**IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"**

**6-7 May 2024**

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[1] This contribution was prepared for the workshop. The views expressed are those of the authors and do not necessarily reflect the views of the Central Bank of the Republic of Türkiye, the BIS, the IFC or the other central banks and institutions represented at the event.

# THE IMPACT OF TEMPERATURE AND PRECIPITATION ON WHEAT PRODUCTION IN TÜRKİYE

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## Abstract

It is now a well-known fact that climate is changing globally at an unprecedented rate and agriculture sector is one of the most vulnerable sector to this change. Considered as a significant threat for food security, climate change and its impact on agricultural practices is one of the hottest topics in the recent economic literature. Climate change poses a significant threat also for the Turkish economy through agricultural production which is crucial with respect to its contribution to employment, exports and national income. With this regard, in this study, the impact of climate change on wheat production is investigated for Türkiye at province-level with unique, up-to-date and comprehensive dataset that is constructed by Central Bank of the Republic of Türkiye (CBRT) under the Early Warning System (EWS) Project. In the analysis, climate change is initially considered in a conventional way via temperature and precipitation measures, later considered with new alternative composite climate indicators. The results obtained from two different alternative climate measures indicate a significant reduction in wheat production in the short, medium and long-term. The impact is found to be increasing over time depending on various climate scenarios. We believe that our understanding regarding climate change-agricultural production relation will improve with the advancements of the data set, and this will support the development of more efficient policy recommendations.

## 1.1 Introduction

Climate change, defined as long-term changes in temperature and weather patterns, is one of the most important issues of this century. Unfortunately over the last decades, we frequently encounter news about droughts, increasing temperatures, decreasing precipitation as well as occurrence of extreme weather events and their adverse impact on our lives. It is now a well-known fact that climate is changing globally at an unprecedented rate and agriculture is one of the most vulnerable sector to this change. Considered as a significant threat to sustainability of agricultural practices, climate changes' impact on

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agricultural production has become one of the most prominent topic both for researchers and policymakers. Among agricultural products, with it's high nutritional value and good storage properties, wheat has been indispensable for world nutrition at all times and it has become essential for modern food production. Wheat has been a major source of protein for humans and covers 20% of their total protein needs (Shiferaw et al., 2013). As the main nutritional source especially for developing countries, such as Türkiye, wheat is considered as a staple food (Shiferaw et al., 2013).

Wheat which is the most produced, harvested and consumed crop across the world is particularly very sensitive to precipitation and temperature changes. Having a leading role in food security and livelihoods, impact of climate change on wheat production draws significant attention. There is a broad range of literature on the impacts of meteorological variables on wheat production especially in major wheat producing regions in Asia, Europe and Northern Africa. For China You et al. (2009), Zhai et al. (2017) and Zhang et al. (2022); for Pakistan Abbas (2022), Gul et al. (2022) and Chandio et al. (2021); for Somalia Warsame et al. (2021); for India Bhardwaj et al. (2022); for Asia Ozdemir (2021) and for selected low-middle income countries Kumar et al (2021) study the impact of climatic factors on wheat production.

As one of the major wheat producers in the world there are also numerous studies on Türkiye using different methodologies. Based on climate simulation models Ozdogan (2011) finds out that higher CO2 level and temperature and lower precipitation would reduce wheat yields between 5% to 35% in the Northwestern part of the country. Dellal et al. (2011) and Dellal and Unuvar (2019) using economic analysis and biophysical models indicate that climate change is expected to decrease yields in major crops up to 10.1% in 2050. The 2019 study extends the results and finds out that yield reductions will be 2% to 7% in 2020, 4% to 12% in 2050 and 5% to 20% in 2080. Chandio et al. (2020) examine the dynamic relationship between climate variables and crop yield in Türkiye between 1968-2014 using an ARDL model. A more recent study by Chandio et al. (2021) examines impact of climate change on wheat production by employing ARDL Model and Johansen and Juselius (JJC) cointegration test for 1980-2016 period. Estimation results reveal negative impact of CO2 emissions and temperature on wheat production in the short and long run and positive impact of precipitation on wheat production. Eruygur and Ozokcu (2022) using panel data approach analyzes the impact of meteorological variables on wheat yields in Türkiye and concludes that 8% reduction in wheat yields is expected based on the "average" scenario until 2100. Similarly, using panel data approach, Dogan and Karakas (2018) concludes that the impact of temperature and precipitation has significant impacts on agricultural production in the long-term. Their estimation results suggest that a 1% increase in temperature would cause a 0.19% and 0.50% reduction in wheat yields while a 1% increase in precipitation would increase wheat yields by 0.10% and 0.13% in drought-regions and non-drought regions, respectively.

Existing studies about the impact of climate change on wheat production using different data, methodology and time periods reveal contradictory and hence inconclusive results. As it was mentioned in Guiteras (2009) and Zhang et al. (2022), vulnerability of each region or country depends on their own adaptive capacity and unique circumstances. Therefore, country specific and regional analysis are critical in understanding the impact of climate change on agricultural production especially for developing countries in the regions already reached to a certain tolerance level with lower adaptive capacities.

