



RESEARCH ARTICLE

Determinants of Barley Output Supply Response in Ethiopia: Application of Ardl Bound Cointegration Approach

Abera Gayesa Tirfi* 

Department of Agriculture and Animal Health, University of South Africa, Ethiopia Regional Learning Centre, Ethiopia

Abstract: This study investigated barley output supply response determinant factors in Ethiopia. An ARDL bound test approach was employed as a method using secondary data from 1981-2020. The study demonstrated that barley output supply was affected positively and significantly by zero-order lagged seasonal rainfall and crop growing period temperature. The study supports the findings of researchers who reported that warming temperature followed by an increase in the amount of rainfall had a positive impact on barley output supply. The positive impact of temperature was induced because of a rise in the ocean and earth's surface average temperature, causing more evaporation that increases overall rainfall while reaching over the highland areas. Studies confirm that ENSO and moist winds coming from the Atlantic and Indian Oceans influence the occurrence of rainfall in the western, southeastern, central, and northern highlands of Ethiopia. The study further exhibited that CSMRF and CGPMT had a positive effect on barley output both in the long-run and short-run, implying that climate parameters have minimal effect on barley production. Non-climatic variables demonstrated that both lagged and current year's producer prices had a positive significant effect on barley output supply in both the long-run and short-run, implying that barley output supply is highly responsive to any price incentive strategies announced before re-allocation of the area towards barley cultivation. Conversely, the study explored that the use of fertilizer in first-order lag had a negatively significant impact on barley output supply in both seasons; implying that increased use of fertilizer in lagged periods may reduce barley output as a result of inappropriate fertilizer application by farmers. The results generated by this study are a useful addendum to the repository of knowledge on the elasticity of crop supply at an aggregate level, which can be used in designing strategies and measures for the mitigation and adaptation of climate change.

Keywords: Changing climate; Supply response; Barley output; ARDL model

*Corresponding Author:

Abera Gayesa Tirfi,

Department of Agriculture and Animal Health, University of South Africa, Ethiopia Regional Learning Centre, Ethiopia;

Email: abera.gayesa@gmail.com

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1. Introduction

Changes in climate factors in terms of warmer temperature and variability in seasonal rainfall patterns have been reported as the main factors reducing agricultural production^[1]. Numerous studies concluded that climate change has posed a strong effect on agricultural output in most of sub-Saharan Africa, including Ethiopia^[2]. Researchers reported that the negative effects exerted due to climate change are anticipated to be more severe in developing countries where food insecurity is a major problem since rainfall is the only source of moisture for soil to meet the water requirement of crops in agricultural production practices^[3]. Agricultural production and its performance in Ethiopia also depend on the pattern of seasonal climate parameters out of which seasonal rainfall such as *short/belg-season* and *long/main-season* rainfalls are key factors in local food production systems, including barley crop^[4].

Barley (*Hordeum vulgare* L.) has been reported as the fourth most important cereal crop in the world in terms of production^[5]. In terms of volume of production, it ranks fourth in the world and fifth in Ethiopia^[6]. It was used by ancient civilizations as food for humans and animals, as well as to make alcoholic beverages. According to CSA^[7], the barley crop is considered as a major cereal crop in Ethiopia accounting for 9% in terms of both the area cultivated under cereal crops (0.95 million hectares) and the volume of total annual cereal production (2.378 million tons). Shreds of evidence show that Ethiopia is considered a center of barley diversity^[8] having diverse landraces and local varieties cultivated under a wide spectrum of land races as a result of its adaptation capability to diverse and harsh climatic conditions and soil types. Such a wide diversity is assumed to be contributed a result of long-term geographic isolation since barley is considered a founder of Old World Agriculture and has been assumed to be cultivated in Ethiopia for the last 5,000 years^[9]. In Ethiopia, barley is currently cultivated at altitudes ranging from 1,400 meters to 4,000 meters above sea level (m.a.s.l) which have an extremely variable climatic and edaphic environment^[10].

Barley is cultivated in all regions of Ethiopia. The most important barley-producing regions are Shewa, Arsi, Bale, Gojam, Gonder, Welo, and Tigray. "Belg" season barley is also produced in Wollo, Shewa, and Bale. The estimated production of barley between 1981 and 2020 was 1.08 and 2.38 million tons respectively, which showed an increase of about 220% over the years.

However, barley production in Ethiopia is constrained by several problems such as climate change (high inter-annual rainfall variability and increasing temperature), unpredictable drought stress, poor soil fertility, water

logging moisture stress, low yield potential of currently grown cultivars, and infestation of diseases, insect pests and weeds^[11]. Among these factors, climate change significantly affects the production of the barley crops. Nowadays, the incidence of climate change of the world is widely agreed upon among the scientific community. The Intergovernmental Panel on Climate Change (IPCC) assessment has confirmed that anthropogenic activities are changing the climate system of the world and regions which may remain to do so^[2]. In the last century, the impacts associated with surface temperatures on the physical and biological systems were increasingly being observed. The findings inform that climate changes may lead to environmental changes, such as a rise in sea level, and alterations of climatic zones due to warmer temperatures and variation in rainfall patterns.

Some African countries, including Ethiopia, are vulnerable to the severe impacts of changes in climate derived as a result of limitations in capacity and access to mitigation and adaptive resources. Most of these countries are considered the ones most susceptible and vulnerable to climatic changes in the world^[12,13]. In Ethiopia, barley production is highly dependent on rainfall, since the contribution of irrigation is estimated to be less than 1% of the country's total cultivated land area under barley. Hence, the impact of these climate changes on the production and supply of barley output should be studied to provide detailed information to researchers and policy planners. There is a scarcity of such empirical studies having a national scope on the impact of climate change on barley production in Ethiopia. The study aimed to investigate the determinant factors influencing barley output supply response in Ethiopia. The results of the study could be used for future planning of the mitigation and adaptation responses to be taken.

2. Materials and Methods

2.1 Description of Study Area

Located in the Horn of Africa, Ethiopia's latitudinal and longitudinal locations are between 3° to 15° N and 33° to 48°E, respectively. According to the World Bank^[14], the country is bordered with Sudan, Eritrea, Djibouti, Somalia, Kenya, and South Sudan. Ethiopia is administratively divided into four levels: regions/city administrations, zones, woredas, and kebeles; kebele being the last grassroots administrative unit. According to the population projection of the United Nations Population Funds^[15], the Ethiopian population has reached 117.90 million with an annual growth rate of 2.6 percent.

Barley, the theme of this study, is among the most im-

portant food crops grown in the country. Shreds of evidence show that the major barley growing belts in the country include: Oromia, Amhara, Tigray, and Southern Nation Nationality and Regional State, which supply about 99.9% of the total national barley production ^[16]. Zone-wise, it is grown mainly in the zones of Arssi, Bale, Shewa, Wollo, Gojam, and Gonder ^[17] (see Figure 1 for the map).

According to Muluken and Jemal ^[18], the wheat crop optimally grows the best at higher locations ranging from 2000 meters to 3500 meters above sea level. Barley crop is mostly grown during two consecutive seasons: the *short/belg-season* and *main / meher-season* at the higher elevations of Dega Agroecologies. In Ethiopia, the crop is substantially grown and supplied by smallholder subsistence farmers, who mostly grow local seed varieties with either little or no application of modern inputs like fertilizers, pesticides, and herbicides.

