of modern irrigation system). Note: [IRR: 0.00002 USD].
Source: Own calculation.

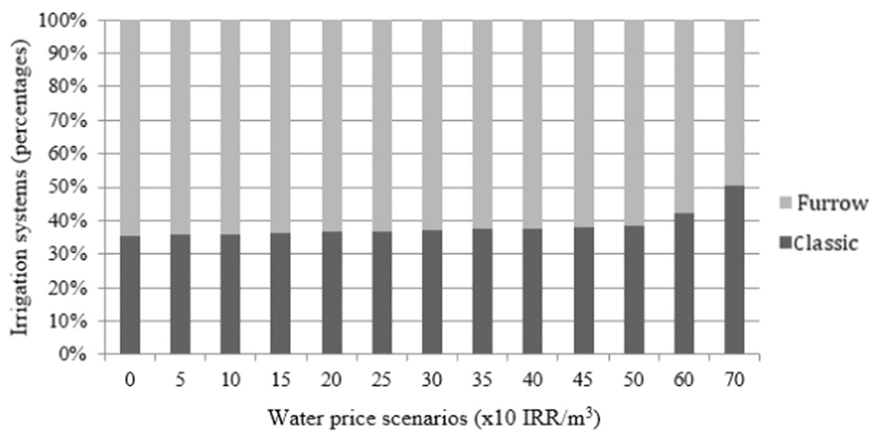

Fig. 6. Changing irrigation systems due to different water price scenarios. Note: [IRR: 0.00002 USD].
Source: Own calculation.

5.3. Impact of water-pricing on irrigation technology

Changing the irrigation system as a result of the policy is manifested in Fig. 6. By increasing the price of water, farmers are trying to replace the traditional irrigation system with furrows, and this change is more significant after the price of water over 500 IRR/m^3. At farm level, this is explained by higher cost of furrow irrigation technology for the farmers when the water price is beyond 500 IRR/ m^3. Essentially, by increasing water prices, farmers invest in more efficient technologies through which they can maintain the farm gross margin. However, the changes for individual crops are inconclusive.

5.4. Impact of water-pricing on water productivity

As explained in the previous sections, we have three indices for water productivity, which have been indicated by NBPD,[3] BPD,[4] and CPD.[5] Among them, we focus on NBPD since it best incorporates the economic incentives of farmers and variable costs. As shown in Fig. 7, water productivity has been indicated for each crop for various water prices. The percentage changes in BPD and CPD in response to pricing policy are similar, as the only difference between them is defined by crop prices which are assumed exogenous and constant. However, the percentage change in NBPD is affected not only by water use reduction (i.e., NBPD formula) but also by decreases in variable costs (i.e., NBPD formula) when water pricing policy is implemented. These two opposite effects cause NBPD to react differently to the price changes considering irrigation technologies and crop types. The reaction of farmers toward increasing water price and thereby gross margin reduction is to decrease water use or replace inefficient irrigation technology (as discussed in the previous section). Depending on water price level, the farmers will reallocate water to more efficient crops or reduce farmland size. Accordingly, the final effect is determined by two factors: water applied by each crop individually and the competition between the crops to absorb more water (and land) at farm level.

Our findings show that water productivity for all indices would increase due to the implementation of a water price, but the inclusion of the market price and variable costs are necessary to represent the cropping pattern in a profit-maximizing problem. Another conclusion is that by increasing water prices, the water productivity for crops under furrow irrigation would increase more compared to the modern irrigation system. This is due to the higher impact of water price in case of more water-intensive furrow irrigation. Additionally, this pattern is more pronounced for less water-intensive products, such as forage corn,