Türkiye being located largely in Mediterranean geographical location where climatic conditions are quite temperate, diverse nature of the landscape and the existence of the mountains parallel to coasts result in significant differences in climatic conditions among its regions. While the coastal areas enjoy milder climates, the inland Anatolian plateau experiences extremes of hot summers and cold winters with limited rainfall (Sensoy et al., 2013). Its favorable climate and geographical conditions, rich soil sources and biological diversity makes Türkiye one of the leading countries in the world in the field of agriculture. Türkiye was ranked as the 12$^{th}$ largest wheat producer in the world (FAOSTAT, 2022). According to 2023 national statistics 22 million tonnes of wheat production constitutes 54.3% of total crop production in Türkiye (TurkStat, 2023). Wheat is the main product in the grain group and is produced almost every province as both spring and winter type. Wheat production is mostly concentrated in Central Anatolia (17%), Southeastern Anatolia (15%) and the Mediterranean (11%) regions (MOAF, 2022). A significant amount of wheat, especially winter wheat, is produced in West Marmara and West Black Sea regions.

Wheat is commonly a cool season crop ideally grown under the temperature between 21°C to 24°C. The crop does not like extreme weather conditions. If the temperature falls below 4°C during germination period, seeds potentially get harmed. If the temperature exceeds 35°C during maturation period, yields are expected to decrease. During the growth stages of wheat, when the grains start to fill out it requires additional sunlight. Temperature is more critical for wheat growth not requiring a lot of precipitation. However, extreme rainfall during late season may slow down the growth of the crop as well as the grain formation in wheat growing regions in the southern parts of the country. Overall, wheat development requires cold and moist weather during cultivation while warm weather and additional sunlight is necessary during harvesting. In general, meteorological conditions during spring, from March through June, is critical for wheat growth.

Regarding Türkiye's different climate conditions of diverse regions in this study, the impact of climate change on wheat production is investigated for Türkiye at province-level using a timely and comprehensive dataset. Initially, the impact of climate change is considered in a conventional manner with province-level temperature and precipitation variables. Then, alternative climate change indicator is constructed as a composite indicator for meteorological variables. The data used in the analysis come from micro-level dataset formed by Central Bank of the Republic of Türkiye (CBRT) under the Early Warning System (EWS) Project. In 2021, within the framework of the Food-EWS Project, data warehouse and analysis module have been established. This warehouse allows the analysis of data on food and agricultural product prices, critical for price stability, in a detailed and timely manner also enables the implementation of necessary precautionary measures. Using the advantages of this comprehensive micro-level dataset, the impact of major meteorological variables on wheat production is investigated by considering the differences in weather and production patterns across wheat growing regions of Türkiye. In addition to the analysis where temperature and precipitation variables are estimated separately, a composite indicator for meteorological variables is constructed and proposed as an alternative climate change variable that can be used as an explanatory variable in the related models.

## 1.2 Data and Methodology

In recent decades, strengthening sector polices for food security and supporting sustainable agricultural practices and estimating the impact of climate change more precisely has become extremely crucial. As it was mentioned in the previous section, existing studies reveal that the impact of climate change on agricultural production displays regional differences. In light of this information, impact of climate change on Türkiye's wheat production is examined by using up-to-date, comprehensive and regional micro-level dataset. The study utilizes a wide range of micro-level data from the Early Warning System Project of Central Bank of the Republic of Türkiye. As far as to our knowledge, data set used in this study is the most comprehensive among similar studies. Agricultural production and meteorological variables at province-level are of main interest of this study. In addition to production and meteorological data prices are also included as explanatory variables in the models. Time span and frequencies of the data are different. Province-level agricultural production data are annual, the meteorological data are daily and price data are monthly. The analysis covers 2000-2023 period. Details about the dataset is provided in Table 1.

Table 1. Data Sources Used under Early Warning System of CBRT

| Data | Time Span | Frequency | Source |
|---|---|---|---|
| **Production** | 1991-2023 | Annual | Ministry of Agriculture and Forestry |
| **Meteorological Data (Temperature & Precipitation)** | 1990-2024 | Daily | Turkish State Meteorological Service |
| **Wheat and Barley Prices** | 1980-2022 | Monthly | TURKSTAT (TL/kg) |
| **Agricultural PPI** | 1991-2024 | Monthly | TURKSTAT (Index) |
| **Fertilizer Prices** | 2000-2024 | Monthly | Ministry of Agriculture and Forestry (Index) |
| **Commodity Prices** | 2000-2024 | Daily | International Grains Council (Index) |
| **Climate Scenarios** | 2030-2050 / 2050-2070 / 2070-2100 | Seasonal | IPCC Interactive Atlas (IPCC, Gutiérrez, et al., 2021) / (Bagcaci et al., 2021) |

Meteorological variables, namely temperature and precipitation, are considered as the main indicators for climate change. In the baseline model, following existing studies in the literature, monthly average temperature and precipitation across provinces over time are used separately as explanatory variables.

