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Climate impact on agroeconomy in semiarid region of Armenia

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Abstract With 21 % of gross domestic product (GDP) in agricultural sector and having consistently experienced natural disasters (e.g., drought, flood), Armenia is very vulnerable to climate and its change. Given the fact that 63 % of the entire land is planted with grains, this study primarily focuses on the market for wheat flour and bread. Economic welfare loss due to drought episodes is calculated using the economic data integrated with climate measures. Economic data are utilized for the period 1995–2011 (obtained from Statistical Office of Armenia) and specifically include the quantity produced and consumed of wheat flour and bread combined with mean prices, population income, GDP in the agricultural sector, GDP in the planting sector, and governmental expenditure on subsidies. Climate data include temperature and precipitation during the period 1966–2011 (obtained from National Hydrometeorological Service of Armenia). The analysis includes three main components. The first utilizes a market framework that analyzes the impact of climate on equilibrium prices and quantities as well as trade and tax effects. The second employs a logarithmic utility function to estimate the effective insurance policy for the agricultural sector using risk management strategies. Lastly, a macroeconomic model has been developed to assess the efficient sum of governmental expenditure on subsidies and irrigation during the drought episodes and during the mean climatic conditions. All three parts of the study are developed for the first time.

Keywords Agricultural production · Climate change · Drought indices · Market equilibrium

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1 Introduction

Mountainous regions within developing economies where the dominant sector is agriculture are extremely vulnerable to climate (EPA 2013). The South Caucasus region (defined as Zone VI by Bouma et al. 1998), with complex topography and developing economy (former Soviet countries including Armenia, Georgia, and Azerbaijan), requires an assessment of the climate impact on the economy and necessitates the development of the models to maximize the economical production within the terms of climate change.

Being a mountainous country, Armenia is vulnerable to climate and its change (SNCCC 2010). According to climate change scenarios developed for Armenia, under IPCC (2007) A2 and B2 greenhouse gas (GHG) emission scenarios, temperature is predicted to increase by 4.8–5.7 °C and precipitation is predicted to decrease by 8–27 % by 2100. The decreasing precipitation together with the increasing temperatures is leading to accelerated desertification process with significant impacts on sectors dependent on climate. The influences (especially water shortages) are noted in the agricultural sector, which accounts for 21 % of gross domestic product (GDP). After the collapse of the Soviet Union, state farms were disbanded, and small family firms emerged; nearly 340,000 relatively small farms produce 98 % of all crops and livestock. Both the urban and rural populations are dependent on family farm's agricultural productivity to avoid food shortages, limit food imports, and keep food prices stable. This small scale of agricultural firms makes food and, hence, earnings and income more vulnerable to climate and climate change, regarding higher expenses for adaptation and mitigation measures in relation to limited profits and scare financial means.

Nearly half of the arable land in Armenia requires irrigation, which places agriculture at risk in existing environmental conditions: temperature increase (0.85 °C increase during the last 80 years); precipitation decrease (6 % decrease compared to the 1961–1990 baseline period); increased evaporation from the soil due to secondary salinization of land plots; inadequate moisture to support plant growth; and heavy rains and floods in northern parts and droughts in southwest parts (estimated 107 million US dollars agricultural damage from 2000 through 2005). These environmental conditions are accompanied with water losses due to irrigation inefficiencies, crop fertility, overgrazing, inappropriate cultivation practices, and limited land resources (IEI 2013).

Being an arid region, there is a heavy reliance on irrigation especially in the southwest of the country, where more than 80 % of the value of agricultural product is currently obtained from irrigated land. Even though the region is rich in the river and lake basins (14 river basins and 100 small mountain lakes, among which is the largest Sevan Lake), the water shortages for agricultural production are remarkable, which might be explained with the inefficient building of irrigation systems done during the years of the Soviet Union (SNCCC 2010).

The water shortage will become more severe in the frames of climate change due to higher temperatures, and precipitations decrease accompanied with evaporation increase from river and lake basins. Unfortunately, there are no local models available yet, but some regional models (based on global circulation models) have been assessed for the South Caucasus region (ECMWF—European Centre for Medium-Range Weather Forecast; HadCM3—Hadley Centre (United Kingdom); GISS ER—Goddard Institute for Space Studies, NASA, USA; ECHAM—European Centre Hamburg Model; and GFDL—Geophysical Fluid Dynamic Laboratory) (ASHMS 2011c). One of the recent studies done in this region (Mannig et al. 2013) investigated to some extent climate change variations in the Caucasus carried out with the Regional Model (REMO) calculated for SRES A1B scenario nested in the global model ECHAM. The authors showed that both summer and winter average temperatures will rise up to 5 K (Fig. 1), and the precipitations are likely to decrease in the region, but here the different models are not consistent. River runoff was projected utilizing WEAP model (Water Evaluation and Planning System; Source, IEI 2013). Figure 2 shows that all of the basins are projected to have higher mean annual runoff under the low-impact scenario in annual basis; in contrast, all of the Armenian basins across all of the scenarios (low, mid, and high) will get reduced mean runoff during the irrigation season (May–September) by the year 2040. Regional models (downscaled from global circulation models) suffer from the shortcoming of not considering topography and land use classes, thereby leading to unreliable results. This will be accounted for in the future with the prospect of utilizing a microscale model (METRAS, developed in Hamburg, Germany) as a means to extend this study presented here.

Despite some differences, in general, all the models indicate temperature increase and precipitation decrease in the region, which will enhance evaporation, reducing river flow (25 % reduction; SNCCC 2010) and decreasing the level of Sevan Lake (it has already decreased by 19 m during the last 3–4 decades), hence making the water shortages even larger.

1.1 Dependence of crop production on climate

To assess the crop vulnerability to economic and climatic factors, it is important to evaluate yield and price risks, acknowledging that yield risk is relatively higher than price risk in this region. To compare the yield and price risks, also known as shocks, the standard deviation of each variable must be normalized with its mean value. In certain countries where droughts are relatively frequent (e.g., Australia, Spain), the yield risk (on the country scale) is relatively higher (0.3 is the yield risk and 0.17 is the price risk) (OECD 2011). In Armenia, we calculate the yield risk as 0.22 and the price risk as 0.18, illustrating the yield dependency on climatic conditions.