In Ethiopia, barley is mainly grown during long-rainy/meher season from June to September when the amount of crop growing period rainfall ranges between 180 mm to 400 mm depending on the altitudinal and geographic location ^[19]. Although the crop mainly grows in the highlands, it can also be grown in a subtropical climate characterized by hot, humid summers and cool to mild winters. Barley best suits a temperature of 12-15 °C during the crop growing period and about 30 °C at maturity time. The crop cannot tolerate frost at all stages of growth, particularly at the flowering stage. The incidence of frost at the crop flowering stage highly affects the yield of the barley crops.

2.2 Data Type and Sources

The data selected for this study included barley output,

the area allocated under barley cultivation, quantity of chemical fertilizers and improved barley seeds consumed, and producer price of the barley crop. These nationally aggregated time series secondary data were obtained and compiled from Agricultural Sample Survey Reports of the Ethiopian Central Statistical Agency (CSA) for the period 1981 to 2020. Furthermore, secondary data on climatic parameters (seasonal temperature and rainfall) for the observation period have been obtained from the Ethiopian National Meteorological Agency (NMA). Weather stations considered representative from barley crop growing belts were selected (12 stations) and crop growing period rainfall and temperature data have been taken as recorded in the NMA database. Specifically, average monthly data covering the crop growing period (F-S) were taken. Historical producer prices of barley crops for the observation period have also been compiled from the FAOSTAT database and CSA.

2.3 Empirical Model Selection and Specification

2.3.1 Variables Considered for Investigation

In this study, the variables considered for investigation included climatic and non-climatic variables that affect output supply response of barley crop. From the climatic variables, temperature and rainfall were included in the study since it was assumed that these variables exert substantial impact on barley output supply response. Furthermore, producer price, fertilizer, and land area were selected from the non-climatic variables. Labor and farm machinery are variable inputs that must have been included in the study but excluded since there is no time series data that matches the other variable inputs. The conceptual structure of this investigation is depicted in Figure 2.

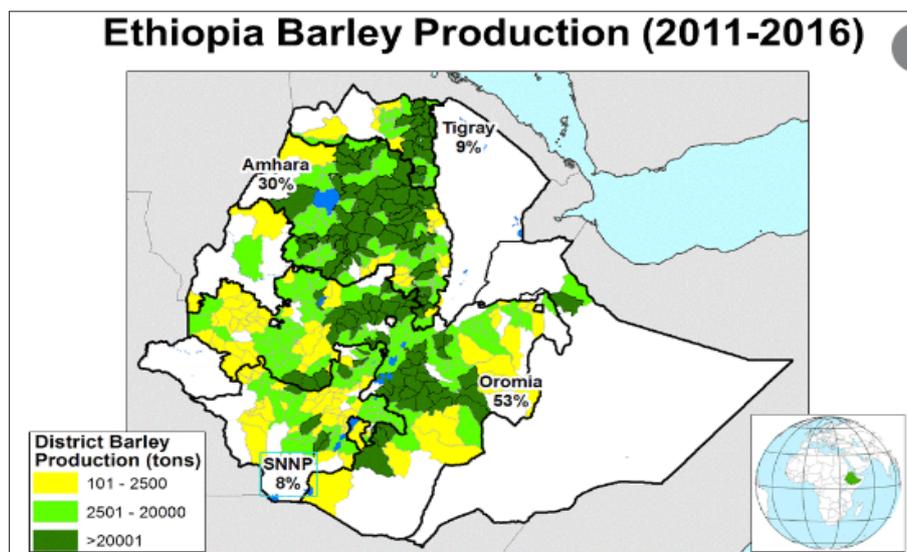


Figure 1. Major barley growing belts of Ethiopia.

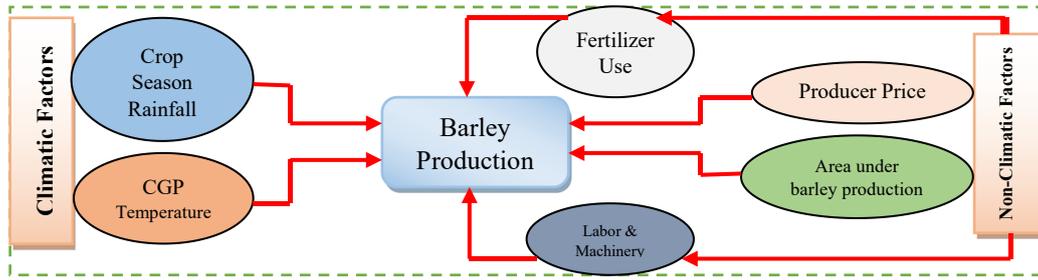


Figure 2. Conceptual structure of the investigation.

2.3.2 Model Review and Selection

To measure the impacts exerted by climatic and non-climatic factors on crop output supply response, researchers have employed different analytical models. Among the models, the general circulation models (GCMs), the Cobweb, Ricardian, and ARDL models are models widely used in empirical studies of supply responses. The GCMs are the most complex climate prediction models developed to predict what would happen to climate around the world in response to a wide variety of changes in the concentrations of greenhouse gases in the atmosphere [20]. However, the GCMs have limitations such as poor knowledge on the ocean circulation processes, lack of knowledge on cloud formation and feedbacks, crude spatial resolution, and inability to simulate current regional climate factors accurately [21].

The Cobweb Model is the lag between production decisions and the realization of demand and market prices [22]. According to Serena Brianzoni (2018), the cobweb model is a dynamical system that describes price fluctuations as a result of the interaction between demand function, depending on current price, and supply function, depending on expected price [23]. The theory focuses on analysis of price fluctuations in market (demand side) which may lead to reduction of food grains production (supply side). However, the Cobweb model has weaknesses; viz. price divergence being unrealistic and not empirically seen. As this study focuses on supply side factors, particularly temperature and rainfall as well as physical inputs like fertilizer and area under barley production, the Cobweb model has not been considered for the study.

The Ricardian model analyzes a cross section of farms under different climatic conditions and examines the relationship between the value of land or net revenue and agro-climatic factors [21]. The model was applied by researchers in the valuation of the contributions made by the environmental factors to farm income by regressing land values on a set of environmental inputs where net revenue or price of land represents farm income. Though the Ricardian model measures climatic factors against value

of land, it possesses weaknesses such as non inclusion of non-climatic factors and impossibility of getting perfect measures for such variables [24], non inclusion of price effects, and does not account the fertilization effect of CO₂ concentrations.

The ARDL Model is an ordinary least square (OLS) based model which is applicable for both non-stationary time series as well as for times series with mixed order of integration. The ARDL approach developed by Pesaran, et al. [25] as modified from the previous traditional cointegration technique was documented by Johansen and Juseline [26]. The model is considered as the best econometric method compared to others to estimate short-run and long-run impact of explanatory variables on output supply response of crops [27,28]. The ARDL approach enjoys several advantages over the others such as its appropriateness for generating short-run and long-run elasticities for a small sample size, affords flexibility about the order of integration of the variables, and suitable for the independent variable in the model which is I(0), I(1), or mutually cointegrated [29]. In view of these, the ARDL Model was selected for the current study.