Based on existing related literature the following empirical baseline model is constructed:

$$log(Prod_{i,t}) = \beta_0 + \beta_1\, log(Prod_{i,t-1}) + \sum_{k=1}^{12} \mu_{ik}\ \ log(MP_{i,k,t}) + \sum_{k=1}^{12} \rho_{ik}\ \ log(MT_{i,k,t}) + \sum_{k=1}^{12} \theta_{ik}\ \ \left(log(MT_{i,k,t})\right)^2$$
$$+\ \alpha_1 \Delta PD_{Wheat,i,t-1} + \alpha_2 \Delta PD_{Barley,i,t-1} + \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4 \Delta P_{Commodity,t-1} + \gamma_i + \Omega_t + e_{i,t}$$

*(Equation 1)*

where $Prod_{i,t}$ refers to wheat production measured in million tons for province i at year t. $MP_{i,k,t}$ denotes mean precipitation measured in millimeters (mm) observed in province i at year t and month k and $MT_{i,k,t}$ is the mean temperature measured in Celsius degrees for province i at year t and month k. In order to capture non-linear relationships between temperature and wheat yield, the simplest non-linear functional form, the squared of the mean temperatures, $(\ log(MT_{i,k,t}))^2$ are added as explanatory variables into the baseline model. $\Delta PD_{Wheat,i}$ refers to deviation of annual change of crop price of wheat at province level from agricultural producer prices for representing domestic price condition. Similarly, $\Delta PD_{Barley,i}$ refers to deviation of annual change of crop price of barley, known to be a substitute for wheat, at province level from agricultural producer prices for Türkiye. $\Delta P_{Fertilizer}$ represents the annual change of fertilizer price which is calculated as a weighted average of different types of fertilizers used in wheat production. The corresponding weights are determined by expert judgement based on the fertilizer types used during the growth stages of wheat. $\Delta P_{Commodity}$ denotes the annual change of commodity price proxied by the International Grains Council's (IGC) Grains and Oilseeds Index (GOI). $\gamma_i$ , $\Omega_t$ and $e_{i,t}$ denote province fixed effects, year fixed effects and error term, respectively.

Estimation results obtained from the baseline model, provided in the Appendix, suggest that precipitation and temperature have statistically significant impact on wheat production that are consistent with the information obtained from relevant reports and regional field experts (Table 10). The baseline model estimation results regarding precipitation suggest that positive impact of spring precipitation and negative impact of precipitation during October and November that coincide with the views obtained from different reports and expert interviews in which reveal that spring precipitation as well as precipitation during October and November are critical periods for wheat production in Türkiye.

The baseline estimation results suggest that temperature increase during winter has a positive impact on wheat production while spring and summer heats negatively impact production. The baseline estimation results reveal existence of non-linear relationships between temperature and wheat yields, controlling for precipitation, prices together with the province and time fixed effects.

Using general to specific modelling strategy based on the Akaike Information Criteria, reduced form baseline model given in Equation 2 is obtained for wheat production in Türkiye:

$$
\begin{aligned}
log(Prod_{i,t}) = {} & \beta_0 + \beta_1\, log(Prod_{i,t-1}) \\
& + \beta_2\, log\left(MP_{March_{i,t}}\right) + \beta_3\, log\left(MP_{April_{i,t}}\right) + \beta_4\, log\left(MP_{May_{i,t}}\right) + \beta_5\, log\left(MP_{June_{i,t}}\right) \\
& + \beta_6\, log\left(MP_{October_{i,t}}\right) + \beta_7\, log\left(MP_{November_{i,t}}\right) + \beta_8\, log\left(MT_{February_{i,t}}\right) + \beta_9\, log\left(MT_{March_{i,t}}\right) \\
& + \beta_{10}\, log\left(MT_{April_{i,t}}\right) + \beta_{11}\, log\left(MT_{May_{i,t}}\right) + \beta_{12}\, log\left(MT_{June_{i,t}}\right) + \beta_{13}\, log\left(MT_{July_{i,t}}\right) \\
& + \beta_{14}\left(log\left(MT_{April_{i,t}}\right)\right)^2 + \alpha_1 \Delta PD_{\substack{Wheat \\ ,i,t-1}} + \alpha_2 \Delta PD_{\substack{Barley \\ ,i,t-1}} + \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4 \Delta P_{Commodity,t-1} + \gamma_i \\
& + \Omega_t + e_{i,t}
\end{aligned}
$$

*(Equation 2)*

Our reduced form baseline model, the impacts of precipitation from March to June as well as October to November together with the temperature change starting from winter months to July were considered as critical months for wheat production. In addition, squared term for the mean temperature of April captures the non-linear impact of temperature on yield in the reduced form model.