[3] Net Benefit per Drop
[4] Benefit per Drop
[5] Crop per Drop

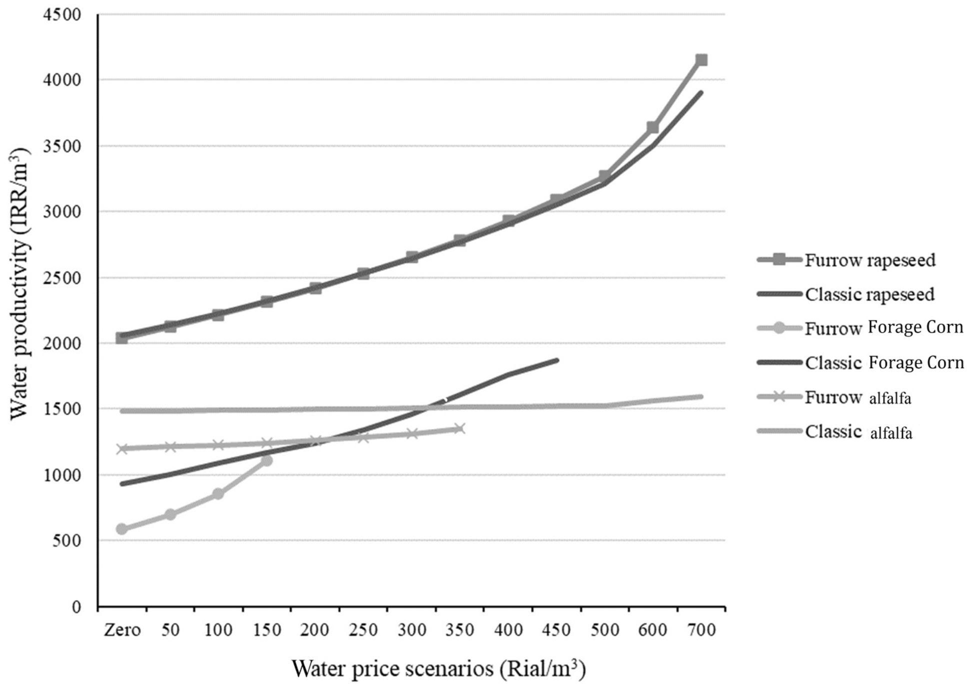

Fig. 7. Water productivity changes in different water price scenarios.

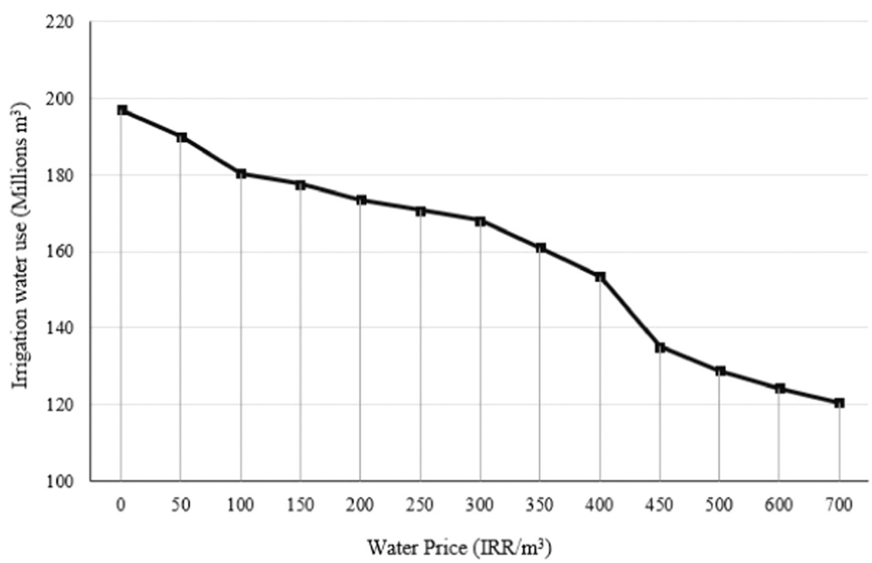

Fig. 8. Total changes in water applied (Million m^3) due to water-pricing policy.

and it is lower for water-intensive crops, such as alfalfa (Tables 2-4).

5.5. Impact of water-pricing on total water demand

Another important result is the development of total water applied. Fig. 8 shows the changes in the total demand for irrigation water as a sum of all crops at different water prices. The overall trend in numbers shows that, as expected, total water applied will decline as the price of water rises. In line with the study by Balali and Viaggi (2015), changes in water demand are more evident in the range of water prices from 400 to 700 IRR/m^3. Conversely, the increase in the price of water results in a slight change in water savings. As mentioned above, this finding is mainly related to crop patterns and land-use change.

5.6. Limiting factors of the chosen methodological approach

Several limitations have to be considered when looking at the results of our model. Firstly, we have made several simplifications in order to produce results. The focus was just on three crops, although in reality, several more possibilities exist, and new plants could be introduced easily. Furthermore, it was assumed that changing the cropping pattern, as well as the irrigation system, is possible without any additional investment (capital and time) and independent of soil type, even though this is highly unlikely in reality. Another shortcoming of the model is that it cannot account endogenously for technological changes such as the breeding of new and more water-efficient varieties or even better irrigation technologies (e.g., drip irrigation).