2.3.3 Model Specification

This study applied an ARDL bound cointegration approach proposed by Pesaran, et al. [25] to examine the impact of climatic and non-climate input variables on barley output supply responses.

To find the relationship between dependent and independent variables, the following general form of the ARDL model was constructed:

$$\text{BaPro}_t = \alpha_0 + \sum_{i=1}^p \beta_1 \text{BaPro}_{t-i} + \sum_{i=0}^q \beta_i X_{t-i} + U_t \quad (1)$$

where BaPro_t represents barley production, BaPro_{t-i} represents barley output supplied in year t-i, X_{t-i} represents explanatory variables in year t-i, t represents the time from 1981 to 2020, and β₀, β₁, ... are coefficients of variables included in the model, and U_t is disturbance term. In this study, it was considered that the relationship between the independent and explanatory variables is expected to take

the following functional form:

$$BaPro_t = f(BaPro_{t-1}, BaPri_t, BaAr_t, FertQ_t, CSMRF_t, CGPMT_t) \quad (2)$$

where $BaPro_t$ is barley output measured in million tons; $BaPro_{t-1}$ is barley output in first-lag order, $BaPri_t$ is producer price of barley output in ETB, $BaAr_t$ is land area allocated under barley cultivation, $FertQ_t$ is fertilizer quantity used in barley production, $CSMRF_t$ is crop season mean rainfall in millimeters, and $CGPMT_t$ is crop growing period mean temperatures in degrees Celsius.

By converting all the variables in Equation (2) into natural log form, the model is expressed as below:

$$\ln BaPro_t = \beta_0 + \beta_1 \ln BaPro_{t-1} + \beta_2 \ln BaPri_t + \beta_3 \ln BaAr_t + \beta_4 \ln FertQ_t + \beta_5 \ln CSMRF_t + \beta_6 \ln CGPMT_t + \varepsilon_t \quad (3)$$

where $\ln CSMRF_t$ is the log of crop season mean rainfall in mm, and $\ln CGPMT_t$ is the log of crop growing period mean temperature in °C. In addition, ε_t represents the disturbance term. To generate some long-run relationships, Equation (3) is hereby modified as:

$$\ln BaPro_t = \alpha_0 + \sum \alpha_1 \ln BaPro_{t-i} + \sum \alpha_2 \ln BaPri_{t-i} + \sum \alpha_3 \ln BaAr_{t-i} + \sum \alpha_4 \ln Fert_{t-i} + \sum \alpha_5 \ln CSMRF_{t-i} + \sum \alpha_6 \ln CGPMT_{t-i} + \varepsilon_{t-i} \quad (4)$$

In case the variables are found cointegrated, the model exemplifies the existence of an error correction representation. After establishing the above long-run relationship between variables, the Error Correction Model (ECM) can be derived from the ARDL model (Equation (4)) through simple linear transformation to find the short-run elasticity coefficients, which integrates short-run adjustments with long-run equilibrium. The short-run elasticity coefficients can be estimated using the following Dynamic ARDL Error Correction Model (ECM):

$$\Delta \ln BaPro_t = \beta_0 + \sum \beta_1 \Delta \ln BaPro_{t-i} + \sum \beta_2 \Delta \ln BaPri_{t-i} + \sum \beta_3 \Delta \ln BaAr_{t-i} + \sum \beta_4 \Delta \ln Fert_{t-i} + \sum \beta_5 \Delta \ln CSMRF_{t-i} + \sum \beta_6 \Delta \ln CGPMT_{t-i} + \psi_i ECT_{t-i} + \varepsilon_{t-i} \quad (5)$$

where Δ represents the first difference while ψ_i is the coefficient of ECM for short-run dynamics. ECM shows the speed of adjustment in long-run equilibrium after a shock in the short-run. In this study, the investigator used the general to a specific approach to select an optimal lag length for the ARDL model.

Before estimating the ARDL bound test using the models established above, the data series on the selected variables should be tested to detect the presence of unit root and long-run cointegration. To this end, an Augmented Dickey-Fuller (ADF) and Philips-Perron (PP) tests have been considered the best approach^[30,31] and used the models to test the presence of unit root in the data series. To estimate the bound tests, all the variables included in the model must be stationary at $I(0)$, $I(1)$, or both. Neverthe-

less, researchers noted that the presence of unit root in data series implies that the analyst may obtain spurious results from analyzing them at their original level^[32,33].

Next to the stationarity test, a cointegration test has been conducted to detect the presence of a stable equilibrium relationship between the variables included in the model as proposed in Enders^[34]. If the presence of cointegration is confirmed with the model for at least two $I(1)$ series and some $I(0)$, the variables can be added to the ARDL model for the estimation which may not alter the $I(0)$ characteristics of the error term. In this study, cointegration analysis was carried out using the Johansen procedure as recommended by Akter and Hong^[35], which first defines an unrestricted vector autoregression (VAR). All of the analyses have been conducted using Eviews 9 Econometric Software.

3. Results and Discussion

3.1 Results of Preliminary Time Series, Specification, and Robustness Tests

Before the estimation of the ARDL model, appropriate tests have been carried out to detect the existence of unit root and long-run co-integration in the data series. Table 1 presents the results of unit root tests conducted on the time series data using ADF and PP approaches. The results imply that log barley output and log fertilizer quantity used in barley production exhibited stationarity at the first-order difference ($I(1)$). Conversely, log producer barley price, log area under barley crop, log CSMRF, and log CGPMT were stationary at level ($I(0)$). The result, therefore, demonstrated a mixture of level-order ($I(0)$) and first-order ($I(1)$) integration of variables^[36].

Whenever the time series data exhibit a mixture of $I(0)$ and $I(1)$, most investigators propose to apply ARDL modeling as the best approach to estimate the coefficients of the parameter included in the models^[37]. To apply the ARDL approach, cointegration bounds test, model stability test, and variance error correction model (VECM) has to be conducted to test the presence of *long-term* co-integration, models' goodness of fit, presence of serial correlation, and model misspecification^[37].

Table 2 presents the outcomes of the cointegration bound test. It can be seen from the table that a linear combination of the variables in the regression model was stationary since the F-statistics exceeds the upper bound at the 5% critical value. This implies that barley output and its determinants are cointegrated, exemplifying the existence of a long-run *relationship* among the variables in the model.

Table 1. Time series unit root test results for barley output and related independent variables.

Variable	ADF						PP						Result
	Level		First Difference				Level		First Difference				
	t-Stat	P-value	C. Value	t-Stat	P-value	C. Value	t-Stat	P-value	C. Value	t-Stat	P-value	C. Value	
LnBaPro	-2.2735	0.4378	-4.2187	-8.6119***	0.0001	-4.2119	-2.0962	0.5317	-4.2119	-9.3237***	0.0000	-4.2191	I(1)
LnBaPri	-2.2660***	0.4416	-4.2119	-5.7388***	0.0002	-4.2191	-2.2649***	0.4422	-4.2119	-6.2363***	0.0000	-4.2119	I(0)
LnBaAr	-3.6455**	0.0387	-3.5297	-8.5007	0.0000	-4.2191	-3.6395**	0.0392	-3.5298	-19.265***	0.0000	-4.2191	I(0)
LnFert	-2.9416	0.1613	-3.1964	7.2393***	0.0000	-4.2191	-2.9228*	0.1668	-3.1964	-13.1899***	0.0000	-4.2191	I(1)
LnCSMRF	-4.9210**	0.0015	-4.2119	-6.5636***	0.0000	-4.2436	-4.8858***	0.0017	-4.2119	-20.979***	0.0000	-4.2191	I(0)
LnCGPMT	-18.986***	0.0000	-4.2119	-20.0798	0.0000	-4.2191	-16.239	0.0000	-4.2119	-54.222***	0.0000	-4.2191	I(0)

Note: ***, ** and * indicates 1%, 5% and 10% level of significance.

