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METHODS

The economic impacts of drought on the economy of Iran: An integration of linear programming and macroeconometric modelling approaches☆

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ABSTRACT

In this paper, we provide economy-wide estimates of the costs of drought in the cropping sector of the Iranian economy, using a linear programming model to estimate the direct costs on agriculture, and a macroeconometric model to trace the indirect impacts on the rest of the economy. The results indicate that a severe drought such as the one that occurred in the crop year 1999–2000 imposes a direct cost of 1605 million USD, equivalent to 30.3% of the total value added of the cropping sector in Iran. This, in turn, leads to a 12.7% reduction in the value added of other agricultural sub-sectors (livestock, fisheries and forestry). In the rest of the economy, the manufacturing and service sectors experience value added declines of 7.8 and 3.7%, respectively. In addition, there is a substantial decrease in investment in the agricultural, manufacturing and service sectors. Thus, such a drought reduces overall GDP by about 4.4%, and it would also result in decreased non-oil exports, increased food imports, and a rise in inflation. The results of some drought mitigation simulations are reported in brief. Such estimates strengthen the case for increased attention to drought strategies and management in agriculture in Iran and elsewhere.

1. Introduction

According to a recent IPCC study, "Production of rice, maize and wheat in the past few decades has declined in many parts of Asia due to increasing water stress, arising partly from increasing temperatures, increasing frequency of El Niño events and reductions in the number of rainy days" (Ch. 5.2 in Bates et al., 2008). In 1999–2000, up to 60 million people in Central and Southwest Asia were affected by a persistent multi-year drought, one of the largest in a global perspective (IRI, 2001), with Iran, Afghanistan, Western Pakistan, Tajikistan, Uzbekistan and Turkmenistan experiencing the most severe impacts. In Iran, this drought was considered to be the worst in 35 years: the national average annual precipitation was just 138.3 mm compared to the long-term average of 249 mm, and seriously affected 18 of the country's 28 provinces.

Over the longer term, there are signs of more frequent and more severe droughts in Iran, due to global climate change,

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population growth, and increased water resource demands from all sectors: agriculture, industries, and municipal uses. Given that 46% of Iranian cropland is rain-fed and that precipitation serves as complementary irrigation for plants cultivated on irrigated land, this climate hazard results in considerable losses to the Iranian agricultural sector, which accounts for 16% of GDP, 25% of employment, and 35% of population. The damage is not limited to the cropping sector, as there are close links within agricultural sub-sectors as well as between agricultural sectors and the rest of the economy.

According to UN Office for the Coordination of Humanitarian Affairs (OCHA, 2000), the 1999–2000 drought in Iran caused agricultural losses of 2.8 million tons in wheat and 280,000 tons in barley and a loss of stubble as fodder resources. Production of alfalfa was down 38% to 4.1 million tons. In addition, an estimated 2.6 Mha of irrigated lands and 4 Mha of rain-fed agriculture experienced the drought's impact, along with 1.1 Mha of orchards growing almonds, apricots, mangoes, and other fruits (IRI, 2001). Furthermore, the drought severely affected the number and productivity of commonly held livestock as it reduced the quantity and quality of forage available on range lands and pastures. 200,000 nomadic livestock herders lost their only source of livelihood, and an estimated 800,000 small animals died due to malnutrition and disease.

The losses caused by the drought were estimated at USD 1.7 billion[1] (OCHA, 2000), and had important implications for state budget as well as imports and exports, as government had to provide emergency food supplies for the most seriously affected populations, fodder supplies for livestock, and livestock procurement programmes. In addition, imports of wheat, barley and other agricultural products had to be increased to compensate for the shortfall in these products. According to Iranian officials, state budget payments direct to agricultural producers were about USD 375 million.

The drought had extreme negative impacts on water resources, and drinking water supply systems in both rural and urban areas (OCHA, 2000). In over 70% of rural areas, the flow of water was moderately to severely disrupted. Almost 80% of drinking-water wells suffered from low water yield due to a drop in the water table, and became brackish. Water reserves in July 2001 were down by 45%. Some 37 million people (more than 50% of Iran's total population) were affected by deteriorated health such as skin and eye infections, and the number of animals infected with enteric and skin parasites had important implications for productivity in the agricultural sector.

Although there is no control over rainfall itself, adjustment to and management of the climatic endowment (such as appropriate varieties, cropping patterns and irrigation systems, and reservoirs) can reduce considerably the adverse effects of the service variability provided by this resource. However, the required degree of adjustment and management has not taken place in Iran, and the country has not invested enough funds in water-saving technology. The reasons for this are twofold: first, governments often respond to drought through crisis management rather than preplanned programs (Wilhite, 1986). Second, government needs to collaborate with water managers and water users in a shift from crisis-based, reaction to risk-based, proactive drought management, with emphasis on monitoring and early warning, prediction, mitigation, and preparedness planning. The government in Iran is poorly prepared for such drought management, mostly because of institutional failures such as the existence of traditional water rights, lack of well-defined water property rights, an inadequate regulatory framework, lack of formal markets to allow water to move to higher-valued economic uses, and almost open access that encourages depletion of ground water for which user does not pay the cost. In addition, limitation of financial resources and a lack of understanding of the economy-wide effects of drought seem to be another reason for not implementing more effective drought management.