For modeling purposes, we also had to assume that the introduction of a water pricing policy would be immediately effective. Monitoring and enforcement difficulties were completely disregarded. Last but not least, farmers are considered to act fully rationally without constraints of capital, know-how, or other social hindrances such as traditions.

6. Conclusion

The aggregate programming models for agricultural water management are still widely used for policy-relevant analysis. They have the ability to easily integrate important policy measures such as the traditional irrigation system with furrows and imply consistency during simulations with primary factor constraints. These advantages, however, come at the price of huge data criteria, often excluding time series compilation and a typical lack of empirical validation. The aim of this study was to investigate the impact of water-pricing policy on water productivity. By collecting data from 213 farms in Hamadan-Bahar Plain in Iran, this study applied a PMP model with a gross margin maximizing the objective function.

Overall, our calculation regarding water productivity is compatible with the literature (e.g., Seyedan and Ghadimi, 2019; Mozaffari, 2020). Rapeseed gives higher economic productivity, just followed by alfalfa and forage corn, respectively. Moreover, modern irrigation technology generally improves water productivity of crops. The results showed that a water-pricing policy can change the cropping pattern and also irrigation system within the limitations of our case study. It can also be a driver to motivate farmers to use modern and more efficient irrigation systems. However, Iran faces severe water scarcity, and unwise water use management, particularly in the irrigation sector due to the use of conventional farm techniques, has led to a decrease in on-farm water efficiency due to the vast quantities of waste water. The results of the current study revealed that a water-pricing policy could improve water productivity and also decrease water applied. The contribution of water pricing to the sustainable management of water resources requires large investments and financial commitments to manage water applied. In this study, considering the technical aspects of irrigation water efficiency with a focus on the water applied, water pricing policy has some potentials to overcome both physical and economic water scarcity. When pricing policy is enforced, the volume of applied water decreases. Considering the current ban on the extension of agricultural lands in our case study, this mechanism has the same consequence as the restricting water deliveries to the farm (or water shortage). However, restricting water deliveries can be a result of different factors. In our case, water applied decreases due to the increases in the irrigation water price.

The results of this study provide a good framework for local/regional farmers to improve the management of water resources in their region, taking into account sustainable development goals. Exploring the economic value and impact of water-pricing policy on water productivity in different Iranian provinces is needed to motivate farmers to use more efficient irrigation technology.

To advance the highly neglected topic of water prices, the proposed methodology of PMP can include more case studies from different regions. This study focuses on evaluating water-pricing and development policies across the country. In this context, this study highlights the country's ability to support the monitoring system for water resource management. Therefore, water-pricing is a part of the responsibility of national policies, and the current policies in the agricultural sector exhibit some shortcomings (e.g., lack of data availability hinders detailed analyses).

In addition, the results of this study capture the different pricing concepts and water demands when offering the PMP method for evaluating irrigation policies by contrasting scarcity, cost conditions, and various agricultural practices. By conducting this study, we have shown that i) the water pricing is a cross-sectoral and multi-dimensional policy issue, and ii) by implementing PMP, we will be able to propose strategies for optimizing the use of groundwater resources by farmers and prevent the destruction of these resources. It is, therefore, the government's responsibility to establish rules and processes for efficient and sustainable use of water and protect highly vulnerable water resources.

In addition, this study concluded that farmers need to be encouraged to use modern irrigation methods. Therefore, the government should support these technologies to increase on-farm water efficiency and water productivity. However, this improvement is subject to water accounting verification. The potential environmental benefits from the improved on-farm irrigation efficiency depend on the government's ability to prevent the extension of the irrigated area. In absence of such controls, the aquifer depletion will be accelerated. Further studies should be carried out to fully understand the potential impact of water-pricing policy implementation, as the model used in this study is based on a purely mathematical model that ignores limited rationality by assuming the farmers' perceptions in the comparison period. The present study succeeded in providing a theoretical and methodological basis for the evaluation of programming models for agricultural water-pricing policies.