Table 2. Estimated cointegration equations for barley output response.

Dependent variable	Type of test	Test statistics	Critical values	Conclusion
Barley output response	Wald test	4.2844**	4.130	Long-run cointegration exists

Note: ** statistically significant at 5% level.

To test the robustness of the ARDL model, diagnostic tests such as non-normality, serial correlation, and heteroscedasticity were conducted. The results of the diagnostic tests for the barley output response equation are presented in Table 3. It can be seen from the table that the p-values for normality (Jarque-Bera), serial correlation (Breusch-Godfrey Lagrange Multiplier (LM)), and heteroscedasticity are greater than a 5% level of significance. The results imply that the residuals are normally distributed; there is no evidence of serial correlation; no autoregressive conditional heteroscedasticity (ARCH).

Table 3. Residual properties of barley output response equation.

Type of test	Test statistic	Test statistic value	Probability
Normality test - Histogram	Jarque-Bera	3.43526	0.17794
Serial Correlation (LM)	Obs*R-squared	13.4639	0.05720
Heteroscedasticity (ARCH)	Obs*R-squared	11.3876	0.5784

In addition to the above diagnostic tests, the stability of long-run estimates has been tested using the cumulative sum of recursive residuals (CUSUM) and cumulative squares of recursive residuals (CUSUMQS) test. Table 4 shows CUSUM stability test results. As can be seen from the table, the model does not suffer from any form of misspecification. Equally, the plot of CUSUM test shown in Figure 2 reveals that the estimated parameters are stable over the observation period at a 5% level of significance.

Table 4. CUSUM stability test results.

Dependent Variable	F-statistic	Probability	Conclusion
Log barley output	0.46382	0.6349	No indication of misspecification

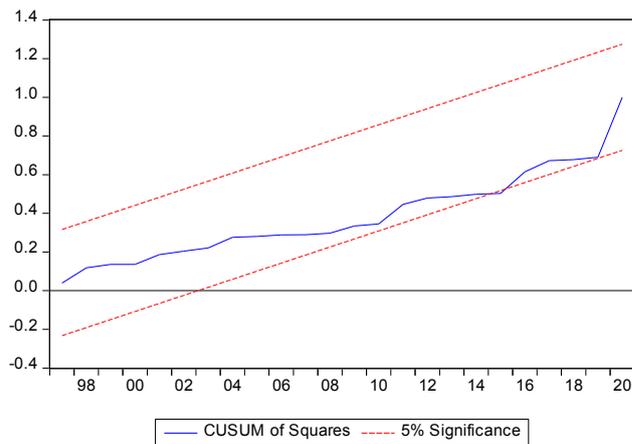


Figure 3. Plot of cumulative sum of squares of recursive residuals.

3.2 Impact of Climate and Non-Climate Parameters on Barley Output Supply Response

This study was organized to examine the long-run and short-run impacts that climatic and non-climatic factors exert on barley output supply response. An ARDL model selected for the study has been estimated for both climatic (CSMRF and CGPMT) and non-climatic parameters (lagged barley output, barley producer price, land area allocated for barley cultivation, and quantity of fertilizer

consumed on barley production). Main-season/meher rainfall and improved barley seed have been initially incorporated into the model but dropped since both have high serial autocorrelation and multicollinearity with other variables. Equally, the irrigated area under barley cultivation was dropped because the total land area allocated under barley cultivation encompassed an irrigated area as well. The effect of the irrigated area under barley cultivation should be treated separately from the total land area allocated under barley crop to avoid double counting and to know their impact contribution individually.

The ARDL model with lag length (1, 0, 0, 1, 0, 0) was selected as optimum to estimate the regression coefficients for the variables included in the model. It was found that the ARDL regression model demonstrated good fitness to the barley output supply time series data, with high values of adjusted R^2 (0.779). Based on the value of adjusted R^2 , the explanatory variables explained 77.9% of the variation in barley output supply. Furthermore, the Durban-Watson showed no evidence of serial autocorrelation. The F-test does not show the presence of any heteroscedasticity of the residual. The tests, therefore, exemplify that the model becomes viable and fits at lag length 1 and first-order differences.

Table 5 presents the estimated regression coefficients of the ARDL model for barley output supply against the determinant variables. The result shows that climatic factors had a positive impact on the current barley output supply both during previous and current years. In this respect, the current year's barley output supply was affected positively and significantly by the amount of zero-order difference in crop season mean rainfall (CSMRF) and crop growing period mean temperature (CGPMT). The result implies that a 1% increase in CSMRF and CGPMT individually boosts barley output supply by 0.47% and 2.27% respectively. This shows that crop season rainfall is among the main determinants of barley output supply in Ethiopia.

This result is inversely related to research results recorded globally by other investigators, the majority of which demonstrated increasing temperature associated with decreasing rainfall^[38]. The current study finding supports the findings of researchers who reported that a warming temperature followed by an increase in the amount of rainfall had a positive impact on barley output supply. As can be seen from Figure 3, crop growing period mean temperature in this study exhibited a significant (at 1% level) rising trend in barley growing areas followed by increasing crop season mean rainfall in the same areas.

The positive impact of temperature can be explained that as the average surface temperature rise, more evaporation arises, which increases the overall rainfall while reaching the highland and mid-highland areas of Ethiopia. Some study reports confirm that the so-called "El Nino-Southern Oscillation (ENSO)" and the moist wind coming from the Atlantic and Indian Oceans influence the western, south-eastern, central, and northern highlands of Ethiopia; which bring moisture from the oceans^[39]. This finding is also in conformity with Fischer and Velthuisen^[40] who in their examination of the impact of climate change on Kenya reported that higher temperatures exert a positive impact in the highland areas.

Among the non-climatic inputs, regression coefficients were estimated for lagged barley output (previous year's output), current year's barley price, land area under barley cultivation, and fertilizer used in barley production. The estimates demonstrated that the current year's barley price, land area under barley cultivation, and fertilizer used had a positive impact on the current year's barley crop output supply. However, only the producer price of barley had a significant impact on the current year's barley production. The result implies that a 1% increase in the current year's producer price of barley will increase barley output supply by 0.7%. Equally, the previous year's (zero-order difference) producer price demonstrated a highly significant positive impact on the current year's barley output supply in which a 1% increase in producer price of barley last year will increase the current year's barley output by 0.82%. Conversely, the use of fertilizer in its first-order lag (previous year) had demonstrated a negative and highly significant (at 5% level) impact on barley output supply, in which a 1% change (increase or decrease) in fertilizer quantity used leads to a decrease of barley output by 0.017%. Furthermore, lagged barley output (first-order lag) exerted a positive and significant (at 1% level) impact on the current year's barley output supply. The result shows that a 1% change in the quantity of previous years' barley output would decrease the volume of the current year's barley output by 0.38%.