This paper provides estimates of drought costs in order to highlight the importance of alleviating the economy-wide effects of drought by investing in mitigating measures such as water-saving technologies, changed cropping patterns and dealing with institutional failure. To this end, a linear programming approach is used to estimate the direct costs, in terms of GDP reduction, of drought on the cropping sectors (cereals, vegetables and fruits). A macroeconometric model for Iran is then used to simulate the impacts of the drought on other sectors and on some other macroeconomic indicators.

Several authors have tried to quantify the effects of drought in the countries experiencing this climate hazard. For example, Iglesias et al. (2003) utilized a dynamic-recursive mathematical programming farm model to evaluate the effects of drought management in irrigated areas of south Spain. Mansouri (2003, 2004) examined the impacts of drought on private consumption, private investment, and economic growth in Morocco while drought is represented by various dummy variables based on the severity of the drought. Block (1999) developed a simple econometric model for Ethiopia in which the drought years was used as a dummy variable to investigate the impacts of drought on the agriculture and manufacturing sectors as well as the effects on some macroeconomic variables in this country. Dinar and Keck (2000) estimated drought losses in grains for sub-Saharan Africa in 1983, and Huang et al. (2000) calculated the decrease in Chinese agricultural production value as a result of drought in the years 1988 and 1994, using simple accounting methods. To the authors' best knowledge, the present study is the first quantitative one of its kind that tries to integrate linear programming and macroeconometric approaches to measure agricultural drought effects, and thus to estimate the economy-wide impacts of this common climate hazard. Given the lack of appropriate methodology for estimation of drought losses observed in countries experiencing droughts, this study may be of help in improving the measurement of drought losses in such countries.

2. Theoretical framework

Drought reduces water availability to plants directly, thus the productivity (yield) of crops, forestry and (grazed) rangeland. It also lowers surface and sub-surface water supplies, which, in turn, may result in reducing cultivated land areas, and increasing livestock and wildlife mortality rates.

[1] All monetary values in this paper are expressed in United States dollars (USD) using the year 2000 exchange rate of 8000 Iranian rials to one USD. Currently (autumn 2008), one USD = 9500 rials approximately.

Moreover, since economic sectors are closely interrelated, indirect impacts span many other sectors of the economy and reach well beyond the sector and area(s) experiencing drought.

The shortage of the rainfall in a drought year affects crop yields on both irrigated and rain-fed land in Iran. On irrigated land, crops cultivated experience only a partial drop in yield if precipitation in critical months (generally, March to May) falls below threshold levels. On the other hand, rain-fed crops depend on rainfall in such a way that yields become zero if either the annual total precipitation or the precipitation in other critical months (September and October) falls below certain threshold levels.

If, for a given region (province) and crop:

R is actual annual precipitation

minRR is the minimum annual precipitation level required for normal crop yields on rain-fed land

RI and RS are the actual seasonal precipitation levels in the critical months, for irrigated and rain-fed land, respectively

minRI and minRS are the minimum seasonal precipitation levels required on irrigated and rain-fed land, respectively, during the critical months

and for a given crop in that region:

YBI is the basic yield on irrigated land, *i.e.* the (sub-optimal) yield based on planned irrigation levels in the absence of complementary rainfall

YI is actual yield on irrigated land, equal to YBI when seasonal rainfall is not above the specified minimum precipitation, and greater than YBI when seasonal rainfall is above this minimum.

YR is the actual yield on rain-fed land.

The following relationships are thus assumed to hold for each crop:

$$\mathrm{YI} = \mathrm{YBI} + \lambda_{\mathrm{I}}.[f_{\mathrm{I}}(\mathrm{RI} - \mathrm{minRI})] \text{ for } \mathrm{minRI} < \mathrm{RI} < \mathrm{maxi} \quad (1)$$

$$\mathrm{YR} = \lambda_{\mathrm{R}}.f_{\mathrm{R}}[(\mathrm{R} - \mathrm{minRR}), (\mathrm{RS} - \mathrm{minRS})] \text{ for } \mathrm{minRR} < \mathrm{R} < \mathrm{maxR} \text{ and } \mathrm{minRS} < \mathrm{RS} < \mathrm{maxRS} \quad (2)$$

where maxI, maxR and maxRS are the levels of precipitation above which further rainfall has no effect on yield increases, $f_I(.)$ and $f_R(.)$ represent assumed linear functions over the specified range of precipitation, and

$$\lambda_{\mathrm{I}} = 1 \text{ if } \mathrm{RI} > \mathrm{minRI}, \text{ and } \lambda_{\mathrm{I}} = 0 \text{ otherwise}$$

$$\lambda_{\mathrm{R}} = 1 \text{ if } \mathrm{R} > \mathrm{minRR} \text{ and } \mathrm{RS} > \mathrm{minRS}, \text{ and } \lambda_{\mathrm{R}} = 0 \text{ otherwise.}$$