Climate is a complex discipline. Therefore, the variable(s) to measure and estimate the dependency of crop production on climate is of critical importance. Alexandrov and Hoogenboom (2000) estimated crop dependency on temperature and precipitation, developing genetic grain cereal model (CERES) to calculate crop phase and morphological development as a function of temperature and daylight length. Previous studies have investigated yield production dependent on an array of agroclimatic parameters that consist of soil temperature and humidity at different depths, water content at field capacity, permanent

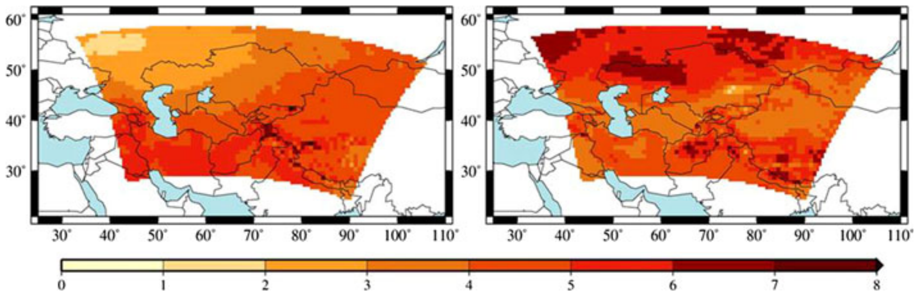

Fig. 1 Temperature changes in °C: mean 2071–2100 to 1971–2000, summer (**a**) and winter (**b**), all changes are significant at the 95 % level (REMO—ECHAM, ½°; *source* Mannig et al. 2013)

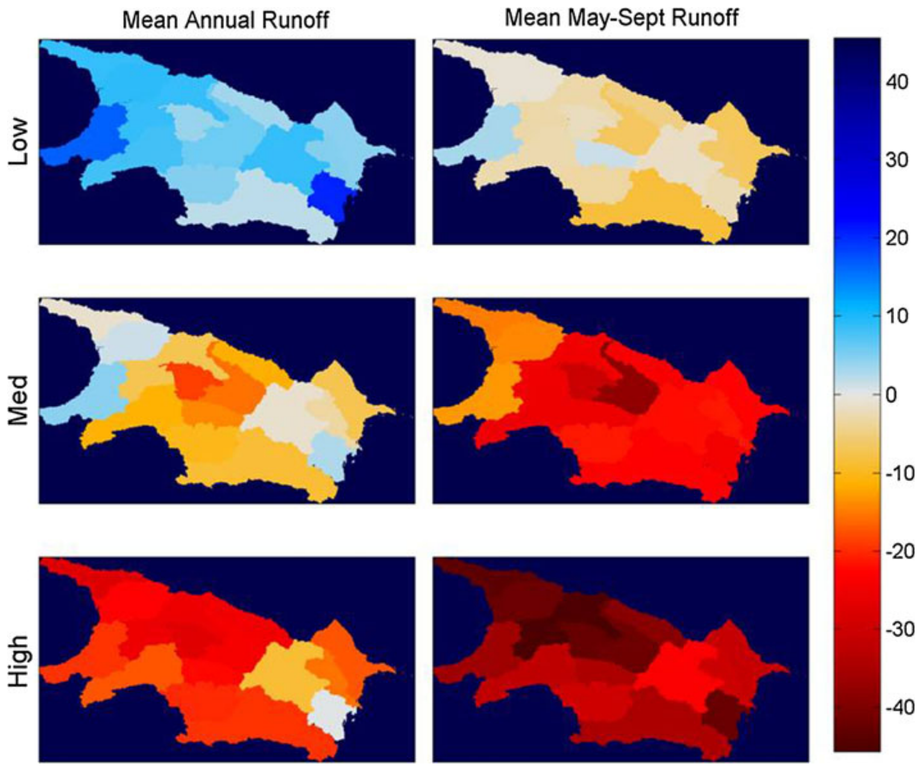

Fig. 2 Mean percentage change in 2040s runoff relative to historical baseline (*left* all months, *right* the period from May to September) projected with WEAP model (*source* Industrial Economics 2013)

wilting point, snow coverage, evapotranspiration, stomata and stand resistance, leaf area index (Bannayan et al. 2011), average solar radiation, average minimum and maximum temperature, water balance (precipitation–evapotranspiration), phase length, number of heat days or frost days (Holzkämper et al. 2011), and river runoff (Hattermann et al. 2011). Given that these agroclimatic factors are highly collinear in econometric analyses dealing with these issues in various countries throughout the world, traditional multiple regression is not feasible (Farrar and Glauber 1967; Abrar et al. 2004; Molua and Lambi 2007; Ngondjeb 2013). While dealing with climatic parameters, one of widely used methods is principal component analysis, reducing dimensionality of a dataset that consists of a large number of interrelated variables by retaining as much as possible variation (Melkonyan 2011). Another model already implemented in Armenia is AquaCrop (developed and maintained by FAO). It is parametric-oriented and is simple to evaluate the impact of climate change and adaptation strategies on crops and the effects of water stores and crop water demand (IEI 2013). But, there are several limitations here: uncertainties in water quality in future, future construction schedule for irrigation and storage projects, future storage capacity of reservoirs, and development of national agricultural system. These limitations should be investigated in future more properly.

These kinds of models only show the dependencies between variables and group them into clusters, without forming a new one-dimensional variable. Thereafter, the preferred approach is to estimate drought indices (NDMC 2013). Eitzinger et al. (2010) indicated that drought stress can be calculated through increased evapotranspiration. Fortunately, however, there exist standard drought indices such as the Palmer index, Crop Moisture Index, Surface water supply index, and standardized precipitation index (SPI) (Guttman 1998; Agnew 2000; Heim and Richard 2002). Some of these indices require various input data (e.g., Palmer index), and others are too limited, requiring only one input which is typically precipitation (e.g., SPI). For this study, another index, namely the Selyaninov hydrothermal ratio, is utilized because of the fact that both precipitation and the temperature during the vegetative period (April to September) are both combined into a single index (Breustedt et al. 2008; Leblois and Quirion 2013).

1.2 Three economic frameworks for analysis

This study utilizes three interrelated economic frameworks for analysis. The first focuses on the market for wheat flour and bread in Armenia through the empirical estimation of demand and supply that include climate variables in addition to the traditional determinants. More specifically, demand and supply of wheat flour and bread are estimated as functions of prices, income, and climate measures. As indicated in the previous section, the Selyaninov hydrothermal coefficient is used as the primary climate variable, which includes not only precipitation, but also temperature during the vegetative period. This coefficient was chosen in order to be able to transfer the market equilibrium model for future climate, where temperature and precipitation (used in this coefficient) are the main indicators to project. Accordingly, the equilibrium price and quantity are estimated, along with estimating the economic welfare loss due to drought in the year 2006, when the supply of grain decreased significantly. On the basis of market equilibrium, trade liberalization and effective tax system are also analyzed, estimating the sum of money being spent on import and the sum of money to be taxed. An effective tax system is vitally important for the Armenian government for budget management, from which subsidies may be funded for the agricultural sector to compensate for lost production during the drought episodes.

The second framework expands this analysis by employing utility functions to estimate the effective insurance policies in the agricultural sector in terms of the drought probabilities in the region. There is a lack of insurance system in Armenia, and the farmers are unable to afford insurance, but subsidized programs would greatly stabilize their incomes and improve their capacity to reinvest in farming. A resulting problem is to maximize the utility function of agricultural sector (especially the planting sector) by estimating the effective governmental expenditures on the systems of irrigation and subsidies.

With these two analyses, the macroeconomic implications of these frameworks are studied in the third model framework to examine the current situation in agricultural sector as the basis for estimating the costs on irrigation and subsidies in terms of the future climate.