Türkiye has a diverse climate across its different regions due to its topography and the literature suggest that the impact of changes in climate related variables on crop production are geographically uneven (Parry et al. 1992, Fischer et al. 2002 and Butt et al. 2006). In order to consider these facts, the analysis is more scrutinized by selecting the regions where the wheat is majorly grown and by considering the climate in that region. In this regard, we estimate the reduced form baseline model in Equation 2 by adding regional dummies for wheat growing regions:

$$
\begin{aligned}
log(Prod_{i,t}) = {} & \beta_0 + \beta_1\, log(Prod_{i,t-1}) \\
& + \beta_2\, log\left(MP_{March_{i,t}}\right) + \beta_3\, log\left(MP_{April_{i,t}}\right) + \beta_4\, log\left(MP_{May_{i,t}}\right) + \beta_5\, log\left(MP_{June_{i,t}}\right) \\
& + \beta_6\, log\left(MP_{October_{i,t}}\right) + \beta_7\, log\left(MP_{November_{i,t}}\right) + \beta_8\, log\left(MT_{February_{i,t}}\right) + \beta_9\, log\left(MT_{March_{i,t}}\right) \\
& + \beta_{10}\, log\left(MT_{April_{i,t}}\right) + \beta_{11}\, log\left(MT_{May_{i,t}}\right) + \beta_{12}\, log\left(MT_{June_{i,t}}\right) + \beta_{13}\, log\left(MT_{July_{i,t}}\right) \\
& + \beta_{14}\left(log\left(MT_{April_{i,t}}\right)\right)^2 + \alpha_1 \Delta PD_{\substack{Wheat \\ ,i,t-1}} + \alpha_2 \Delta PD_{\substack{Barley \\ ,i,t-1}} + \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4 \Delta P_{Commodity,t-1} \\
& + ¥_1\, log\left(MP_{March_{i,t}}\right) * D_r \\
& + ¥_2 log\left(MP_{April_{i,t}}\right) * D_r + ¥_3\, log\left(MP_{May_{i,t}}\right) * D_r + ¥_4\, log\left(MP_{June_{i,t}}\right) * + ¥_5\, log\left(MP_{October_{i,t}}\right) * D_r \\
& + ¥_6\, log\left(MP_{November_{i,t}}\right) * D_{region} + ¥_7\, log\left(MT_{February_{i,t}}\right) * D_r + ¥_8\, log\left(MT_{March_{i,t}}\right) * D_r \\
& + ¥_9\, log\left(MT_{April_{i,t}}\right) * D_r + ¥_{10}\, log\left(MT_{May_{i,t}}\right) * D_r + ¥_{11}\, log\left(MT_{June_{i,t}}\right) * D_r + ¥_{12}\, log\left(MT_{July_{i,t}}\right) * D_r \\
& + \gamma_i + \Omega_t + e_{i,t}
\end{aligned}
$$

*(Equation 3)*

where $D_r$ is a dummy variable for seven wheat growing regions of Türkiye.[3] An additional model is estimated for "dry regions" in which West Marmara and Black Sea regions are left out due to their different climatic conditions. In this alternative version of the estimation, dummy variables for wheat growing regions ($D_r$) are replaced with dummies only for wheat growing regions with drier conditions ($D_{dr}$). The estimation results for these models are provided in Table 4.

As an alternative, instead of inclusion of monthly temperature and precipitation data separately as independent variables, using the reduced form baseline model estimation results together with the expert judgement, two composite climate change indictors are constructed and used as explanatory variables in the empirical model. To compile the individual impacts of a large set of variables in a single index composite indicators (CIs) are widely used as a policy tool in climate literature (Saltelli et al.,2006) where the advantages and disadvantages of using it is thoroughly discussed in OECD (2008). We construct an alternative proxy for climate conditions as a composite indicator of meteorological variables, namely temperature and precipitation $\left(PCP_{i,t} \text{ and } PCT_{i,t}\right)$. A CI is constructed to evaluate the overall performance of the model with multiple criteria formed in equation 2. Similar to Equation 2, the CI is used as an independent variable in the empirical model for wheat production:

$$\begin{aligned} log(Prod_{i,t}) = \beta_0 + \beta_1 \log\left(Prod_{i,t-1}\right) \\ + \beta_2 \log\left(PCP_{i,t}\right) + \beta_3 \log\left(PCT_{i,t}\right) + \alpha_1 \Delta PD_{\substack{Wheat \\ ,i,t-1}} + \alpha_2 \Delta PD_{\substack{Barley \\ ,i,t-1}} + \alpha_3 \Delta P_{Fertilizer,t-1} \\ + \alpha_4 \Delta P_{Commodity,t-1} + \gamma_i + \Omega_t + e_{i,t} \end{aligned}$$

*(Equation 4)*

Constructed CIs $\left(PCP_{i,t} \text{ and } PCT_{i,t}\right)$ are based on Principal Component Analysis (PCA). A PCA is a method that is commonly used for large data sets, by transforming a large set of variables (in our case meteorological variables) into a compact one (climate indicators -$PCP_{i,t}$ and $PCT_{i,t}$) without losing much information (OECD, 2008).