Based on these relationships, and given data on yields of different plants as well as precipitation data for both normal and drought years, and assuming all other factors of production including technology are constant between the two periods, one can compute the yield gain per millimeter of rainfall (the yield loss due to drought) within the specified range of precipitation. This can then be used as the coefficient in the yield Eq. (1)[2] to estimate the yield change for each crop in each region. The basic yield plus the change in yield constitutes the actual yield of each crop in each region which then is used in modeling value added of agricultural sector in two different periods (normal and drought years) and to estimate the loss in value added of the sector given the cropping pattern (areas of each crop).

To estimate the impact of the drought on the agricultural sector in terms of value added, a linear programming model (Shahnooshi, 2004) was developed to maximize the following value added of crop products (the objective function) considering the availabilities of water, irrigated (i) and rain-fed (r) land areas as the model constraints:

$$Max \sum_j VA_j = \sum_j \sum_i A_{ji}^*(P_{ji}^*YI_{ji} - C_{ji}) + \sum_j \sum_r A_{jr}^*(P_{jr}^*YR_{jr} - C_{jr}) \quad (3)$$

subject to the following constraints:

$$\text{water}: \quad \sum_j \left(\sum_{i=1}^{N} \delta_{ji} A_{ji} + \sum_{i=N+1}^{M} \lambda_{ji} A_{ji} \right) \le TW \quad (4)$$

$$\text{irrigated land for crop production}: \quad \sum_j \sum_{i=1}^{N} A_{ji} \le CA_i \quad (5)$$

$$\text{rain–fed land for crop production}: \quad \sum_j \sum_{r=1}^{n} A_{jr} \le CA_r \quad (6)$$

$$\text{irrigated land for fruit production}: \quad \sum_j \sum_{i=1}^{F} A_{ji} \le FA_i \quad (7)$$

$$\text{rain – fed land for fruit production}: \quad \sum_j \sum_{r=1}^{f} A_{jr} \le FA_r. \quad (8)$$

In the above relationships, TW is total cubic meters of water available from underground and surface sources. δ_{ji} and λ_{ji} are water requirements (technical coefficients) for irrigated crop i and fruit i in region j, respectively, and CA_i and CA_r are, respectively, total irrigated and rain-fed land available for crop production in Iran. Similarly, FA_i and FA_r are total irrigated and rain-fed land available for fruit production in the country. Besides the above constraints, Eqs. (1) and (2) and their related conditions are used as conditional relationships to calculate the actual yields under specified precipitation conditions.

As the objective function shows, for each region j, value added is calculated by multiplying the regional crop area of each product (A_{ji} and A_{jr}, respectively, for irrigated and rain-fed areas in ha, in region j) by the margin per ha, i.e. price (P_j, price of rain-fed products and irrigated one are the same in region j) multiplied by yield ($Y_{ji,}$ and Y_{jr}) of irrigated and rain-fed respectively, minus intermediate input costs (C_{jiR}, and C_{jrR}) per ha for irrigated and rain-fed areas, respectively. Using this model, one can compute differences in the value added of the cropping sector by comparing the maximum attainable value added in normal and drought years given all variables including crop areas unchanged between two

[2] Similarly, one can compute the coefficient for the yield function (2). These yield equations are not input-dependent production functions estimated econometrically, but simply interpolated linear rainfall response relationships.

periods. In addition, one can estimate the loss-mitigating effects of water-saving technology (such as sprinkler irrigation) as well as the change in the crop pattern in response to drought. Water-saving technology can be modeled in terms of reducing water requirements (technical coefficients) in the linear programming model. The change in crop pattern is considered by allowing the model to substitute crops with lower water requirements for those with higher water requirements. This is done by changing the land constraints for different crops to the extent that is technically plausible for cultivation.

When supplies of agricultural products decline following a drought, product prices increase and offset some decline in value added. In 1999–2000, the price of grain barley doubled shortly after the drought. However, in the longer run, such price changes in Iran are relatively small because imports are used to compensate for domestic supply declines of most agricultural products including wheat and animal feedstuffs (barley, corn, etc.), and because most product prices are controlled by government.