In the conditions of dry climate in the region, which is estimated to become even drier (SNCCC 2010) with extreme high temperatures, frequent droughts, and limited water resources, the government of Armenia will face a crucial problem to organize the expenditures on irrigation and subsidies so that to obtain maximum profitability in the GDP in agricultural sector.

This study is unique, and all the components have been developed for the first time (even though one limitation is the lack of reliable climate change scenarios, which are being developed at this stage); hence, a comparison of the results within literature study is not available.

2 Research area

Armenia is a small country in the southern Caucasus, with an area of nearly 29,800 km^2 and population of about 3.2 million (NSSRA 2012). It is an extremely mountainous country with a well-defined mountain relief and ramified river drainage. The average territorial elevation is 1,800 m, the maximum height is 4,090 m (Mount Aragats), and the minimum is 375 m above sea level (ASHMS 2011a) (Fig. 3).

Of 29,000 km^2, approximately 13,000 km^2 is used for agriculture. Arable lands and pastures are the highest share in the whole agricultural territory, representing 35 and 49 %, respectively. Approximately 40 % of the land being used for agricultural production must be regularly irrigated, causing a high water demand (Fig. 4).

The territory of Armenia consists of 11 political districts or states. Twenty-one percent of GDP is formed in agricultural sector. Grains (55 % of agricultural production at the total sown area), fruits and grapes (30 %), potatoes (11 %), and vegetables (6 %) are the most important agricultural products in Armenia being sown especially in the states of Ararat and Armavir (located in western region) because of their relatively low heights above sea level (up to 1,000 m) (see Table 1). Given this, our analysis is concentrated on the state of Armavir. It is important not only because of the fact that agriculture is concentrated there, but also because of the fact that the presence of dry climatic conditions in the western region of Armenia makes it more vulnerable to drought conditions.

Armenia is a transitional economy due to the fact that the country was a part of the Soviet Union for 70 years. Like other former Soviet countries, former state and collective farms were downsized and transformed into cooperatives or private family farms

Fig. 3 Topographical map of South Caucasus, Armenia

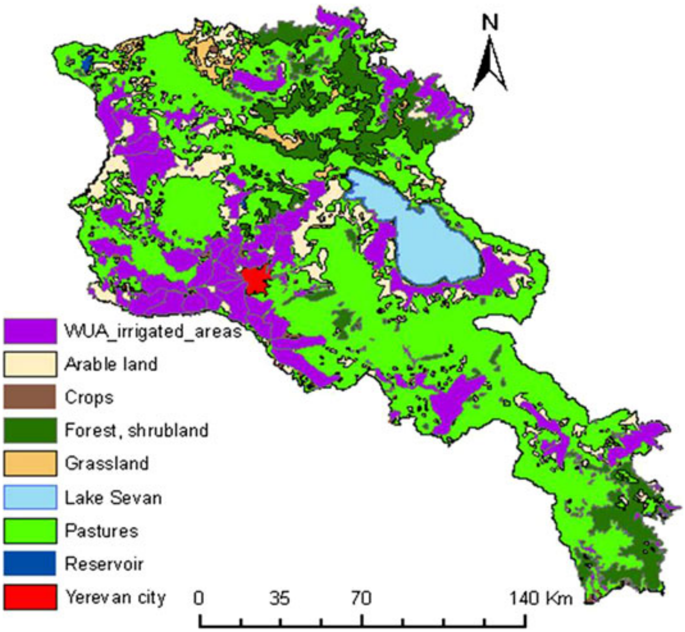

Fig. 4 Land use map of Armenia (modified from Armenian State Hydrometeorological Service 2011b)

Table 1 Production (in percent) of the main agricultural crops in different states of Armenia (modified from Statistical Service of Armenia, 2012), the highest values are marked in bold

States	Production (%)					
	Grain	Vegetables	Potatoes	Water melons	Fruits and berries	Grape
Aragatsotn	9.5	3.7	6.7	2.4	18.0	5.6
Ararat	9.6	32.1	5.7	24.8	21.1	41.6
Armavir	14.1	38.0	7.2	70.8	25.2	40.1
Gegharkunik	17.6	5.9	34.9		6.2	
Kotayk	5.5	4.7	4.5	0.2	11.2	1.3
Lori	6.9	3.3	18.3	0.1	3.0	0.2
Shirak	21.3	5.3	10.9	0.0	1.5	
Syunik	8.7	2.7	5.5	0.4	4.3	0.5
Tavush	5.3	1.6	5.4	0.6	4.6	6.8
Vayots Dzor	1.3	1.3	0.7	0.7	3.6	2.2
Yerevan	0.3	1.2	0.3	0.2	1.4	1.9

(Breustedt et al. 2008). During this process, the production technologies and practices have been affected. As such, poor technological development accompanied with adverse weather conditions makes the production process inefficient. Given this, there is an important and critical role for the Armenian government to support farms with subsidies or an effective irrigation system in an effort to increase efficiency and effectiveness, which is one of the main focuses in this study.

3 Data

3.1 Meteorological and economic data

Meteorological data (i.e., precipitation and temperature) were obtained by Armenian State Hydrometeorological and Monitoring Service (ASHMS 2011c) for the state of Armavir. The data are measured three times a day from the period consisting of the years 1966–2010. Data have been validated for quality through the use of box-plots; outliers account for no more than 1 % of the data.

Economic data (i.e., GDP in agricultural production; GDP in the planting sector; prices, quantity demanded and quantity supplied of wheat flour and bread; governmental expenditure on subsidies) are received from National Statistical Service of Republic of Armenia (NSSRA 2012). Economic data are for the period consisting of the years 1995–2012.

The data on both economy and climate (Selyaninov coefficient based on temperature and precipitation) are included in Table 2.

Information on natural disasters (e.g., floods, droughts, storms, and other extreme events) and their economic damage (in millions of Armenian drams) is provided by Armenian National Rescue Service (ANRS 2011a).

3.2 Drought indices

To examine the drought conditions, the SPI and Selyaninov hydrothermal coefficient are utilized.

Standardized precipitation index deals with the frequency distribution of the precipitation monthly sums during the vegetative period. Precipitation frequency follows a gamma distribution.