## 1.3 Model Estimation Results

The estimation results for the reduced form baseline model of Equation 2 is presented in Table 2 which are in line with the field information gathered from the Ministry of Agriculture and Forestry as well as the literature. Estimation results in Table 2 reveal that precipitation during stem extension period, commonly March to May, positively impacts wheat production whereas precipitation during harvesting period, that is to say June, has negative impact. The observed impact of precipitation is limited possibly

[3] Regions are selected at NUTS1 level. Wheat is mainly cultivated in the Aegean, West Anatolia, Mediterranean, Central Anatolia, Southeast Anatolia, West Marmara and West Black Sea regions of Türkiye.

due to irrigation systems in the wheat growing regions, yet, the impact of temperature is observed more significantly. The impact of temperature on production is predominant. Higher mean temperature from March, May and June is expected to decrease wheat production. Especially, temperature increases during harvesting period (spring), negatively affected the production of wheat. Estimated "$\beta$" coefficients of Equation 2 (sum of the coefficients $log(MT_{May})$ to $log(MT_{June})$) implies a 1% increase in mean temperature during May to June decreases wheat production by 1.7% (Table 2 (1)). Moreover, the squared term for mean temperature in April indicates that while temperature increase up to a certain level is beneficial for wheat growth, it starts harming the production after a threshold. The results are in line with the field information as well as the literature. According to Table 2, while precipitation during stem extension in spring positively impacts wheat production, additional precipitation during harvesting, June, negatively impacts production.

In addition, our regression coefficient estimates of the reduced form baseline model behave similarly when we add dummies for wheat growing regions (Equation 3). The estimation results of Equation 3 are presented in Table 2 (2) and (3). The restricted sample results suggest that the positive impact of increased precipitation is significant in March and the negative impact is observed earlier in the year. Moreover, when we restrict the sample to only dry regions excluding West Marmara and West Black Sea, the more restricted sample supports the similar results (Table 2 (3)).

Table 2. Model Estimation Results[4][5]

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| $log(Prod)$ | 0.580*** | 0.557*** | 0.581*** |
| | (0.0221) | (0.0228) | (0.0225) |
| $log(MP_{March})$ | 0.0514*** | 0.102*** | 0.0305 |
| | (0.0151) | (0.0337) | (0.0227) |
| $log(MP_{April})$ | 0.00447 | -0.0733*** | -0.0235 |
| | (0.0131) | (0.0272) | (0.0177) |
| $log(MP_{May})$ | 0.00920 | 0.0433* | 0.0355** |
| | (0.0114) | (0.0257) | (0.0170) |
| $log(MP_{June})$ | -0.0309*** | 0.0212 | 0.0132 |
| | (0.00891) | (0.0224) | (0.0165) |
| $log(MP_{October})$ | -0.0118 | 0.0112 | 0.00671 |
| | (0.00848) | (0.0183) | (0.0136) |
| $log(MP_{November})$ | -0.0180* | -0.0113 | -0.00149 |
| | (0.00947) | (0.0160) | (0.0122) |
| $log(MT_{February})$ | 0.0506*** | 0.00963 | 0.0301 |
| | (0.0174) | (0.0252) | (0.0211) |
| $log(MT_{March})$ | -0.102*** | -0.114** | -0.100** |
| | (0.0394) | (0.0476) | (0.0460) |
| $log(MT_{April})$ | 3.596*** | 3.396*** | 3.143*** |
| | (0.861) | (0.877) | (0.879) |
| $log(MT_{May})$ | -0.960*** | -0.835*** | -0.969*** |
| | (0.215) | (0.279) | (0.238) |
| $log(MT_{June})$ | -0.751** | -0.891** | -0.432 |
| | (0.294) | (0.406) | (0.341) |

[4] Reduced form baseline model is selected based on general to specific AKAIKE information criteria.
[5] Additional models using various control variables were tested for robustness showing similar results with the reduced form baseline model.