From the results of non-climatic factors, it can be concluded that the current barley output supply is positively and significantly responsive to both the current and previous year's producer prices. Barley producer price change or price incentives announced before land area allocation to specific crops had a significant and positive contribution in boosting the current year's barley output supply.

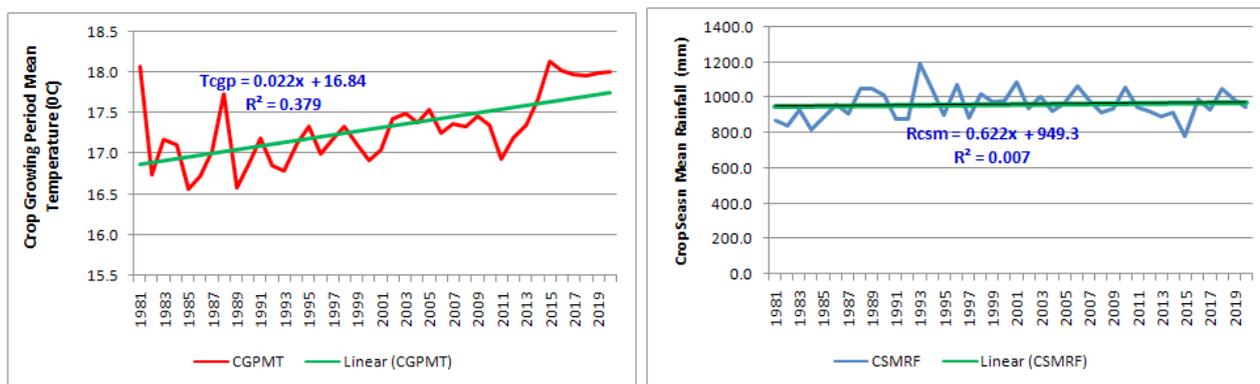


Figure 4. Trend of CGP mean temperature and CSM rainfall in barley growing areas.

Table 5. Estimates of regression coefficients for ARDL model of barley output supply response.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Cons	-3.24905	3.56716	-0.91083	0.3714
LNBAAPRO(-1)	-0.2928***	0.09994	-2.93004	0.0073
LNBAAPRI(-1)	0.6955***	0.16548	4.20280	0.0003
LNBAAR(-1)	0.0252	0.03266	0.77163	0.4479
LNBFERT(-1)	0.1054	0.07360	1.43225	0.1650
LNCSMRF(-1)	0.2319	0.21385	1.08438	0.2890
LNCGPMT(-1)	0.4676	1.05533	0.44306	0.6617
D(LNBAAPRO(-1))	-0.3787***	0.11631	-3.25630	0.0034
D(LNBAAPRI)	0.8220***	0.10730	7.66077	0.0000
D(LNBAAR)	-0.0278	0.06776	-0.40977	0.6856
D(LNBFERT)	0.0193	0.06897	0.27907	0.7826
D(LNBFERT(-1))	-0.174**	0.07787	-2.23457	0.0350
D(LNCSMRF)	0.4715***	0.14154	3.33140	0.0028
D(LNCGPMT)	2.26702**	0.85321	2.65706	0.0138
R-squared	0.8565	Mean dependent var		0.02455
Adjusted R-squared	0.7787	S.D. dependent var		0.13759
S.E. of regression	0.0647	Akaike info criterion		-2.36011
Sum squared resid	0.1006	Schwarz criterion		-1.75679
F-statistic	11.0159	Hannan-Quinn criter.		-2.14545
Prob(F-statistic)	0.0000	Durbin-Watson stat		2.28889

Note: *, ** & *** indicate significance at 10%, 5% and 1% level.

Since the cointegration test confirmed the presence of long-run cointegration among the variables included in the model, long-run elasticity coefficients have been estimated for the barley output determinant variables. Table 6 presents estimated long-run elasticity coefficients of the climate and non-climate variables included in the barley output ARDL model with a lag length of (1, 0, 0, 1, 0, 0). The estimated elasticity coefficients of all climatic and non-climatic variables, except the log of lagged barley output, demonstrated a positive relationship with the dependent variable in the long-run. Nevertheless, only barley producer price had demonstrated a positively significant impact on the supply of barley output in the long-run. This implies that a 1% rise in producer price of barley output will boost barley output supply by 0.54%. Conversely, log barley output included as lagged (first-order lag) explanatory variable exerted a negative and significant (1% level) impact on the current year's barley output supply in the long-run. This implied that a 1% change (decrease or increase) in first-order lagged output will decrease barley output by 0.23%.

The study result exhibited that average crop season rainfall and crop growing period mean temperature exhibited a positive influence on the supply of barley output, although it is statistically non-significant. This implies that climate parameters have minimal impact on the supply of barley output in the long-run. The reason for this result is that barley is grown during the main rainy season when rainfall is relatively plentiful and the temperature is relatively cool. Furthermore, barley is grown in the highlands and mid-highlands where the temperature is naturally cool and has a moderate to high amount of rainfall.

The Error Correction Model which engages short-term fluctuations in the long-run has been estimated employing the ARDL bounds test approach. The outcomes of the elasticity coefficients for the variables with lag length (1, 0, 0, 1, 0, 0) model are presented in Table 7. The results show that CSMRF and CGPMT had a positive and significant influence on the current barley output supply in the short-run. This indicates that a 1% increase in CSMRF and CGPMT would boost barley output supply by 0.34% and 0.32% respectively.

Furthermore, non-climatic factors included in the model showed mixed results in the short-run. Accordingly, the log producer price of barley (at zero-order difference) showed a positively significant effect on barley output supply in the short-run. This indicates that a 1% increase in log producer price at zero-order difference would lead to an increase in barley output by 0.66%. This specifically implies that barley output supply is highly responsive to any strategy of price incentive announced before re-

allocation of the land area towards barley cultivation in the short-run. Conversely, the elasticity coefficients of log area and log fertilizer used at zero-order differences demonstrated a negative effect on barley output supply in the short-run. Nevertheless, only fertilizer quantity used in barley production had a significant effect on barley output supply. The result indicates that a 1% increase or decrease in fertilizer quantity used would decrease the quantity of barley output supply by 0.13% in the short-run. The result implies that increased use of fertilizer in lagged period (last year) will reduce the current year's supply of barley output. This was achieved since farmers in Ethiopia do not use fertilizer as per recommendations of the extension service. Equally, any incentivized barley price in zero-order difference will affect barley output supply positively, i.e. price incentive announced during the previous year will encourage producers to allocate more land and boost barley output supply.

On the other hand, the lagged error correction term which captures the speed of adjustment towards long-run equilibrium exemplified the correct sign and magnitude. The speed of adjustment was found to be -0.948 which is highly significant (1% level) and indicates the speed of adjustment to be back to the long-run equilibrium after a short-run shock on barley crop output and climate variables. It is crucial to note that the coefficient of -0.948 precisely means that it takes 1.05 years ($1/0.948$) for the barley crop output to return to its equilibrium position following a shock. The estimated coefficient (ECT_{t-1}) also portrays that 94.8% of the disequilibrium created will be corrected within 1 year.