Gamma distribution is given by:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(a)} x^{\alpha-1} e^{\frac{-x}{\beta}} \tag{1}$$

For $x > 0$, α is the shape parameter, β is a scale parameter, x is the precipitation sum, and $\Gamma(\alpha)$ is the gamma function. Thom (1966) estimated α and β parameters on the basis of the maximum likelihood method:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{2}$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \tag{3}$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \tag{4}$$

From these, estimated parameters are used to calculate cumulative probability distribution for a specific precipitation event described by:

$$G(x) = \int_0^x g(x)\mathrm{d}x = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1} e^{\frac{-x}{\hat{\beta}}} \mathrm{d}x \tag{5}$$

Table 2 Data on demand, supply, price of wheat flour and bread, population income (in Armenian drams), and Selyaninov index (data of economical parameters are taken from Armenian Statistical Service, 2012; Selyaninov coefficient is calculated)

Years	Demand (D) (1,000 t)	Supply (S) (1,000 t)	Price (P) (ARM dram)	Income of ppl (mln dram) (I)	Selyaninov index
1995		561	161	289,285	0.33
1996	637	528	207	434,340	0.39
1997			219	503,569	0.29
1998		477	264	581,253	0.30
1999	532		246	628,123	0.53
2000			232	814,539	0.29
2001	494	413	219	865,159	0.52
2002	479	404	209	1,015,216	0.43
2003	494	426	226	1,165,021	0.60
2004	463	441	278	1,343,338	0.59
2005	486	435	258	1,456,509	0.54
2006	505	447	253		0.60
2007	468	442	278	1,996,915	0.36
2008	460	425		2,407,194	0.36
2009	439	434	333	2,512,205	0.68
2010	423	454	347	2,827,149	0.49
2011	420	454	381	3,064,858	
Mean	466	434	278	1,865,356	0.52

In a relatively small number of periods, there are a sufficient number of events when there was no precipitation; however, the gamma function is not defined when $x = 0$. Therefore, the cumulative distribution is modified to include these dry periods as well:

$$H(x) = q + (1 - q)G(x) \tag{6}$$

where q is the probability of no rainfall at the specific time periods.

From this, the Z transformation, and hence calculating SPI values, is done in a following way:

$$Z = \mathrm{SPI} = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for} \quad 0 < H(x) \leq 0.5 \tag{7}$$

$$Z = \mathrm{SPI} = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for} \quad 0.5 < H(x) < 1.0 \tag{8}$$

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \quad \text{for} \quad 0 < H(x) \leq 0.5 \tag{9}$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \quad \text{for} \quad 0.5 < H(x) < 1.0 \tag{10}$$

$$c_0 = 2.1; \quad c_1 = 0.8; \quad c_2 = 0.01, \quad d_1 = 1.43; \quad d_2 = 0.18, \quad d_3 = 0.001.$$

After converting gamma distribution into the normal distribution, the median corresponds to the value of 0 in the normal distribution. The values smaller than 0 represent drought conditions, and the values larger than 0 represent wet conditions. The ranking of SPI is given in Table 3 (Guttman 1998; Agnew 2000; Heim and Richard 2002).

Selyaninov hydrothermal coefficient is defined as:

$$\text{Sel coef} = \sum P \Big/ \sum T \cdot 0.1 \tag{11}$$

where $\sum P$ is the sum of the precipitation and $\sum T$ is the sum of temperature during vegetative period (April–October) (ANRS 2011b).

Precipitation frequency distribution firstly in gamma and then after using Z transformation and hence transformed into SPI is given in Fig. 5.

As explained in Table 3, an SPI value equal to 0 (on the right-hand side) corresponds to the median in gamma distribution (left-hand side). Here, SPI < -0.5 is taken as a mild drought, $-0.5 <$ SPI < -1 as moderate drought, and SPI larger than -1 as severe drought. As it can be seen from Fig. 5 (right side), moderate droughts occurred 101 times (out of possible 252 events), hence making the probability equal to 0.4. This distribution of SPI is utilized within the macroeconomic model. Detailed analysis of SPI monthly distribution (Fig. 6) showed that positive values are recorded during "wet seasons" in spring—April and May; in contrast, "dry periods" are registered starting from June in summer months. On annual basis, the driest year was 2006 (Fig. 7), and during this year, drought caused a high damage to economy. The data of this year are used in further economic analysis.

Table 3 SPI and its classification for different values

SPI	Classification
2.00>	Extremely wet
1.50–1.99	Very wet
1.00–1.49	Moderately wet
0–0.99	Mildly wet
0 to −0.99	Mild drought
−1 to −1.49	Moderate drought
−1.50 to −1.99	Severe drought
−2.00<	Extreme drought

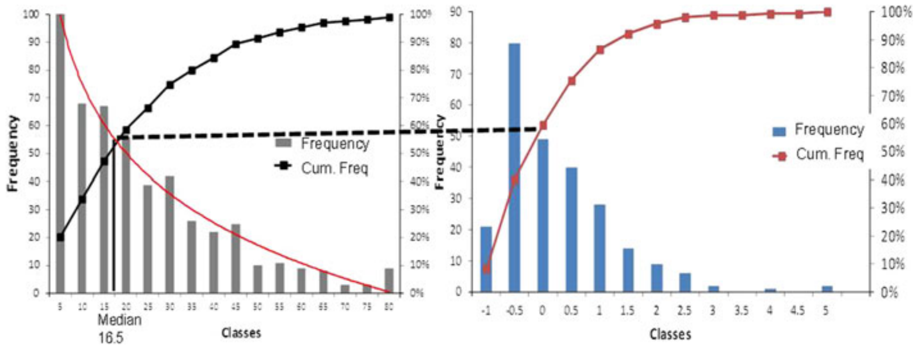

Fig. 5 Precipitation frequency (cumulative frequency) (*left-hand side*) and its transformation into SPI and its frequency (*right-hand side*) in Armavir, Armenia (1966–2010)

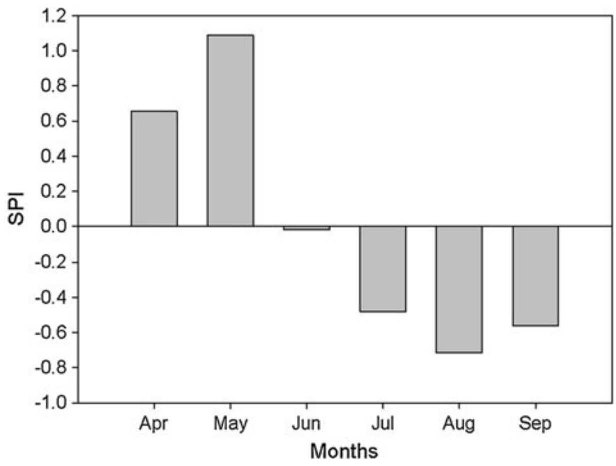

Fig. 6 SPI distribution on monthly basis; Armavir, Armenia (1966–2010)

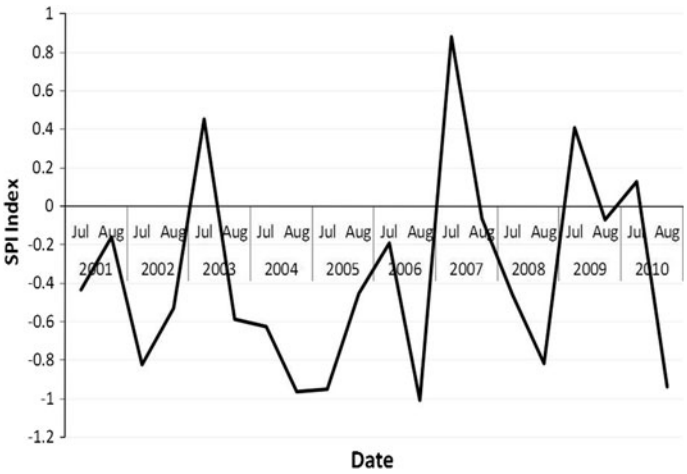

Fig. 7 SPI distribution on annual basis; Armavir, Armenia (2001–2010)

This "dryness" is accompanied with high temperatures, creating unfavorable climatic conditions for crops. To analyze these conditions, Selyaninov hydrothermal coefficient has been used. As it can be seen in Fig. 8, these two drought indices are very well correlated with each other (correlation is 0.83, with 95 % significance). The values of Selyaninov index are included in Table 2.