| | | | |
|---|---|---|---|
| $log(MT_{July})$ | -0.200 | -0.376 | 0.0560 |
| | (0.323) | (0.458) | (0.362) |
| $(log(MT_{April}))^{2}$ | -0.805*** | -0.753*** | -0.687*** |
| | (0.184) | (0.191) | (0.190) |
| $\Delta PD_{Wheat}$ | 0.00809 | 0.00869* | 0.00868* |
| | (0.00506) | (0.00511) | (0.00505) |
| $\Delta PD_{Barley}$ | 0.00350 | 0.00353* | 0.00298 |
| | (0.00214) | (0.00213) | (0.00212) |
| $\Delta P_{Commodity}$ | 0.991 | 0.770 | 1.101 |
| | (0.758) | (0.756) | (0.761) |
| $\Delta P_{Fertilizer}$ | -0.484 | -0.405 | -0.462 |
| | (0.311) | (0.310) | (0.310) |
| $log(MP_{March})$*$D_r$ | | -0.0590 | |
| | | (0.0368) | |
| $log(MP_{April})$* $D_r$ | | 0.0872*** | |
| | | (0.0286) | |
| $log(MP_{May})$* $D_r$ | | -0.0421 | |
| | | (0.0274) | |
| $log(MP_{June})$* $D_r$ | | -0.0602** | |
| | | (0.0238) | |
| $log(MP_{October})$*$D_r$ | | -0.0274 | |
| | | (0.0188) | |
| $log(MP_{November})$* $D_r$ | | -0.00910 | |
| | | (0.0169) | |
| $log(MT_{February})$* $D_r$ | | 0.0642** | |
| | | (0.0293) | |
| $log(MT_{March})$*$D_r$ | | 0.0358 | |
| | | (0.0482) | |
| $log(MT_{April})$*$D_r$ | | -0.0294 | |
| | | (0.143) | |
| $log(MT_{May})$*$D_r$ | | -0.145 | |
| | | (0.267) | |
| $log(MT_{June})$*$D_r$ | | 0.397 | |
| | | (0.398) | |
| $log(MT_{July})$*$D_r$ | | 0.154 | |
| | | (0.449) | |
| $log(MP_{March})$*$D_{dr}$ | | | 0.0224 |
| | | | (0.0297) |
| $log(MP_{April})$* $D_{dr}$ | | | 0.0474** |
| | | | (0.0232) |
| $log(MP_{May})$* $D_{dr}$ | | | -0.0512** |
| | | | (0.0217) |
| $log(MP_{June})$* $D_{dr}$ | | | -0.0522*** |
| | | | (0.0192) |
| $log(MP_{October})$* $D_{dr}$ | | | -0.0211 |
| | | | (0.0148) |
| $log(MP_{November})$* $D_{dr}$ | | | -0.0287* |
| | | | (0.0148) |
| $log(MT_{February})$*$D_{dr}$ | | | 0.0649** |
| | | | (0.0282) |
| $log(MT_{March})$* $D_{dr}$ | | | 0.0209 |
| | | | (0.0468) |
| $log(MT_{April})$* $D_{dr}$ | | | -0.220 |
| | | | (0.142) |
| $log(MT_{May})$* $D_{dr}$ | | | -0.157 |
| | | | (0.249) |
| $log(MT_{June})$* $D_{dr}$ | | | -0.284 |
| | | | (0.363) |
| $log(MT_{July})$* $D_{dr}$ | | | -0.464 |
| | | | (0.421) |
| Constant | 8.406*** | 8.101*** | 10.25*** |

| | | | |
|---|---|---|---|
| | (1.580) | (1.671) | (1.910) |
| Observations | 1,330 | 1,330 | 1,330 |
| Number of Province | 76 | 76 | 76 |
| Year FE & City FE | YES | YES | YES |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Alternatively, a composite indicator is constructed to evaluate the overall performance of the model formed in Equation 2. Constructing the CI, we use statistically significant variables in general to specific identification as well as field information gathered from related local institutions. Accordingly, the findings of PCA are in line with the findings of Table 2. In both estimations, the impact of precipitation tends to be positive while the impact of temperature is negative in wheat production. Moreover, PCA confirms the impact of temperature being larger compared to precipitation.

Table 3. Principal Component Analysis

| Variables | (a) | (b) |
|---|---|---|
| *log(Prod)* | 0.584*** | 0.586*** |
| | (0.0217) | (0.0221) |
| $PCP$ | 0.0345*** | 0.0380*** |
| | (0.00845) | (0.00991) |
| $PCT$ | -0.0692*** | -0.106*** |
| | (0.00837) | (0.0150) |
| $\Delta PD_{Wheat}$ | 0.00903*** | 0.00929* |
| | (0.00348) | (0.00513) |
| $\Delta PD_{Barley}$ | 0.00462** | 0.00327 |
| | (0.00219) | (0.00218) |
| $\Delta P_{Commodity}$ | -0.0188 | 1.510*** |
| | (0.0573) | (0.497) |
| $\Delta P_{Fertilizer}$ | -0.0381 | -0.693*** |
| | (0.0238) | (0.240) |
| Constant | 4.953*** | 6.042*** |
| | (0.258) | (0.366) |
| Observations | 1,330 | 1,330 |
| R-squared | 0.416 | |
| Number of Province | 76 | 76 |
| Year FE & Province FE | | YES |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The estimation results suggest that weather conditions in spring significantly impact wheat production in Türkiye. Accordingly, an increase in mean temperature during spring causes a decline in wheat production. While precipitation in spring is highly crucial, continuous precipitation during summer potentially slows down crop development, delaying the maturity of wheat.

In Türkiye, wheat is grown in multiple regions with a wide range of climatic conditions. As the results of Equation 3 suggest, the impact of precipitation and temperature on wheat production varies when we add regional interaction terms. Therefore, we further extend our analysis at NUTS 1 level highlighting regional differences across different parts of the country. Table 4 provides separate regression outputs constraining the sample to only wheat producing regions. Each estimation result under Table 4 are the estimations of Equation 2 for different regions. It is estimated that a 1% change in mean temperature during April and May decrease wheat production in major wheat growing regions, namely, Central Anatolia, Mediterranean, Southeast Anatolia, West Marmara and West Black Sea by 1.4% (Table 4 (8)). When we restrict the sample to dry regions, the impact remains to be similar (Table 4 (6)). Among other regions, Mediterranean and Southeast Anatolia, accounting 33.5% of total wheat production[6], is found to be more sensitive to temperature increase (Table 4 (5)). It is important to note that the impact of temperature increase is expected earlier in these hotter regions in the south.