Following a contraction in cropping in a drought year, the output of the livestock and fisheries sectors will reduce, since crops provide inputs for the latter sectors. In turn, a decrease in value added in all these sectors constrains investment in agriculture. In addition, agricultural products are used as the raw materials in manufacturing sectors such as food and feed processing, and in the textiles sector, and, again, investment in these sectors is discouraged. Further, through the impacts on marketing and processing chains, and through income effects, activity levels in the private and public service sector depend on the production levels of the agricultural and manufacturing sectors. Therefore, value added in services, and so GDP as a whole, will be affected by drought experienced in the agricultural sector. Additionally, a fall in domestic production will result in a rise in demand for imports and a fall in exports. Finally, to the extent that domestic shortages are not offset by imports of the similar products, the deficit in supply will cause an increase in prices, which in turn will affect the welfare of the consumers. In sum, the occurrence of a drought will affect the value added of all economic sectors, sectoral investment, exports and imports, and price levels.

To estimate the economic impacts of a drought similar to that in the year 1999–2000, a relatively simple econometric model was developed to depict the linkages among the economic sectors in Iran. Several authors have tried to develop macro-econometric models for Iran since the mid-1960s, when UNCTAD (1968) developed the first model of this type. Noferesti (2000) reviewed all such studies, and formulated a model to evaluate the effects of financial policies on the macro-economy of Iran, using an error-correction model (ECM) framework (Lütkepohl, 1991) for formulating the behaviour of economic variables: our model is in line with this author's methodology. The ECM form is used for all the behavioural equations, because, as pointed out by Hendry (2001, Ch.7), as long as the variables are non-stationary and co-integrated, a unique Granger causality, seldom results in spurious regressions when adopting ECM. Several other authors have utilized the ECM framework in developing a macroeconometric model for different countries, e.g. Dreger and Marcellino (2007) and Andersen et al. (2005) for European countries, and Singh (2005) for India. In the present study, the Iranian economy was divided into four production sectors: agriculture, manufacturing, services, and the oil sector (which was not modeled as it is not much affected by changes in the other sectors). An investment function was formulated for each of the first

Table 1 – Macroeconomic model of Iran: variables and equations

Variables

ΔYA	Value added in agriculture	ΔCon	Consumption
ΔYA1	Value added in cropping (crops and horticulture)	ΔIM	Non-oil imports
ΔYA2	Value added in other agriculture	ΔEXN	Non-oil exports
ΔYI	Value added in manufacturing	ΔLCon	Lagged consumption
ΔYS	Value added in services	ΔLIM	Lagged imports
ΔYO	Value added in the oil sector	ΔER	Difference between official and black market exchange rates
ΔIAG	Investment in other agriculture	ΔIMP	Import price index
ΔIIn	Investment in manufacturing	ΔCPI	Consumer price index
ΔISV	Investment in services	ΔGDP	GDP
ΔLA2	Workers in other agriculture	ΔQMon	Money supply
ΔLI	Workers in manufacturing	LRA2	ECF in other agriculture
ΔLS	Workers in services	LRII	ECF in manufacturing
ΔKA	Capital stock in agriculture	LRSS	ECF in services
ΔKA2	Capital stock in other agriculture	LRAA	ECF in agricultural investment
ΔKI	Capital stock in manufacturing	LRRN	ECF in manufacturing investment
ΔKS	Capital stock in services	LRSV	ECF in services investment
ΔINO	Income from exporting oil	LRX	ECF in non-oil exports
ΔCRI	Credit available to manufacturing	LRM	ECF in imports
ΔCRS	Credit available to services	LRCon	ECF in consumption
ΔCRA	Credit available to agriculture	LRCPI	ECF in CPI
ΔYD	Disposable Income		

Equations

$\Delta YA2=\alpha_1+\alpha_2\ \Delta LA2+\alpha_3\ \Delta KA2+\alpha_4\ \Delta YA1+\alpha_5\ \Delta YI+\alpha_6\ LRA2$

$\Delta YI=\beta_1+\beta_2\ \Delta LI+\beta_3\ \Delta KI+\beta_4\ \Delta YA+\beta_5\ \Delta YO+\beta_6\ LRII$

$\Delta YS=\gamma_1+\gamma_2\ \Delta LS+\gamma_3\ \Delta KS+\gamma_4\ \Delta YA+\gamma_5\Delta YI+\gamma_6\ \Delta YO+\gamma_7\ LRSS$

$\Delta IAG=\delta_1+\delta_2\ \Delta INO+\delta_3\ \Delta CRA+\delta_4\ \Delta YA+\delta_5\ \Delta KA+\delta_6\ LRAA$

$\Delta IIn=\theta_1+\theta_2\ \Delta INO+\theta_3\Delta YI+\theta_4\Delta CRI+\theta_5\ \Delta KI+\theta_6\ LRRN$