4 Results: models and analysis

4.1 Market model

Demand model is defined in the following way. The quantity demanded (i.e., consumed) of wheat flour and bread (Q_D) is assumed to be determined by mean price of wheat flour and

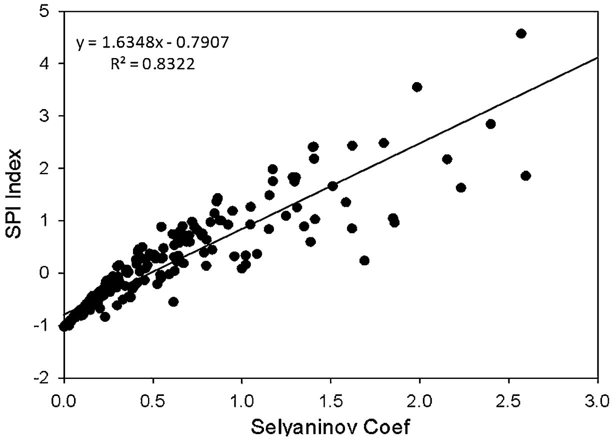

Fig. 8 Correlation between SPI and Selyaninov hydrothermal coefficient; Armavir, Armenia (1966–2010)

bread (P) and population income (I). More formally, $Q_D = D(P, I)$. The data are presented in Table 2 (here only the period 2000–2011 given the number of missing observations in prior years). From these data, we define the model with the following form:

$$Q_D(P, I) = 10500P^{-0.3}I^{-0.1} \tag{12}$$

From (12), the price elasticity of demand is -0.3, consistent with a priori expectations. Income elasticity of demand is -0.1, showing also a negative correlation between income and consumption, which is unexpected. This effect might be explained by the fact that having higher incomes, people prefer to consume more expensive products (e.g., beef) instead of bread.

For the supply model, the quantity supplied (i.e., produced) of wheat flour and bread (Q_S) is assumed to be determined by price (P) and drought index (w) (i.e., the Selyaninov coefficient). More formally, $Q_S = S(P, w)$. Using the data in Table 2, we define supply as:

$$Q_S(P, w) = 92\,P^{0.3}w^{0.2} \tag{13}$$

From (13), the price elasticity of supply is 0.3, again consistent with a priori expectations. A positive correlation between supply and Selyaninov coefficient implies that with better climatic conditions (efficient precipitation and not too high temperatures), the grain production (as input for wheat flour and bread) increases (and vice versa). As indicated previously in Fig. 8, the highly positive correlation between the SPI and the Selyaninov index indicates that both indices can be used. However, given the more comprehensive nature of the Selyaninov index (including temperature in addition to precipitation), we decided to utilize the Selyaninov index exclusively as the measure of climate.

In order to estimate constant elasticities from the demand and supply models formulated above, the natural logarithmic transformations of (12) and (13) were taken and yielded the following models:

$$\text{Demand} : \operatorname{Ln} Q_D = 9.26 - 0.3 \operatorname{Ln} P - 0.1 \operatorname{Ln} I + \varepsilon \tag{14}$$

$$\text{Supply} : \operatorname{Ln} Q_S = 4.52 + 0.3 \operatorname{Ln} P + 0.2 \operatorname{Ln} w + \varepsilon \tag{15}$$

where ε is the stochastic error term with the usual properties.

Equations (14) and (15) were estimated using regressions using the data in Table 2 and are described as follows:

$$\text{Demand}: \mathrm{Ln}\, Q_D = 7.6 - 0.24\, \mathrm{Ln}\, P - 0.1\, \mathrm{Ln}\, I \tag{16}$$

$$\text{Supply}: \mathrm{Ln}\, Q_S = 5.05 + 0.2\, \mathrm{Ln}\, P + 0.14\, \mathrm{Ln}\, w \tag{17}$$

With these regression results ($R^2 = 0.95$ for Eq. 16, statistically significant at the 5 % level, and $R^2 = 0.94$ for Eq. 17, statistically significant at the 5 % level), the actual and estimated demand and supply are presented in Fig. 9a, b). For the illustration, Ln I is constant and evaluated at the mean where Ln $I = 14.3$ and $I = 1{,}885{,}356$ from Table 2; Ln w is also held constant and evaluated at the mean where Ln $w = -0.65$ and $w = 0.52$ from Table 2.

Solving demand and supply equations together, we calculate the estimated equilibrium (*) price and quantity of wheat flour and bread in Armenia (Ln $P = 5.68$, hence $P^* = 292$;

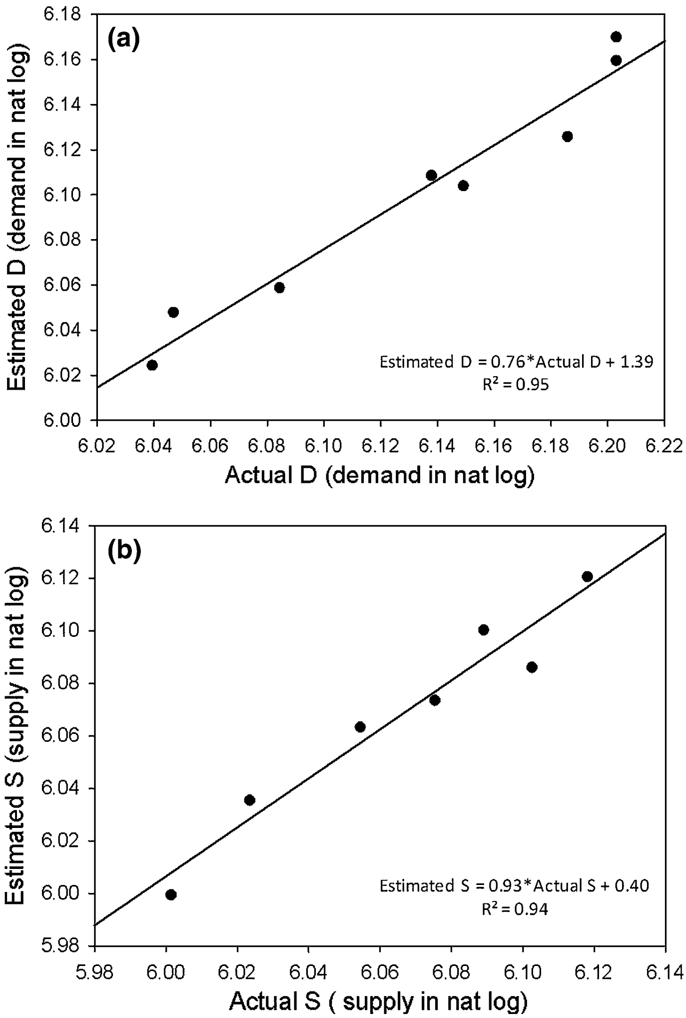

Fig. 9 Estimated and actual demand (**a**) and supply (**b**)

Ln $Q = 6.1$; $Q^* = 445$). The demand and supply curves are given in Fig. 10, where the market equilibrium represents the intersection of them.