In order to evaluate the suggested hypotheses (H1-H4), this paper revealed that: 1) the farmers change cropping patterns and reduce their water applied, and by increasing water prices, farmers will invest in more efficient technologies; therefore, the first hypothesis is confirmed by the results; 2) by increasing water prices, the water productivity for crops under furrow irrigation would increase more compared to the modern irrigation system; this result also confirms the second hypothesis; 3) a water-pricing policy (based on assessing various prices) could improve water productivity and also decrease water applied; both hypotheses 3 and 4 have been confirmed accordingly.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Al-Rubaye, S. Al-Ezzy, J. 2018. Water productivity and performance of irrigated corn farms in Babil Governorate. Paper presented at the 1st International Conference on Applied Agricultural Sciences and Prospective System Technology System, February 22–26 2018, Luxor, Egypt.

Al-rubaye, Sh, 2018. Agricultural irrigation pricing: review of theories and practices. Irrig. Drain. https://doi.org/10.1002/ird.2296.

Al-Saidi, M., Dehnavi, S., 2019. Comparative scorecard assessment of urban water pricing policies—the case of Jordan and Iran. Water 11, 704. https://doi.org/10.3390/w11040704.

Asaadi, M.A., Mortazavi, S.A., Zamani, O., Najafi, G.H., Yusaf, T., Hoseini, S.S., 2019. The impacts of water pricing and non-pricing policies on sustainable water resources management: a case of Ghorveh plain at Kurdistan Province, Iran. Energies 12, 2667.

Balali, H., Khalilian, S., Viaggi, D., Bartolini, F., Ahmadian, M., 2011. Groundwater balance and conservation under different water pricing and agricultural policy scenarios: a case study of the Hamadan-Bahar plain. Ecol. Econ. 70 (5), 863–872.

Balali, H., Viaggi, D., 2015. Applying a system dynamics approach for modeling groundwater dynamics to depletion under different economical and climate change scenarios. Water 7 (10), 5258–5271.

Banihabib, M.E., Hashemi, F., Shabestari, M.H., 2016. A framework for sustainable strategic planning of water demand and supply in arid regions. Sustain. Dev. 25 (3), 254–266.

Barati, A.A., Azadi, H., Scheffran, J., 2019. A system dynamics model of smart groundwater governance. Agric. Water Manag. 221, 502–518.

Boazar, M., Yazdanpanah, M., Abdeshahi, A., 2019. Response to water crisis: how do Iranian farmers think about and intent in relation to switching from rice to less water dependent crops? J. Hydrol. 570, 523–530.

Chebil, A., Frija, A., Thabet, Ch, 2010. Irrigation water-pricing between governmental policies and farmers' perception: implications for green-houses horticultural production in Teboulba (Tunisia). Agric. Econ. Rev. 11 (2), 44–54.

Cortignani, R., Severini, S., 2011. An extended PMP model to analyze farmers' adoption of deficit irrigation under environmental payments. Span. J. Agric. Res 9 (4), 1035–1046.

de Fraiture, C., Perry, C. 2002. Why is irrigation water demand inelastic at low price ranges? Paper Presented at the Conference on Irrigation Water Policies: Micro and Macro Considerations15–17 June 2002, Agadir, Morocco.

Dinar, A., 2015. Water Pricing Experiences and Innovations. Springer International Publishing, Switzerland, p. 471.