Similar to our initial methodology, principal component analysis is conducted for wheat growing regions. The findings are in line with the primary results supporting the negative impact of temperature increase on wheat production. Regardless of the regional restriction, principal component coefficients are found to be negative and significant (Table 5).

[6] Agricultural Products Markets Report: July 2022. Ministry of Agriculture and Forestry.

Table 4. Regional Model Estimation Results

| Variables | (1) Reduced form baseline model | (4) Aegean, West and Central Anatolia | (5) Mediterranean and Southeast Anatolia | (6) **Dry regions** | (7) West Marmara and Black Sea | (8) **All wheat growing regions** |
|---|---|---|---|---|---|---|
| $log(Prod)$ | 0.580*** | 0.448*** | 0.313*** | 0.311*** | 0.702*** | 0.403*** |
| | (0.0221) | (0.0504) | (0.0538) | (0.0367) | (0.0433) | (0.0289) |
| $log(MP_{March})$ | 0.0514*** | 0.0280 | 0.00952 | 0.0319* | 0.00571 | 0.0321** |
| | (0.0151) | (0.0236) | (0.0336) | (0.0185) | (0.0226) | (0.0140) |
| $log(MP_{April})$ | 0.00447 | 0.0715*** | 0.0517* | 0.0491*** | -0.0333* | 0.0162 |
| | (0.0131) | (0.0195) | (0.0291) | (0.0166) | (0.0187) | (0.0121) |
| $log(MP_{May})$ | 0.00920 | -0.0252 | -0.00743 | -0.0180 | 0.0208 | 0.00358 |
| | (0.0114) | (0.0181) | (0.0230) | (0.0144) | (0.0164) | (0.0106) |
| $log(MP_{June})$ | -0.0309*** | -0.0315** | -0.0451*** | -0.0381*** | -0.00979 | -0.0401*** |
| | (0.00891) | (0.0157) | (0.0145) | (0.00925) | (0.0182) | (0.00801) |
| $log(MP_{October})$ | -0.0118 | 0.00820 | -0.0236 | -0.00727 | 0.00239 | -0.0150* |
| | (0.00848) | (0.0106) | (0.0163) | (0.00916) | (0.0139) | (0.00781) |
| $log(MP_{November})$ | -0.0180* | -0.0364*** | 0.00806 | -0.00560 | 0.0155 | -0.00621 |
| | (0.00947) | (0.0141) | (0.0211) | (0.0113) | (0.0128) | (0.00903) |
| $log(MT_{February})$ | 0.0506*** | 0.0488** | 0.0867 | 0.0591*** | 0.0236 | 0.0509*** |
| | (0.0174) | (0.0211) | (0.0533) | (0.0225) | (0.0267) | (0.0180) |
| $log(MT_{March})$ | -0.102*** | 0.0327 | -0.153 | -0.0275 | -0.0974 | -0.0561 |
| | (0.0394) | (0.0474) | (0.152) | (0.0468) | (0.0972) | (0.0403) |
| $log(MT_{April})$ | 3.596*** | -1.696 | 10.64*** | 5.384*** | 0.0177 | 4.688*** |
| | (0.861) | (1.382) | (2.837) | (1.083) | (1.682) | (0.925) |
| $log(MT_{May})$ | -0.960*** | -1.381*** | -0.435 | -0.818*** | -1.712*** | -0.953*** |
| | (0.215) | (0.315) | (0.508) | (0.273) | (0.314) | (0.213) |
| $log(MT_{June})$ | -0.751** | -0.110 | -0.421 | -0.00598 | 1.079** | -0.198 |
| | (0.294) | (0.394) | (0.857) | (0.386) | (0.450) | (0.293) |
| $log(MT_{July})$ | -0.200 | -0.630 | 1.661 | -0.436 | -0.333 | -0.304 |
| | (0.323) | (0.445) | (1.020) | (0.426) | (0.476) | (0.314) |
| $(log(MT_{April}))^2$ | -0.805*** | 0.368 | -2.360*** | -1.250*** | -0.0133 | -1.064*** |
| | (0.184) | (0.306) | (0.552) | (0.228) | (0.355) | (0.195) |
| $\Delta PD_{Wheat}$ | 0.00809 | -0.00830 | 0.0153 | 0.00459 | 0.00175 | 0.0104 |
| | (0.00506) | (0.0105) | (0.0163) | (0.00982) | (0.00858) | (0.00658) |
| $\Delta PD_{Barley}$ | 0.00350 | -0.000376 | 0.00349 | 0.00818 | -6.34e-07 | 0.00266 |
| | (0.00214) | (0.00727) | (0.0102) | (0.00609) | (0.00156) | (0.00190) |
| $\Delta P_{Commodity}$ | 0.991 | 1.477 | 3.380* | 2.401** | 0.657 | 1.436* |
| | (0.758) | (1.264) | (1.854) | (0.980) | (1.111) | (0.737) |
| $\Delta P_{Fertilizer}$ | -0.484 | -0.308 | -0.946 | -0.557 | -0.731* | -0.564* |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (0.311) | (0.494) | (0.775) | (0.400) | (0.435) | (0.302) |
| Constant | 8.406*** | 15.13*** | -4.182 | 8.124*** | 6.992*** | 8.219*** |
| | (1.580) | (2.163) | (4.547) | (2.003) | (2.509) | (1.594) |
| Observations | 1,330 | 342 | 327 | 669 | 312 | 981 |
| Number of Province | 76 | 19 | 17 | 36 | 15 | 51 |
| Year FE & Province FE | YES | YES | YES | YES | YES | YES |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5. Regional Principal Component Indicators