4.1.1 Economic welfare loss analysis

To evaluate economic welfare loss due to drought, market equilibrium (Fig. 10) was used. In Fig. 11, point *B* represents the market equilibrium; point *C* corresponds to the quantity supplied in 2006, where drought episode was registered. The vertical line (from the *C* point) along the *x*-axis shows the supplied quantity ($e^{6.07}$, or 436 thousand tons). The first horizontal line along the *y*-axis (from the *C* point) shows the price at which the suppliers were ready to produce or sell ($e^{5.53}$, or 251 ARM dram per kg), and the second horizontal line (from the point *A*) shows the price the consumers would be ready to pay ($e^{5.75}$ or 314

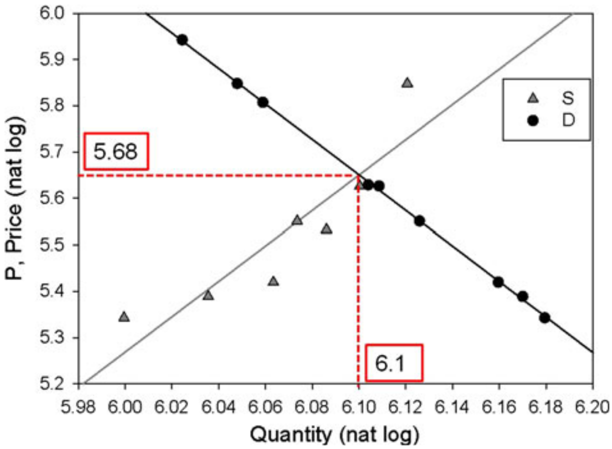

Fig. 10 Demand and supply of wheat flour and bread; market equilibrium, Armenia

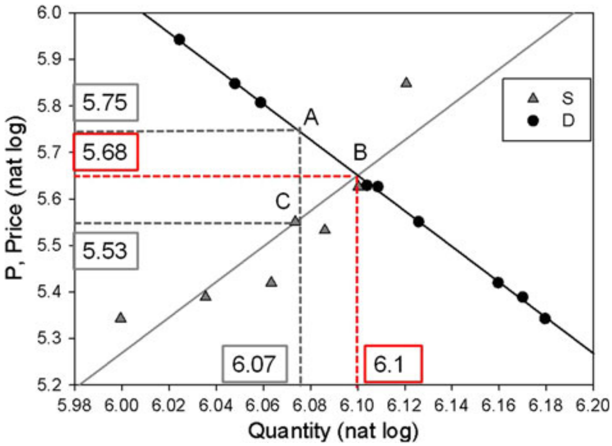

Fig. 11 Demand and supply of wheat flour and bread; market equilibrium, and economical loss due to drought in 2006

ARM dram). The *ABC* triangle represents the deadweight loss (Nicolson and Snyder 2008; Eichberger 2004).

This economic welfare (i.e., "deadweight") loss represents the area of the *ABC* triangle and can be calculated in the following manner:

$$\left(e^{5.75} - e^{5.53}\right) \cdot \left(e^{6.1} - e^{6.07}\right) \tag{18}$$

which is equivalent to (314−251)*(445−436) = 284. This results in a loss of 284 ARM dram per kg; hence, in terms of thousands of tons, the loss was 284 million ARM dram (or 7 million US$, where 1 US$ = 411 ARM dram).

4.1.2 Tax analysis

Before examining the macroeconomic model, where the main task is to optimize costs on irrigation and subsidies, it is essential to examine how these costs might be financed. Traditionally, subsidies are funded via taxes (Lipsey and Harbury 1992; Demmler 2000; Lorz 2007; Beck 2008).

The market equilibrium calculated in the previous section is $e^{6.1}$ (or 445 thousand tons) (Fig. 10). With the introduction of a tax, we must now distinguish between the price paid by the demanders (P_D) and the price received by the suppliers (P_S). As traditionally explained, the per-unit tax (t) is the "wedge" between these two magnitudes; hence, $t = P_D - P_S$ (Nicolson 2008). Considering again the situation in year 2006 (Fig. 12), the modeled quantity of wheat flour and bread was $e^{6.07}$ (436 thousand tons). If we use this as Q_D and Q_S in demand and supply Eqs. (16) and (17), respectively, and solve for P_D and P_S, we obtain:

$$\text{Ln } P_D = 5.75; \quad P_D = 314 \text{ ARM Dram}$$

$$\text{Ln } P_S = 5.59; \quad P_S = 267 \text{ ARM Dram}$$

In Fig. 12, $t = P_D - P_S$, and from the calculations, it was obtained that $P_D = 314$ and $P_S = 267$; hence, $t = 314-267 = 47$ million ARM dram or 0.11 million US$ in tax revenue. Later on, we compare this amount with optimal subsidies.

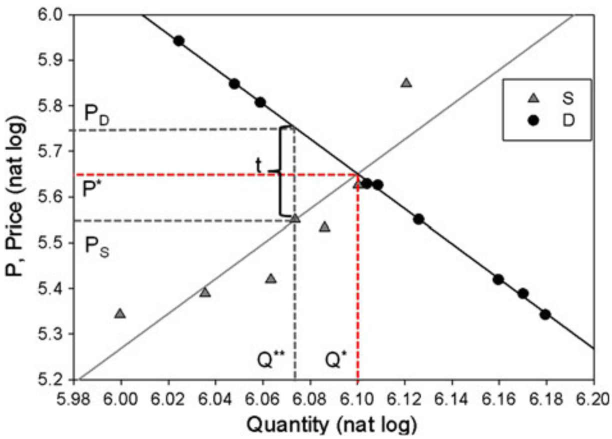

Fig. 12 Demand and supply of wheat flour and bread; market equilibrium, demand and supply prices, tax

4.1.3 Trade liberalization

As it is traditionally known, supply is not only dependent on domestic production, but also on international trade (i.e., imports and exports) (Straub 2004; Wiese 2005; Schotter 2009). Most of the former Soviet Countries signed bilateral free trade agreements with each other to support the trade (FAO 2009). Given this, Armenia imports grains mainly from Russia, and hence, the quantity and price of wheat flour and bread are dependent not only on domestic market equilibrium, but also on prices in Russia; 1,000 kg wheat flour in Russia costs 375 US$, means that 1 kg costs 154 ARM dram (1 US$ = 411 ARM dram), and 1 kg bread in Russia costs 410 ARM dram (Alibaba.com 2013), means that the mean price for wheat flour and bread is 282 ARM dram ($e^{5.64}$). Bread price is also taken into consideration because of the fact that the analysis above was based on mean prices of wheat flour and bread in order to avoid inconsistencies in further analyses, despite the fact that bread is not being imported to Armenia.