$\Delta ISV=\rho_1+\rho_2\ \Delta YS+\rho_3\ \Delta CRS+\rho_4\ \Delta KS+\rho_5\ \Delta INO+\rho_6\ LRSV$

$\Delta EXN=\omega_1+\omega_2\ \Delta YA+\omega_3\ \Delta YI+\omega_4\ \Delta YS+\omega_5\ \Delta ER+\omega_6\ \Delta Con+\omega_7\ LRX$

$\Delta IM=\Phi_1+\Phi_2\ \Delta IMP+\Phi_3\ \Delta YA1+\Phi_4\ \Delta YI+\Phi_5\ \Delta INO+\Phi_6\ \Delta LIM+\Phi_7\ LRM$

$\Delta Con=\Psi_1+\Psi_2\ \Delta YD+\Psi_3\ \Delta CPI+\Psi_4\ \Delta LCon+\Psi_5\ LRCon$

$\Delta CPI=\zeta_1+\zeta_2\ \Delta GDP+\zeta_3\ \Delta QMon+\zeta_4\ \Delta IMP+\zeta_5\ LRCPI$

Note: ECF — error correction factor.

three sectors.[3] In addition, a total import demand function was formulated to represent the effects of GDP reduction, along with an export supply equation, and an equation to depict the behavior of prices within the Iranian economy. The variables and equations of the model, specified as a recursive system in an ECM framework, are presented in Table 1. The exogeneity of certain variables is justified on the basis of the structure of the Iranian economy, e.g. a relatively undeveloped services, with few spillovers. As the main sector generating foreign exchange for Iran, the oil sector has spillover effects on all other economic sectors.

The two integrated modeling frameworks outlined above are justified on the grounds of appropriateness (a programming model seems a natural approach to water-constraint analysis), simplicity (unnecessary detail was avoided) and convenience (versions of both models were readily available). Alternatives or extensions, such as multi-year or dynamic modeling, CGE modeling, and possibly labour components (see remarks in Conclusions section below), might have provided more or deeper insights, though at the cost of considerably increased modeling effort and additional assumptions, both within each of the programming and econometric models, and between them.

3. Data and variable construction

The year 1997–98 was a normal cropping year in Iran, with the long-term national average precipitation of 249 mm. For this year, and for the drought year 1999–2000, annual and seasonal precipitation data was obtained from meteorological sources, and crop yield data for crops and horticultural products (cropping sector) which together cover more than 90% of the planted land in Iran. Since there was no substantial change in other yield-affecting factors, such as the level of technology, between 1997 and 1999, the yield differences between these two years can be considered as a consequence of the differences in precipitation. Based on this, we calculated a weighted average (over provinces) of the yield changes for each product (see Table 2). The basic yields, those using planned irrigation levels without complementary rainfall, are reported in Table 3.

All other required agricultural data were collected from published and unpublished sources in the *Jahad Keshavarzi* (Ministry of Agriculture, Tehran). These data comprised: (i) prices and quantities of the various crops and fruits produced in each province, (ii) costs per ha of intermediate inputs utilized, (iii) annual water requirements per ha, (iv) the critical seasonal amounts of water for each of the plants in the different regions, (v) the maximum amount of water available for agricultural production, and (vi) total arable farm land. For estimating the parameters of the macroeconometric model, we used time series for the period 1973 to 2003 for the variables defined in the model. These data were collected from published and unpublished sources in the Central Bank of Islamic Republic of Iran.

Table 2 – Differences in yield in a drought year and a normal year

Product	Yield difference (kg/ha)	Product	Yield difference (kg/ha)
Crops on rain-fed land		*Horticultural plants on irrigated land*	
Oilseeds	345	Palm	0
Lentils	117	Apples	12.5
Cotton	33	Cherries	942
Wheat	630	Almonds	253
Barley	760	Walnuts	87
Peas	210	Saffron	2.03
		Pomegranate	611
Crops on irrigated land		Grapes	–
Wheat	678	Avocados	89
Barley	411	Citrus	17
Peas	257	Pistachios	0
Beans	–		
Lentils	68	*Horticultural plants on rain-fed land*	
Alfalfa	915	Grapes	264
Potatoes	595	Almonds	225
Rice	450	Figs	94
Corn	–		
Oilseeds	–		
Cotton	–		
Sugar beet	1467		
Cucumbers	419		
Onions	–		
Tomatoes	150		
Watermelon	0		