3.3 Comparison of the Study with Other Studies

The results of this study are analogous to the study results of various researchers based in the country as well as in other countries. Among these researchers, Dumrul and Kilicarslan^[41] in their study on the economic impacts of changes in climate on agriculture in Turkey reported that log average temperature had a positive and significant impact on agricultural GDP. In contrast to theory, positive effects of warmer temperatures on selected crops have also been demonstrated by Lobell, et al.^[42] and Schlenker and Roberts^[43], although only below the threshold of temperature.

Equally, Chandio, et al.^[44] in their study on the relationship between climatic and wheat production in Turkey reported that rainfall has exerted a positive influence on wheat production in the long-run, although insignificant. The result implies that a 1% increase in precipitation level would lead to an increase in wheat production by 0.06% in the long-run. However, their findings are contrary to

Table 6. Long-run estimated elasticities of parameters in barley output supply model.

Variable	Coefficient	Std. Error	t-Statistic	P-value
Constant	-2.51316	2.73879	-0.91762	0.3679
lnBaPro(-1)	-0.22649***	0.059793	-3.788003	0.0009
lnBaPri	0.53797***	0.102486	5.249228	0.0000
lnBaAr	0.01949	0.024653	0.790720	0.4369
lnFert	0.08154	0.05632	1.44784	0.1606
LnCSMRF	0.17938	0.168013	1.067625	0.2963
LnCGPMT	0.36167	0.810883	0.446021	0.6596
R-squared	0.85646	Mean dependent var		0.02455
Adjusted R-squared	0.77872	S.D. dependent var		0.13759
S.E. of regression	0.06472	Akaike info criterion		-2.36011
Sum squared resid	0.10054	Schwarz criterion		-1.75679
F-statistic	11.01587	Hannan-Quinn criter.		-2.14545
Prob(F-statistic)	0.000000	Durbin-Watson stat		2.28889

Note: ** indicates significance at 5% level.

Table 7. Short-run elasticities of variables in barley output dynamic ECM model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Cons	0.16093	0.15513	1.03739	0.3073
ECT(-1)	-0.948***	0.06303	-15.0414	0.0000
D(LNBAPRI)	0.6646***	0.10845	6.12856	0.0000
D(LNBAAR)	-0.12303	0.07689	-1.59999	0.1194
D(LNFERT)	-0.13170*	0.07390	-1.78212	0.0842
D(LNCSMRF)	0.33554**	0.12665	2.64937	0.0124
D(LNCGPMT)	0.32123*	0.16913	1.89927	0.0666
R-squared	0.65255	Mean dependent var		0.02035
Adjusted R-squared	0.58741	S.D. dependent var		0.13827
R-squared	0.65255	Mean dependent var		0.02035
Adjusted R-squared	0.58741	S.D. dependent var		0.13827
S.E. of regression	0.08882	Akaike info criterion		-1.84334
Sum squared resid	0.25243	Schwarz criterion		-1.54475
F-statistic	10.0168	Hannan-Quinn criter.		-1.73621
Prob(F-statistic)	0.000003	Durbin-Watson stat		2.27756

Note: *, ** and *** indicates significance at 10%, 5% and 1% level, respectively.

the result of this study since average temperature had negatively and significantly impacted wheat production in Turkey. This implies that a 1% rise in the average level of temperature will lead to a decline in wheat production by 0.29% in the long-run. This implies that a rising level of mean temperature in Turkey had adversely affected the production of wheat. It is evident that a decrease in wheat production leads to reduced growth in the agricultural sector and creates a challenge to food security in the country. On the other hand, Ketema^[45] in his study on determinants of agricultural output in Ethiopia reported that rainfall had a positive and significant impact on agricultural output,

which is similar to the current study finding. The result implied that a 1% increase in the amount of rainfall boosts agricultural output by 0.56%. The study findings of Taye, et al.^[46] are also congruent with the result of the current study; studying the impacts that a changing climate and fertilizer exert on barley production in Ethiopia reported that rainfall had a positive and significant impact on barley production at zero-order difference both in the *short- and* long-run. These indicate that a 1% increase in the amount of rainfall during the short- and long-run boosts barley production by 0.03% and 0.41% respectively.

The current study result is further consistent with that

of Chandio, et al. ^[47], who, in their study on short- and long-run impacts exerted by changing climate on the production of agricultural outputs in China have reported that log temperature and log rainfall had a positive influence on agricultural production in the short-run, although statistically insignificant. Equally, Taye, et al. ^[46] who studied the impact of change in climate and fertilizer use on the production of barley output in Ethiopia reported that precipitation and rainfall have a positive and significant influence on the supply of barley output. The results indicated that a 1% rise in current precipitation increases barley output supply by 2.8% in the long-run. Furthermore, the finding related to the producer price of barley is similar to that of Elbeydi, et al. ^[48], who in their study on the response of barley in Libya, reported that the coefficient of producer price of barley is positive (0.543) and significant in the long-run. Conversely, Taye, et al. ^[46] reported that fertilizers (DAP and UREA) demonstrated a negatively significant influence on the production of barley output in the *long run*. This indicates that a 1% increase in the use of DAP and UREA fertilizers decreases the supply of barley output by 28.8% and 3.4% respectively in the long-run.

Similarly, Taye, et al. ^[46] in their study on the impacts exerted by changing climate and fertilizer use on the production of barley output in Ethiopia exemplified that current year barley output is negatively and significantly affected by the use of current year DAP fertilizer in the short-run. This implies that a 1% increase in the use of current DAP fertilizer would decrease barley output by 4.44% in the short-run. Conversely, they reported that barley production is affected positively by the current and previous year's (first-order lag) quantity of UREA fertilizers consumed in the short-run. In this respect, every 1% rise in the use of current and previous year's UREA fertilizer boosts barley output supply by 6.87% and 6.57% respectively.

3.4 Implication and Explanation of Findings

The study results demonstrated that climatic factors had a positive impact on the current barley output supply both during previous and current years. In this context, the current year's barley output supply was affected positively and significantly by the amount of zero-order difference average crop season rainfall (CSMRF) and crop growing period mean temperature (CGPMT). This result is inversely related to the research results recorded globally by other investigators, the majority of which reported that increasing temperature is associated with decreasing rainfall ^[38]. The current study result supports the findings of researchers who reported that a warming temperature

followed by an increase in the amount of rainfall had a positive impact on barley output supply.

The positive impact of temperature on barley output supply can be explained by the fact that as the average temperature on the earth's surface rise, more evaporation occurs, which in turn, increases overall rainfall mostly while reaching the highland and mid-highland areas of Ethiopia. Study reports confirm that El Nino-Southern Oscillation (ENSO) and the Atlantic and Indian Oceans influence the occurrence of rainfall in the western, south-eastern, central, and northern highlands of Ethiopia; which bring moisture from the oceans ^[39].