We take again demand and supply equations obtained above and input the price for Russia ($P_w = 282$ or $e^{5.64}$) and solve them to find the demanded and supplied quantities. The difference between Q_D and Q_S represents the quantity of imports. We compute:

Q_D is equal to $e^{6.11}$ or 450 thousand tons from (16)
Q_S is equal to $e^{6.09}$ or 436 thousand tons from (17)

This implies $Q_D - Q_S = (450-436) = 14$ thousand tons is imported. Multiplying this by import costs, P_w, implies $282 \cdot 14 = 3{,}948$ million ARM drams (9.6 million US$) is spent on import. These calculations are illustrated in Fig. 13 below.

4.2 Utility function and insurance in agriculture of Armenia

In this section, an insurance system in the agricultural sector in Armenia is analyzed. For that reason, logarithmic form of utility function (McAllister and Tarbert 1999; Barbera et al. 2004) in agricultural sector was taken. Formally, $U(W) = \mathrm{Ln}(W)$, where W is GDP in agricultural sector. A random year, year 2003, is selected for the analysis. During this year, the GDP (in millions of US$) in agricultural sector was 655, and the GDP in only the

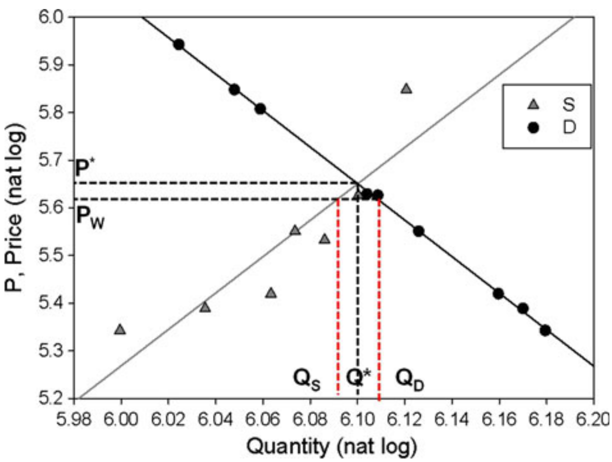

Fig. 13 Demand and supply curves of wheat flour and bread; market equilibrium, imports

planting sector was 428. The frequency distribution of SPI shown in Fig. 6 is utilized. From this, we calculated that the probability of moderate drought (when SPI < -0.5) is 0.4 (i.e., (21 + 80)/252) in the region. Thus, the expected utility, $E\,(U)$, measured in millions of US$ is calculated for the next year as:

$$E(U) = 0.6\ U(655) + 0.4\ U(655 - 428) = 0.6\ \mathrm{Ln}(655) + 0.4\ \mathrm{Ln}(227) = 19.87 \quad (19)$$

This implies that the total expected utility will be 19.87, if there is no insurance at all. If there is insurance, it should represent 40 % of the GDP in the planting sector, which means $428 \cdot 0.4 = 171$. The expected utility will be (independent of drought conditions):

$$E(U) = U(655 - 171) = \mathrm{Ln}(655 - 171) = 19.99 \quad (20)$$

Given that the expected utility with insurance (19.99) is larger than the expected utility without insurance (19.87) taking into consideration the probability of drought conditions, insurance should be purchased.

A question that follows is the maximum amount of insurance that should be purchased. The maximum amount of insurance (n) is defined as the expected utility of GDP production in agricultural sector minus this insurance amount is equal to the expected utility of GDP production in agricultural sector depending on drought conditions so that:

$$U(655 - n) = \mathrm{Ln}(655 - n) = 19.87, \quad \text{solving for } n = 229 \quad (21)$$

The difference between the maximum amount of insurance that should be purchased and the actual amount purchased equals 58 (229−171), which might be interpreted as administrative costs of insurance policies.

4.3 Macroeconomic model to maximize the production of agriculture

In the last part of this study, a macroeconomic model is developed to find the optimum governmental costs on irrigation and subsidies using the Lagrange method, which is the most appropriate to solve constrained optimization problems (Rubinov and Yang 2003) widely used in econometrics (Train 1993; Demmler 2000). If a function of two and more variables is to be optimized as a subject to any constraint, Lagrange method gives a solution with the help of Lagrange multipliers (Chow 1997).

The macroeconomic model's objective is to maximize the utility function of GDP production in agricultural sector (planting sector), where one of the main problems is to solve the optimum governmental costs on irrigation and subsidies to cover the loss due to drought conditions in terms of governmental budget constraint. This is very essential for Armenia, because of the fact that drought conditions are very frequent and, in the context of climate change, are likely to become increasing frequently. Between 1998 and 2006, Armenia experienced five drought events: Daily average air temperature anomaly was 6–8 °C during the drought episode of the year 1999, and precipitation and runoff decreases were 55–80 and 40–50 %, respectively, in 2000 (ASHMS 2011c). In 2001 and 2004, Armenia suffered shorter, less severe droughts before another longer, more damaging drought in 2006 (temperature amplitude was more than 10 °C).

Moreover, Armenia is not endowed with water resources and has a poor infrastructure to reallocate water resources from the "wetter" toward "drier" areas, which makes irrigation extremely expensive. Therefore, to solve this problem, we define:

W_0 = GDP in agriculture (planting sector)

a = Irrigation expenditure

d = Economic loss due to drought

s = Subsidies to recover the damage
π = Probability of drought
G = Governmental expenditure on subsidies
If there are no drought conditions,

$$W_1 = W_0 - a \tag{22}$$

Despite this, irrigation is required in semiarid conditions of Armenia (Fig. 4), especially in Armavir region, which is located in western region such that we expect $a > 0$.

However, if there are drought conditions,

$$W_2 = W_0 - a - d + s \tag{23}$$

in which, in addition to irrigation costs, economical loss due to drought is compensated for via subsidies.

The objective of this problem is to maximize the utility function:

$$U(W) = (1 - \pi)\, U(W_1) + \pi\, U(W_2) \tag{24}$$

whereby the first term indicates a state without drought conditions; the second indicates a state of drought conditions.