4. Results

The impacts of the drought on the cropping sector were calculated in three different stages, using the linear programming model. In the first stage, the effects (in terms of value added) of precipitation shortfalls in a drought year were estimated assuming that normal crop patterns (areas) prevailed, and that the effects of the shortages on the availability of underground water could be ignored. This resulted in an estimated loss of USD 1355 million. In the second stage, cropping area adjustment by farmers to reduced availability of underground water was represented by changes in farmland under summer fallow, resulting in a further value added loss of USD 167.5 million. In the third stage, a simulated shift from irrigated land to rain-fed land added a further loss of USD 82.5 million, resulting in a total loss of USD 250 million. Thus, in the worst case, the total loss in cropping and horticulture value added due to a drought such as that in 1999–2000 was put at USD 1605 million. Given that total value added of these two sub-sectors in 1999–2000 was USD 5302 million (Central Bank of Islamic Republic of Iran, 2000), this represents a loss in value added equivalent to 30.3%. Since the loss of 1605 million is due to a 110.7 mm shortfall of precipitation, one can conclude that a one millimeter of rainfall creates a value of

[3] In Iran, most investment is financed by the (public sector) Management and Planning Organization, on the basis of compensating depreciation and some net investment. Therefore, annual investment in each sector is defined as a function of capital stock in that sector (see Parhizgar, 1976).

USD 14.5 million in Iran. In other words, a 1% decrease in precipitation below the long-run average results in a 0.68% decline in the value added of the crops and horticulture sector.

To examine the effects of water-saving technology on mitigating drought losses in the cropping sector, we assumed (based on the views of experts) that farmers can save 10% of water by utilizing such a technology. Accordingly, we changed the water coefficient and expanded the total cultivable land constraint by relaxing the summer fallow land constraint to allow the model to utilize the saved water. This resulted in a reduction in the drought loss of USD 282 million or about 17.5%. In elasticity terms, this implies that a 1% increase in water availability through water-saving technology results in a 1.75% reduction in the loss of crops and horticulture value added.

In a different scenario, we investigated the effect of change in the crop pattern. To this end, we expanded the land constraints for wheat and barley by 40%, those for corn, beans, peas, lentils, cotton, sugarbeet and oilseeds by 20%, and those for rice, potatoes, onions, tomato, water melon, cucumbers and alfalfa by 10%, while keeping the total land constraint unchanged.[4] The model produced a combination of crop areas that maximized value added under drought conditions. The result of this simulation revealed that the loss in value added can be reduced by about 37.2% to USD 597 million.

To examine the consequences of the drought losses in the cropping sector (crops and horticulture) on the rest of the economy, we estimated the macro-econometric model. To test the appropriateness of the ECM framework, we followed Engle and Granger (1987) methodology. A Dickey and Fuller (1981) unit root test revealed that the model series were characterized by first-difference stationary processes, I(1). In addition, the null hypothesis of non-stationarity of the linear combination of the variables considered in each of the equations (the residuals of the cointegration regressions) was rejected at the 10% level. According to Engle and Granger (1987), when the above conditions prevail, one should use the ECM as the appropriate functional relationship between time series variables, as was done by Mansouri (2003, 2004) in a similar study for Morocco. As a result, in the present study, the equations of the ECM were estimated in a two-stage procedure, and are presented in Table 4.

As the structure of the above model shows, change in value added of the cropping sector enters the first equation as an independent variable ($\Delta YA1$). Thus, the drought shock is transmitted to the rest of the economy via this variable. Based on the estimated parameters, growth of USD 1 billion in the value added of the cropping sector results in growth of USD 178 million in rest of agriculture. Given that the total loss in value added of the cropping sector following a drought year is USD 1605 million, the total loss in other agricultural sector amounts to USD 286 million or 12.7% of GDP. This, together with the loss in the value added of the cropping sector, in turn affects the value added of the service sector through the coefficient of ΔYA in the third equation. Since a USD 1 billion increase in the value added of other agricultural sector results in growth of USD 450 million in the value added of the service sector, and given the effect of the cropping sector on the value added of the other agricultural sector, one can conclude that the decrease in the value added of the cropping sector, results directly in a decline of USD 851 million in the value added of the service sector. Based on Eq. (3) in Table 4, the service sector is also indirectly affected by the reduced value added in manufacturing following drought losses in the cropping sector. Taking into the account the indirect effect, the total loss in value added of service sector amounts to USD 1049 million (3.7%). Since the loss of USD 1605 million in the cropping sector is the result of a 110.7 mm reduction in precipitation, the above results imply that a 1 mm reduction in rainfall below the long-run average causes a USD 2.6 million reduction in the value added of the other agricultural sector and a USD 9.5 million decrease in service-sector value added.