Ehsani, M., Hayati, B., Dashti, G.H., Ghahremanzade, M., Hossenzad, J., 2012. Water economic value estimation in barley production at Qazvin plane irrigation network. Water Soil Sci. 2, 187–200.
Ehsani, M., KHaledi, H., 2003. Agricultural Water Productivity. Iranian National Committee on Irrigation and Drainage press, Tehran, Iran.
Expósito, A., Berbel, J., 2016. Why is water pricing ineffective for deficit irrigation schemes? A case study in Southern Spain. Water Res. Manag. 31 (3), 1047–1059.
Faramarzi, M., Yang, H., Schulin, R., Abbaspour, K.C., 2010. Modeling wheat yield and crop water productivity in Iran: implications of agricultural water. Agric. Water Manag. 97 (11), 1861–1875.
Farokhzadeh, B., Attaeian, B., Akhzari, D., Razandi, Y., Bazrafshan, O., 2015. Combination of boolean logic and analytical hierarchy process methods for locating underground dam construction. Ecopersia 3 (3), 1065–1075.
Fragoso, R., Marques, C., 2013. The Economic Impact of Alternative Water-pricing Policies in Alentejo Region. In University of Evora, Evora, Portugal.
Galioto, F., Guerra, E., Raggi, M., Viaggi, D., 2017. The impact of new regulations on water pricing in the agricultural sector: a case study from Northern Italy. Agric. Econ. Rev. 18 (2), 77–95.
Garrido, A., Calatrava, J., 2010. Agricultural Water Pricing: EU and Mexico. Retrieved from Paris, France.
Gómez-Limón, J.A., Gutiérrez-Martín, C., Riesgo, L., 2016. Modeling at farm level: Positive multi-attribute utility programming. Omega 65, 17–27.
Gorjian, Sh, Ghobadian, B., 2015. Solar desalination. A sustainable solution to water crisis in Iran. Renew Sust. Energ. Rev. 48, 571–584.
Graveline, N., 2016. Economic calibrated models for water allocation in agricultural production: a review. Environ. Modell. Softw. 81, 12–25.
Habibi Davijani, M., Banihabib, M.E., Nadjafzadeh Anvar, A., Hashemi, S.R., 2016. Optimization model for the allocation of water resources based on the maximization of employment in the agriculture and industry sectors. J. Hydrol. 533, 430–438.
Hashemy Shahdany, S.M., Hasani, Y., Majidi, Y., Maestre, J.M., 2017. Modern operation of main irrigation canals suffering from water scarcity based on an economic perspective. J. Irrig. Drain. Eng. 143 (3).
Iglesias, E., Blanco, M., 2008. New directions in water resources management: the role of water pricing policies. Water Resour. Res. 44, 6.
Jacob, T., Bernard, C., 2013. Exploring the politics of local participation in rural development projects: small dams rehabilitation project in Zimbabwe. Rus. J. Agric. Socioecon. Sci 14.
Julio, B., Jose, A., 2000. The impact of water-pricing policy in Spain: an analysis of three irrigated areas. Agric. Water. Manag. 43 (2), 219–238.
Kahil, M.T., Ward, F.A., Albiac, J., Eggleston, J., Sanz, D., 2016. Hydro-economic modeling with aquifer–river interactions to guide sustainable basin management. J. Hydrol. 539, 510–524.
Kanellopoulos, A., Berentsen, P., Heckelei, T., Van Ittersum, M., Oude Lansink, A., 2010. Assessing the Forecasting performance of a generic bio-economic farm model calibrated with two different pmp variants. J. Agric. Econ. 61 (2), 274–294.
Kijne, J.W., Barker, R., Molden, D.J. (Eds.), 2003. Water Productivity in Agriculture. Limits and Opportunities for Improvement. CABI Pub, Oxon, Cambridge, MA. In association with the International Water Management Institute (Comprehensive assessment of water management in agriculture series, [1]).
Lee, H., Eom, J., Cho, C., Koo, Y., 2019. A bottom-up model of industrial energy system with positive mathematical programming. Energy 173, 679–690.
Liu, J., Williams, J.R., Zehnder, A.J.B., Yang, H., 2007. GEPIC–modelling wheat yield and crop water productivity with high resolution on a global scale. Agric. Syst. 94 (2), 478–493.
Madani, K., 2014. Water management in Iran: what is causing the looming crisis? Environ. Stud. Sci. 4, 315–328.
Madani, K., AghaKouchak, A., Mirchi, A., 2016. Iran's socio-economic drought: challenges of a water-bankrupt nation. Iran. Stud. 49 (6), 997–1016.
Mérel, P., Howitt, R., 2014. Theory and application of positive mathematical programming in agriculture and the environment. Annu. Rev. Resour. Econ. 6, 451–470.
Merel, P.R., Bucaram, S., 2010. Exact calibration of programming models of agricultural supply against exogenous sets of supply elasticities. Eur. Rev. Agri Cult. Econ. 37, 395–418.