However, the study result exhibited that CSMRF and CGPMT had a positive impact on the supply of barley output, which implies that climate parameters have minimal impact on the supply of barley output in the long-run. This was realized since barley is mainly grown during the main rainy season when rainfall is relatively plentiful and the temperature is cool. Furthermore, barley is grown in the highlands and mid-highlands where the temperature is naturally cool and has a moderate to high amount of rainfall. In the short-run, CSMRF and CGPMT revealed a positively significant influence on the current barley output supply indicating that a 1% increase in CSMRF and CGPMT will boost barley output supply by 0.34% and 0.32% respectively.

Similar investigations demonstrated that previous and current year's barley producer prices had a positively significant influence on the current year's barley production. From this result, it can be concluded that barley output supply is positively and significantly responsive to both current and previous year's (first-order lag) own producer prices. Change (increase) in barley producer price or price incentives announced before land area allocation to specific crops had a significant and positive contribution to boosting the current year's barley output supply. Conversely, the study result explored that use of fertilizer in its first-order lag (previous year) had exerted a negatively significant (at a 5% level) influence on barley output supply.

On the other hand, the producer price of barley demonstrated a positively significant influence on the supply of barley output in both the long- and short-term. This specifically exemplifies that barley output supply is highly responsive to any strategy of price incentive announced before re-allocation of the land area towards barley cultivation. Conversely, the study result exemplified that fertilizer used at zero-order difference had a negatively significant influence on barley output supply in the short-run, implying that increased use of fertilizer in lagged period (last year) will reduce the current year's barley output supply. This may be due to the inappropriate use of

fertilizers among farmers in Ethiopia.

4. Conclusions

This study aimed to investigate the determinant factors influencing barley output supply response in Ethiopia. The study applied an ARDL model proposed by Pesaran, et al.^[25] to examine the impact of climatic and non-climate input variables on barley output supply responses. The study used secondary time series data covering the period from 1981-2020. The study results demonstrated that climatic factors had a positive impact on the current barley output supply both during zero-order lag (previous) and current years. In this context, the current year's barley output supply was affected positively and significantly by the amount of zero-order lag CSMRF and CGPMT. The result is inversely related to research results recorded globally by other investigators, the majority of which reported that rising temperature is associated with decreasing rainfall^[38]. The current study result supports the findings of researchers who reported that a warming temperature followed by an increase in the amount of rainfall had a positive impact on barley output supply. The positive impact of temperature on barley output supply can be explained by the fact that as average surface temperature rise, more evaporation would be created which increases overall rainfall while reaching the highland and mid-highland areas of Ethiopia. Studies by Conway^[39] confirm that El Nino-Southern Oscillation (ENSO) and moist winds from the Atlantic and Indian Oceans influence the occurrence of rainfall in the western, southeastern, central, and northern highlands of Ethiopia; which bring moisture from the oceans.

Furthermore, the study result exhibited that CSMRF and CGPMT had a positive impact on the supply of barley output in the long-run, although non-significant, which implies that climate parameters have got a minimal impact on the supply of barley output. This result has been realized because barley crop is mainly grown during the main rainy season when rainfall is relatively plentiful and the temperature is cool. Furthermore, barley is grown in the highlands and mid-highlands where the temperature is naturally cool and has a moderate to high amount of rainfall. Conversely, CSMRF and CGPMT revealed a positively significant influence on current barley production in the short-run, indicating that a 1% increase in CSMRF and CGPMT will boost barley output supply by 0.34% and 0.32% respectively.

Similar investigations on non-climatic variables demonstrated that the previous year (first-order lag) and the current year's barley producer price have had a positively significant influence on the current year's barley produc-

tion. From this result, it can be concluded that barley output supply is positively and significantly responsive to both current and previous year's (first-order lag) producer prices. An increase in barley producer price or price incentives announced before land area allocation to specific crops had a significant and positive contribution to boosting the current year's barley output supply. Conversely, the study result explored that use of fertilizers in its first-order lag (previous year) induced a negatively significant (at 5% level) influence on barley production.

On the other hand, the producer price of barley demonstrated a positively significant effect on the supply of barley output both in the long- and short-run, specifically indicating that barley output supply is greatly responsive to any strategy of price incentive announced ahead of reallocation of the land area towards barley cultivation. Conversely, the study result exemplified that fertilizer used at zero-order difference had a negatively significant effect on barley output supply in the short-run, which implies that increased use of fertilizer in lagged period (last year) will reduce the current year's barley output supply. This may be due to the inappropriate use of fertilizers among farmers in Ethiopia.

In conclusion, the elasticity estimates of climatic and non-climatic variables presented in this study can be a useful addition to the repository of knowledge on the supply elasticity of agricultural commodities in the country at an aggregate level. The results can also be used to design appropriate mitigation and adaptation strategies and measures in the future.

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Data Availability

The data used for this study can be made available upon request provided there is going to be compliance with the owners' policy concerning sharing.

Conflict of Interest

The author declares that there are no competing interests.