The cropping sector contributes 70.2% of the value added of the total agricultural sector (Central Bank of Iran, 2000). According to Eq. (2), the value added of overall agriculture (ΔYA) is an important factor affecting the manufacturing sector (ΔYI); growth of USD 1 billion in value added of overall agricultural sector leads to manufacturing growth of USD

Table 3 – Basic yields on irrigated and rain-fed land for different crops

Products	Cultivated area (ha)	Yields (kg)
Wheat	109,0697	2931
Barley	245,441	2255
Rice	391,834	3427
Peas	11,047	950
Beans	45,788	1698
Lentils	6394	1109
Alfalfa	206,752	5468
Potatoes	63,434	23,370
Onions	18,228??	31,386
Tomatoes	40,516	28,158
Water melons	39,004	25,345
Cucumbers	40,037	16,938
Sugar beet	104,081	26,342
Corn	125,177	6434
Cotton	145,356	1953
Oilseeds	42,585	1404
Grapes	65,042	13,248
Pistachios	255,376	1103
Dates	75,116	3937
Apples	81,404	15,099
Citrus	116,176	18,637
Apricots	14,885	9528
Cherries	13,338	8036
Almonds	19,096	1989
Walnuts	14,260	2343
Pomegranates	21,478	12,625
Saffron	44,240	2.8
Rain-fed wheat	1,538,608	na*
Rain-fed barley	277,845	na
Rain-fed peas	226,779	na
Rain-fed lentils	56,196	na
Rain-fed cotton	22,728	na
Rain-fed oil seeds	35,575	na
Rain-fed grapes	64,474	na
Rain-fed almond	49,926	na
Rain-fed figs	2345	na

* na stands for not applicable.

[4] All numbers are based on agricultural expertise view on technical plausibility of crop substitution.

300 million. Therefore, a USD 1 billion contraction in value added of cropping sector causes a USD 210 million decline in the manufacturing sector. Given that the loss in cropping sector results in a USD 296 million decline in the value added of other agricultural sectors, the total loss in value added of the manufacturing sector amounts to USD 567 million or 7.8% of GDP. This implies that a 1 mm decrease in rainfall below the long-run average causes a loss of USD 5.1 million in the value added of the manufacturing sector in the Iranian economy framework.

Contraction in the agriculture, manufacturing, and service sectors has consequences for the investment in these sectors. In the Iranian economy, a USD 1 billion reduction in the value added of the agricultural sector results in a decline of about USD 0.1 million in investment expenditure in the agricultural sector, meaning that the loss of USD 1891 (1605+286) million in value added of the agricultural sector reduces investment expenditure in the sector by USD 189 million or 35%. Based on the coefficient of agriculture in Eqs. (5) and (6), the decline in investment expenditures in the manufacturing and service sectors following the losses in the agricultural sector, are USD 323 and 368 million respectively. Therefore, the drought shock in the cropping sector which contracts production in manufacturing and services will result in reducing the investment in these two sectors, respectively, by 12 and 3.7%.

Non-oil exports and imports are affected by drought shocks in the cropping sector, since, among other factors, these variables are functions of domestic production levels (income generated) in the production sectors. Based on Eqs. (7) and (8), a USD 1 billion decline in the value added of the cropping sector raises total imports by USD 1.22 million and reduces total non-oil exports by USD 1.01 (1.44*0.702=1.01) million.

Table 4 – Estimated macro-econometric model of Iran

No.	Equation	R^2
1	$\Delta YA2 = 121.29 + 0.001^*\Delta LA2 + 0.0013^*\Delta KA2 + 0.178^*\Delta YA1 + 0.0098^*\Delta YI - 0.53^*LRA2$	0.76
2	$\Delta YI = 52.876 + 0.0012^*\Delta LI + 0.00025^*\Delta KI + 0.3^*\Delta YA + 0.1^*\Delta YO - 0.55^*LRII$	0.80
3	$\Delta YS = 5107 + 0.000047^*\Delta LS + 0.0006^*\Delta KS + 0.45^*\Delta YA + .35^*\Delta YI + 0.11^*\Delta YO - 0.68^*LRSS$	0.64
4	$\Delta IAG = 81.11 + 0.017^*\Delta INO + 0.25^*\Delta CRA + 0.1^*\Delta YA + 0.0014^*\Delta KA - 0.73^*LRAA$	0.91
5	$\Delta IIn = -116.4 + 0.21^*\Delta INO + 0.57^*\Delta YI + 0.62^*DCRI + 0.0033^{**}\Delta KI - 0.78^*LRRN$	0.62
6	$\Delta ISV = -288.8 + 0.351^*\Delta YS + 0.46^*\Delta CRS + 0.0026^*\Delta KS + 0.13^*\Delta INO - 0.7^*LRSV$	0.78
7	$\Delta EXN = -406.6 + 1.44^*\Delta YA + 0.23^*\Delta YI + 0.1^*\Delta YS + 0.711^*\Delta ER - 0.045^*\Delta Con - 0.17^*LRX$	0.78
8	$\Delta IM = 400.85 - 10.254^*\Delta IMP - 1.22^*\Delta YA1 + 0.83^*\Delta YI + 0.097^*\Delta INO + 0.2^*\Delta LIM - 0.92^*LRM$	0.90
9	$\Delta Con = 654.44 + 0.174^*\Delta YD - 3.4^*\Delta CPI + 0.33^*\Delta LCon - 0.78^*LRCon$	0.44
10	$\Delta CPI = 2.7 - 0.00053^*\Delta GDP + 0.0015^*\Delta QMon + 0.32^*\Delta IMP - 0.33^*LRCPI$	0.97

Note: All coefficients are statistically significant at the 95% or higher level except the intercepts in Eqs. (5) and (6), the coefficient of ΔCRS in Eq. (6), the coefficients of ΔYS and ΔCon in Eq. (7), and the coefficient of ΔCPI in Eq. (9).