Mobin-ud-Din, A., Turral, H., Nazeer, A., 2009. Diagnosing irrigation performance and water productivity through satellite remote sensing and secondary data in a large irrigation system of Pakistan. Agric. Water. Manag. 96 (4), 551–564.
Molden, D., 1997. Accounting for Water Use and Productivity. IWMI.
Molle, F., Venot, J.P., Hassan, Y., 2008. Irrigation in the Jordan Valley: are water pricing policies overly optimistic? Agric. Water Manag. 95 (4), 427–438.
Mozaffari, L., 2020, Investigation of virtual water balance in the agricultural sector of Hamedan Province, Iran. Thesis of MSc degree, Agricultural Faculty, Bu_Ali sina University, Hamedan, Iran (In Persian).
Nabavi, E., 2017. (Ground)water governance and legal development in Iran, 1906–2016. Middle East Law Gov. 9 (1), 43–70.
Ørum, J.E., Boesen, V., Zorica, J., Søren Marcus, P., 2010. Farmers' incentives to save water with new irrigation systems and water taxation—a case study of Serbian potato production. Agric. Water Manag. 98 (3), 465–471.
Perry, C., 2007. Efficient irrigation; inefficient communication; flawed recommendations. Irrig. Drain. 56, 367–378.
Perry, C., Steduto, P., 2017. Does Improved Irrigation Technology Save Water. FAO,, Cairo, Egypt.
Pulido-Velazquez, M., Alvarez-Mendiola, E., Andreu, J., 2012. Design of efficient water-pricing policies integrating basinwide resource opportunity costs. J. Water Resour. Plan Manag. 139 (5), 583–592.
Putri, P., 2016. Moulding citizenship: urban water and the (Dis) appearing kampungs. In: Bell, S., Allen, A., Hofmann, P., Teh, T.-H. (Eds.), Urban Water Trajectories. Springer, London.
Regional Water Company of Hamedan, 2017. Report on groundwater in Hamedan-Bahar plain.
Renzetti, S., 2000. The Political Economy of Water Pricing Reforms, pp. 23–40.
Rogers, P., Silva, R.Dd, Bhatia, R., 2002. Water is an economic good: how to use prices to promote equity efficiency and sustainability. Water Policy 4, 1–17.
Seyedan, S., Ghadami, F.A., 2019. Productivity of garlic production factors in sprinkler and surface irrigation systems in Hamadan province. Iran. J. Irrig. Drain. 13 (3), 845–854.
Shi, M., Wang, X., Yang, H., Wang, T., 2014. Pricing or quota? A solution to water scarcity in oasis regions in China: a case study in the Heihe River Basin. Sustainability 6 (11), 7601–7620.
Singh, A., 2016. Optimal allocation of water and land resources for maximizing the farm income and minimizing the irrigation-induced environmental problems. Stoch. Environ. Res. Risk Assess. 31 (5), 1147–1154.
Soto Rios, P.C., Soto Rios, T.A., Nagabhatla, N., Ayala, G, 2018. Explaining water pricing through a water security lens. Water 10 (9), 1173.
Tahamipour, M., Kalashami, Kavoosi, Chizari, A, M., 2014. Irrigation water pricing in Iran: the gap between theory and practice. Int. J. Agric. Manag. Dev. 5 (2), 109–116. https://doi.org/10.5455/ijamd.168344.
Talebmorad, H., Eslamian, S., Abedi-Koupai, J., Mousavi, S.F., Akhavan, S., Ostad-Ali-Askari, K., Singh, V.P., 2018. Evaluation of integrated hydro geosphere hydrologic model in modeling of large basins subject to severe withdrawal. J. Environ. Chem. Toxicol. 2 (1), 30–40.
Varela-Ortega, C., Sumpsi, J.M., Garrido, A., Blanco, M., Iglesias, E., 1998. Water-pricing policies, public decision making and farmers' response: implications for water policy. Agric. Econ. 19 (1), 193–202.
Venot, J.-P., Molle, F., 2008. Groundwater depletion in the jordan highlands: can pricing policies regulate irrigation water use? Water Res. Manag. 22 (12), 1925–1941.
World Bank, 2003. Performance Assessment Report: Jordan. Agricultural Sector Adjustment (Loan No. 3817-JO) and Agricultural Sector Technical Support Project (Credit No. 3818-JO). World Bank, Washington, D.C.
Xu, D., Shi-Hong, G., Yi-Nong, L., Yu, L., 2010. Overview of recent study on improvement approaches and methods for crop water productivity. Shuili Xuebao/J. Hydraul. Eng. 41 (6), 631–639.
Yazdanpanah, M., Hayati, D., Hochrainer-Stigler, S., Zamani, Gh.H., 2014. Understanding farmers' intention and behavior regarding water conservation in the Middle-East and North Africa: a case study in Iran. J. Environ. Manage. 135, 63–72.
Zamani, O., Grundmann, P., Libra, J.A., Nikouei, A., 2019. Limiting and timing water supply for agricultural production–the case of the Zayandeh-Rud river basin, Iran. Agric. Water Manag. 222, 322–335.
Ziolkowska, J.R., 2015. Shadow price of water for irrigation—a case of the high plains. Agric. Water Manag. 153, 20–31.