References

- [1] Gardi, M.W., Memic, E., Zewudu, E., et al., 2022. Simulating the effect of climate change on barley yield in Ethiopia with the DSSAT-CERES-Barley model. *Agronomy Journal*. 114, 1128-1145.
- [2] AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability [Internet]. IPCC (Intergovernmental Panel on Climate Change); 2014. Available from: <https://www.ipcc.ch/report/ar5/wg2/>
- [3] Martinez, R., Hemming, D., Malone, L., et al., 2012. Improving Climate Risk Management at Local Level: Techniques, Case Studies, Good Practices and Guidelines for World Meteorological Organization Members [Internet]. IntechOpen. DOI: <https://doi.org/10.5772/51554#>
- [4] Winthrop, M., Kajumba, T., McIvor, S., 2018. Ethiopia Country Climate Risk Assessment Report, Irish Aid [Internet]. Available from: https://www.climate-learningplatform.org/sites/default/files/resources/ethiopia_country_climate_risk_assessment_report
- [5] Yawso, D.O., Adu, M.O., Armah, F.A., 2020. Impacts of climate change and mitigation policies on malt barley supplies and associated virtual water flows in the UK. *Scientific Reports*. 10, 376.
- [6] CSA (Central Statistical Agency), 2012. Annual Statistics Bulletin. Addis Ababa, Ethiopia.
- [7] CSA (Central Statistical Agency), 2020. Report on area and production of major crops in Ethiopia. Agricultural Sample Survey 2019/2020, Addis Ababa, Ethiopia.
- [8] Lakew, B., Semeane, Y., Alemayehu, F., et al., 1997. Exploiting the diversity of barley landraces in Ethiopia. *Genetic Resources and Crop Evolution*. 44, 109-116.
- [9] Bekele, B., Alemayehu, F., Lakew, B., et al., 2005. Food barley in Ethiopia. Food barley: Importance, uses and local knowledge. ICARDA: Aleppo, Syria. pp. 53-82.
- [10] Asfaw, Z., 2000. GENES in the FIELD: On-Farm conservation of crop diversity. International Development Research Centre: Ottawa; International Plant Genetic Resources Institute: Rome; Lewis Publishers: New York.
- [11] Wosene, G.A., Berhane, L., Bettina, I.G.H., et al., 2015. Ethiopian barley landraces show higher yield stability and comparable yield to improved varieties in multi-environment field trials. *Academic Journals*. 7(8), 275-291.
- [12] Samson, J., Berteaux, D., McGill, B.J., et al., 2011. Geographic disparities and moral hazards in the predicted impacts of climate change on human populations. *Globa Ecology and Biogeography*. 20(4), 532-544. DOI: <https://doi.org/10.1111/j.1466-8238.2010.00632.x>
- [13] Bekele, B., Wu, W., Yirsaw, E., et al., 2019. Climate change and its effect on land use change in the Central Rift Valley of Ethiopia. *Applied Ecology and Environmental Research*. 17(4), 7693-7713.
- [14] Overview [Internet]. World Bank; 2021. Available from: <https://www.worldbank.org/en/country/ethiopia/overview>
- [15] World Population Dashboard Ethiopia [Internet]. United Nations Population Funds; 2021. Available from: <https://www.unfpa.org/data/world-population/ET>
- [16] CSA, 2018. Report on area and production of major crops in Ethiopia. Agricultural sample survey 2017/18, Addis Ababa.
- [17] Gashaw, G., Tura, K., 2015. Review of barley value chain management in Ethiopia. *Journal of Biology, Agriculture and Healthcare*. 5(10), 84-98.
- [18] Muluken, B., Jemal, E., 2011. Achievements in food barley breeding research in the early production systems of northwest, Ethiopia. *Review of Barley Research and Development in Ethiopia*. Proceedings of the 2nd National Barley Research and Development Review Workshop, 2006 Nov 28-30; HARC, Holetta, Ethiopia.
- [19] Cammarano, D., Hawes, C., Squire, G., et al., 2019. Rainfall and temperature impacts on barley (*Hordeum vulgare* L.) yield and malting quality in Scotland. *Field Crop Research*. 241, 107559. DOI: <https://doi.org/10.1016/j.fcr.2019.107559>
- [20] Climate Change: The Scientific Basis [Internet]. IPCC (Intergovernmental Panel on Climate Change); 2001. Available from: <http://www.ipcc.ch/>
- [21] Deressa, T.T., 2007. Measuring the economic impact of climate change on Ethiopian agriculture: Ricardian approach. Policy Research Working Paper. DOI: <https://doi.org/10.1596/1813-9450-4342>
- [22] Zaremba, Ł., 2018. Cobweb theorem in relation to the fruit market. *AgEcon Search*. 20(3), 190-195. DOI: <https://doi.org/10.5604/01.3001.0012.1516>
- [23] Brianzoni, S., Mammana, C., Michetti, E., et al., 2008. A stochastic cobweb dynamical model. *Discrete Dynamics in Nature and Society*. Article ID 219653. DOI: <https://doi.org/10.1155/2008/219653>
- [24] Mendelsohn, R., Tiwari, D., 2000. Two essays on climate change and agriculture: A developing country perspective. FAO Information Division: Rome, Italy.
- [25] Pesaran, M.H., Shin, Y., Smith, R.J., 2001. Bounds

- testing approaches to the analysis of level relationships. *Journal of Applied Economics*. 16(3), 289-326.
- [26] Johansen, S., Juselius, K., 1990. Maximum likelihood estimation and inference on cointegration—with application to the demand for money. *Oxford Bulletin of Economics*. 52, 169-210.
- [27] Hassler, U., Wolters, J., 2006. Autoregressive distributed lag models and cointegration; Working Paper, No. 2005/22, Free University of Berlin, School of Business and Economics: Berlin.
- [28] Duasa, J., 2010. Real exchange rate and trade variables: Asymmetric cointegration relationship. *International Journal of Applied Business and Economic Research (IJABER)*. 8(1), 1-14.
- [29] Frimpong, M.J., Oteng, E.F., 2006. Bound Testing Approach: An Examination of Foreign Direct Investment, Trade and Growth Relationships [Internet]. Available from: https://mpr.ub.uni-muenchen.de/352/1/MPRA_paper_352.pdf
- [30] Dickey, D.A., Fuller, W.A., 1979. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*. 74(366a), 427-431.
- [31] Gujarati, D., 2004. *Basic econometrics*. McGraw Hill: New York.
- [32] Heij, C., de Boer, P., Franses, P.H., et al., 2004. *Econometric methods with applications in business and economics*. Oxford University Press: Oxford.
- [33] Wooldridge, J.M., 2013. *Introductory econometrics: A modern approach*. Cengage Learning: Boston. pp. 868.
- [34] Enders, W., 2010. *Applied econometric time series (3rd ed.)*. John Wiley & Sons, Inc.: Hoboken, New Jersey.
- [35] Akter, N., Hong, S.J., 2011. Education and economic growth in Haryana (India): Application of cointegration analysis and vector error correction model on supply response of pulses in Bangladesh. *South Asian Studies*. 17(1), 277-295.
- [36] Ssekuma, R., 2011. A study of cointegration models with applications [Master's thesis]. Pretoria: University of South Africa.
- [37] Sharma, S., Singh, S., 2019. The validity of Wagner's Law in India: A postliberalisation analysis. *South Asian Journal of Social Studies and Economics*. 4(2), 1-13.
- [38] *Climate Change 2013: The Physical Science Basis* [Internet]. IPCC; 2013. Available from: <https://www.ipcc.ch/report/ar5/wg1/>
- [39] Conway, D., 2000. Some aspects of climate variability in the North East Ethiopian Highlands, Wolli and Tigray. *Ethiopian Journal of Science*. 23(2), 139-161.
- [40] Fischer, G., Velthuisen, H.T.V., 1996. *Climate Change and Global Agricultural Potential Project: A Case Study of Kenya* [Internet]. International Institute for Applied Systems Analysis: Laxenburg. Available from: <https://pure.iiasa.ac.at/id/eprint/4956/>
- [41] Dumrul, Y., Kilicarslan, Z., 2017. Economic impacts of climate change on agriculture: Empirical evidence from ARDL approach for Turkey. *Journal of Business, Economics and Finance (JBEP)*. 6(4), 336-347.
- [42] Lobell, D.B., Schlenker, W., Costa-Roberts, J., 2011. Climate trends and global crop production since 1980. *Science*. 333, 616-620.
- [43] Schlenker, W., Roberts, M., 2009. Nonlinear temperature effects indicate severe damages to U.S. crops yields under climate change. *Proceeding of the National Academy of Science*. 106, 15594-15598.
- [44] Chandio, A.A., Gokmenoglu, K.K., Ahmad, F., 2021. Addressing the long- and short-run effects of climate change on major food crops production in Turkey. *Environmental Science and Pollution Research*. 28, 51657-51673.
- [45] Ketema, A.M., 2020. Determinants of agricultural output in Ethiopia: ARDL approach to co-integration. *International Journal of Business and Social Research*. 10(3), 1-10.
- [46] Taye, B.A., Asfaw, F.F., Yirsaw, B.G., et al., 2021. Modeling the impact of climate and fertilizer on barley production. *American Journal of Biological and Environmental Statistics*. 7(2), 44-51.
- [47] Chandio, A.A., Rehman, A., Jiang, Y., et al., 2020. Short and long-run impacts of climate change on agriculture: An empirical evidence from China. *International Journal of Climate Change Strategies and Management*. 12(2), 201-221.
- [48] Elbeydi, K., Eljadi, A.A., 2007. Measuring the supply response function of barley in Libya. *African Crop Science Conference Proceedings*. 8, 1277-1280.