Table 5 – Estimated drought impacts on the Iranian economy

		Total loss (million USD)	Loss (%)
Value added:	Cropping	1605	30.3
	Other agriculture	286	12.7
	Manufacturing	567	7.8
	Services	1049	3.7
	Total (GDP)	3222	4.4
Investment:	Agriculture	189	35.0
	Manufacturing	323	12.0
	Services	368	3.7
Non-oil exports		2958	75.6
Imports		1487*	18.5*
Consumption		561	2.0
Consumer Price Index (CPI)		13.6*	9.6

Note: * indicates a rise in value.

This means that the drought-led USD 1605 million decline in the value added of the cropping sector causes directly and indirectly a rise of USD 1487 million (18.5%) of the total non-oil imports and a USD 2958 million (75.6%) decrease in total non-oil exports in Iran. This implies that a 1% decline in rainfall results in a 0.4% increase in total non-oil imports and a 1.7% decrease in non-oil exports.

Finally, changes in the value added of all three sectors sum to a USD 3221 million or 4.4% change in overall GDP. Through effects on disposable income, these in turn affect the level of consumption and the consumer price index as indicated by Eqs. (9) and (10), respectively, by 2 and 9.6%. Table 5 summaries the effects of the USD 1605 million drought losses in the cropping sector on the rest of the economy. Production of all three sectors is adversely affected by this phenomenon. The cropping sector, the sector most dependent on the climate, experiences the largest decline in its value added. Livestock, the main other agricultural sub-sector, with a share of 18% in overall agricultural value added, depends heavily on crop products, with inputs ranked in the second place. Manufacturing and services are also hit, although with lower degrees. Furthermore, investment is reduced, especially in agriculture. Additionally, reduced supplies of food increase the consumer price index by nearly 9.6%.

Since most of the non-oil exports in Iran consist of agricultural commodities, mostly fruits and nuts, a drought year harms Iranian total exports substantially. In addition, Iran is a net importing country of many agricultural products such as barley, corn, and other feeding materials. The domestic production of these products is considerably affected by the precipitation shortfalls. A drought shock in the cropping sector such as that in 1999–2000, results in an 11.2% increase in total Iran imports.

5. Conclusions

Using a linear programming model of Iranian agriculture and a four-sector error-correction model (ECM) of the Iranian economy, this paper has explored the macro-economic effects of a severe drought (a 45% decline from average precipitation) such as occurred in Iran in 1999–2000. That drought is estimated to have reduced value added in the cropping subsector by 30% and in the rest of agriculture (livestock, fisheries and forestry) by 13%. The manufacturing and service sectors lost 8 and 7% of value added respectively. Investment in agriculture, manufacturing and services declined by 35, 12 and 4% respectively, and overall GDP dropped by about 4.4%. Non-oil net imports increased, and the consumer price index rose by nearly 10%. Elasticity-type response coefficients to a 1% reduction in precipitation are also reported. Sensitivity analysis based on water-saving technology which would allow greater use of summer fallow land suggests that a 10% reduction in water usage per ha can mitigate drought losses by about 17.5%.

Based on the results of this study, and the likelihood of more frequent severe water shortages in Iran (whether due to droughts or increasing demands from rising populations and incomes), it seems wise to invest more in water reservoir projects and on water-saving technology in the Iranian agricultural sector. In addition, serious consideration should be given to measures designed to prevent, mitigate and adapt to drought in Iranian cropping agriculture. As Hijmans (2003) suggests, drought-resistant cropping such as fairly simple modifications in potato growing (changed planting dates, and different maturity-date cultivars) can reduce likely climate change-induced losses in future decades from 40% to 13%.

This paper has not explored non-economic aspects of drought, including those impacting on labour productivity, such as increased human morbidity due directly or indirectly to lack of water, or to polluted water supplies. Numerical assessment of these drought effects would require a much expanded modeling framework, and/or heroic assumptions about the extent and distribution of such problems. This is not to underplay the significance of such considerations, especially in dry and/or low-income areas, where climatic change is likely to have severe impacts (Ch. 4 in Bates et al., 2008).

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