Substituting (22) and (23) into (24), we obtain:

$$U(W) = (1 - \pi)\, U(W_0 - a) + \pi\, U(W_0 - a - d + s) \tag{25}$$

The constraint is such that the costs of irrigation and subsidies cannot be larger than the governmental expenditure on subsidies:

$$a + \pi s < G \tag{26}$$

To find the optimum irrigation and subsidies, we construct the Lagrange (L) function as follows, maximizing (25) subject to (26), again assuming again a logarithmic utility function:

$$L = (1 - \pi)\, \mathrm{Ln}(W_0 - a) + \pi\, \mathrm{Ln}(W_0 - a - d + s) + \lambda(G - a - \pi s) \tag{27}$$

where λ is the Lagrange multiplier. Solving this yields:

$$\mathrm{Ln}\,(W_0 - \pi s + G)/\mathrm{Ln}\,(W_0 - \pi s + s - d - G) = (\pi - 1)/(\pi + 1) \tag{28}$$

considering again the data of the year 2006, when the drought conditions occurred. In 2006, the SPI was -1.02 (Fig. 7); if we calculate the probability of SPI being smaller than or equal to -1.02 (data are taken for the period 1966–2010), we find that the probability of severe drought like the one in 2006 is 0.15. Thus, we utilize $\pi = 0.14$.

$$W_0 = 357{,}000(\text{million ARM Dram}); \quad G = 22{,}174(\text{million ARM Dram});$$
$$d = 113{,}554(\text{million ARM Dram}).$$

Inputting these values into (27), we obtain the following results:

$$s = 489{,}181(\text{million ARM Dram})(1{,}190 \text{ million US\$});$$

$$a = 22{,}174 - 0.15 \cdot 489{,}181 = -51{,}203(\text{million ARM Dram}; -125 \text{ million US\$}).$$

This implies that 125 million US$ or more should be spent on irrigation and that the government should have paid 1,190 million US$ as subsidies to compensate for the economical loss.

If we take the mean conditions (data taken as the mean for the period 1995–2010; $W_0 = 283{,}000$ (million ARM dram); $\pi = 0.15$; $G = 21{,}513$ (million ARM dram), we can define the Lagrange function as follows:

$$L = (1 - \pi)\,\mathrm{Ln}(W_0 - a) + \pi\,\mathrm{Ln}(W_0 - a + s) + \lambda(G - a - \pi\, s) \tag{29}$$

It is important to note that we eliminate d from (29), because we replace drought conditions with normal mean climatic conditions.

Solving (29), we find that $s = 325{,}453$ (million ARM dram; 791 million US$) and $a = 21{,}513 - 0.15 \cdot 325{,}453 = -27{,}304$ (million ARM dram; −66 million US$).

The difference in subsidies in mean and drought conditions is 1,190−791 = 399 million US$. In comparison with taxes, which were modeled to be 0.11 million US$, tax revenue is insufficient to fund subsidies, and it may be necessary to seek external support for funding via grants from World Bank, United Nations Development Programme (UNDP), Food and Agriculture Organization (FAO), or other international organizations.

5 Conclusions

In this study, the effect of climate change on agriculture in a small, mountainous country, Armenia, has been estimated. The demand and supply of the wheat flour and bread were modeled as determined not only on prices and income, but also on climatic conditions (SPI and Selyaninov hydrothermal ratio based on precipitation and temperature sums during the vegetative period were taken as a variable to model the supply curve). The correlations between modeled and actual demand and supply were highly positive (above 0.94), implying that the developed demand and supply models are significantly reliable.

The first framework of our study employed a market analysis estimating demand and supply of wheat flour and bread in dependence on climatic variables, and calculating the market equilibrium price and quantity as well as the economic welfare (i.e., "deadweight") loss due to drought. Year 2006, having the minimum SPI value of −1.02, was taken as a representative drought episode. It was estimated that during this year, deadweight market loss was 7 million US$. Using the same demand and supply model for the other main crops for Armenian agriculture (e.g., grapes, potatoes), nearly 90 % of the whole agricultural loss can be estimated. This is critically important for a country where 21 % of GDP is formed in agricultural sector and which frequently experiences dry episodes. Using the same estimated demand and supply model, it was estimated that the tax revenue generated during the "worst-case scenario" (i.e., drought episodes) can approach 0.11 million US$, which can be allocated to subsidies as compensation. Because of the fact that supply is dependent not only on domestic production but also on imports/exports, the trade impact on market equilibrium was also calculated. It was shown that approximately 9.6 million US$ is spent on import costs. This information is important for decision-makers to calculate dependency of the Armenian economy on world prices; in the event of a shortage of domestic supply/production due to climate change, more unfavorable climatic conditions will lead to a shift to grain production.

The second analysis employing a logarithmic utility function allowed for an analysis of the optimal amount of insurance in the agricultural sector to avoid risk of GDP loss in the planting sector due to drought conditions. It was shown that the expected utility with insurance is higher than the expected utility without any insurance when the probability of drought is 0.4 (for severe episodes as well as relatively mild droughts with SPI < -0.5). It was estimated that effective insurance should be 229 million US$, which represents approximately 30 % of the GDP in the planting sector; this result seems plausible given the probability of drought is 40 %.

In the third component of analysis, a macroeconomic model was developed, the aim of which was to maximize the utility function of the GDP in agricultural (planting) sector, finding the optimal governmental expenditure on irrigation and subsidies in terms of severe drought and mean climatic conditions (severe drought was defined for an SPI < -0.1, as in the year 2006). The results showed that during the drought conditions, the government should provide 1,190 million US$ in subsidies and an additional 125 million US$ for irrigation to cover the loss of GDP in the planting sector. In comparison, during the mean climatic conditions (database during 1966–2010), governmental expenditures on subsidies are estimated to be 791 million US$ along with an additional 66 million US$ for irrigation. Thus, the difference in subsidies during drought and mean conditions approximates 400 million US$, and the difference in irrigation costs during drought and mean conditions equals almost 60 million US$.

The key factor in providing this critical economic support rests with the Armenian government. This public action is essential in order to combat fight climate change in region through the adaptation and mitigation mechanisms. At the private sector level, these mechanisms include installation of small-scale rainwater storage tanks in the yards. In terms of public sector, there are greater opportunities, such as building dams and reservoirs to increase water storage capacity by 1–2 billion cubic meters, upgrading the irrigation water distribution system to reduce losses, extending the existing irrigation system to cover more arable lands, or raising the public awareness to deal with water shortness related to climate change. Assessing adaptive capacity of Armenia is challenging, because of the fact that it reflects a wide range of socio-economic, policy, and institutional factors combined with climate change uncertainties at the farm, regional, and national levels. In addition, financial resources are the most limiting factors, as most adaptation measures require relatively large-scale investments, as demonstrated by the results of this study. The main financial problems are limited access to credit for farmers and decreasing agricultural support from the Armenian government, despite the fact that it appears to be sufficient based on the results of this study. In the present, however, there are some attempts to protect farms in the region. For example, “The Wheat Seed Production Development Program” allocated 1.44 million US$ to produce high-quality seeds from 2010 to 2014 (IEI 2013). Nevertheless, farmers consistently face problems to attain subsidies for agricultural inputs, due to the fact that tax revenues (as evaluated in this study) would be insufficient to fund the estimated subsidies. Given this, it is a cause for external support from international organizations such as the World Bank, UNDP, and FAO to assist the Armenian government in order to combat climate change with the objective of maximizing GDP in agricultural sector. One of the most important recent efforts is the cooperation between Armenian government and the Millennium Challenge Corporation (the MCC; project budget is 112 million US$, the goals) to solve irrigation problems and water supply in Armenia through rehabilitation of six main channels, renovation and resizing of 68 pumping stations, and rehabilitation of the Ararat Valley drainage system. It is through this and other related projects that will allow Armenia to meet the climate challenges of the agricultural system in the future.

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