| Variables | (b)<br>Reduced form baseline model | (c)<br>Aegean, West and Central Anatolia | (d)<br>Mediterranean and Southeast Anatolia | (e)<br>**Dry regions** | (f)<br>West Marmara and Black Sea | (g)<br>**All wheat growing regions** |
|---|---|---|---|---|---|---|
| *log(Prod)* | 0.586*** | 0.426*** | 0.314*** | 0.290*** | 0.694*** | 0.410*** |
| | (0.0221) | (0.0510) | (0.0555) | (0.0382) | (0.0418) | (0.0296) |
| *PCP* | 0.0380*** | 0.00847 | 0.0428* | 0.0291** | 0.00772 | 0.0217** |
| | (0.00991) | (0.0155) | (0.0257) | (0.0135) | (0.0140) | (0.00977) |
| *PCT* | -0.106*** | -0.118*** | -0.0803** | -0.0794*** | -0.116*** | -0.100*** |
| | (0.0150) | (0.0257) | (0.0333) | (0.0206) | (0.0188) | (0.0149) |
| $\Delta PD_{Wheat}$ | 0.00929* | -0.000027 | 0.0171 | 0.0122 | -0.000684 | 0.0111 |
| | (0.00513) | (0.0106) | (0.0176) | (0.0104) | (0.00851) | (0.00676) |
| $\Delta PD_{Barley}$ | 0.00327 | -0.00139 | 0.00224 | 0.00494 | 0.000350 | 0.00274 |
| | (0.00218) | (0.00736) | (0.0110) | (0.00647) | (0.00155) | (0.00198) |
| $\Delta P_{Commodity}$ | 1.510*** | 1.522** | -0.966 | -0.144 | 1.886*** | 0.728 |
| | (0.497) | (0.714) | (0.960) | (0.622) | (0.608) | (0.488) |
| $\Delta P_{Fertilizer}$ | -0.693*** | -0.582* | 0.650 | 0.218 | -1.190*** | -0.355 |
| | (0.240) | (0.344) | (0.471) | (0.301) | (0.288) | (0.234) |
| Constant | 6.042*** | 8.003*** | 8.584*** | 9.290*** | 5.019*** | 8.167*** |
| | (0.366) | (0.675) | (0.872) | (0.569) | (0.609) | (0.447) |
| Observations | 1,330 | 342 | 327 | 669 | 312 | 981 |
| Number of Province | 76 | 19 | 17 | 36 | 15 | 51 |
| Year FE & Province FE | YES | YES | YES | YES | YES | YES |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

## 1.4 Climate Scenarios

In climate analysis, using climate scenarios is a common tool to make predictions. “A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change” (IPCC, 2001). Regional assessments are crucial in climate analysis as the impact of climate change varies across different regions in the world. Improvements in data and modelling has revealed that adverse impacts of climate change are more substantial in some regions especially in lower latitude countries (Parry et al., 2004). Türkiye, being located in the Mediterranean basin, an arid to semi-arid region, is expected to be affected by the negative consequences of climate change significantly (IPCC, 2007).

Climate scenarios released by International Panel on Climate Change (IPCC) utilizing Global Circulation Models (GCMs) are widely accepted in climate literature. With the advancement of data, the regional performance of GCMs has improved significantly especially in simulating temperature and precipitation changes. The influential 2021 IPCC Report provides an Interactive Atlas offering regional information on projected changes in climate related variables, mainly mean temperature and precipitation change. The Interactive Atlas have advanced the understanding of regional climate variability through providing different climate related variables over time and across regions. The Atlas provides projections on the Mediterranean region, yet, the predicted temperature and precipitation change at province level is not available based on publicly accessible data of the IPCC.

A novel study by Bagcaci et al. (2021) extends the projections of the IPCC specifically for Türkiye using the same methodology as the Interactive Atlas. In their study, Bagcaci et al. (2021) consider the 2021 IPCC Report with baseline years 1995 to 2014 and estimate mean temperature and total precipitation over the short (2030–2050), medium (2050–2070) and long-term (2070–2100) across different regions of the country. Their predictions also distinguish between two major IPCC climate scenarios: high emissions scenario (SSP5-8.5) and low emissions scenario (SSP2-4.5). Their study is crucial for our analysis as it provides regional projections for each season of the year over a time span in line with the existing literature.

According to the estimations of Bagcaci et al. (2021), mean temperature projections are all positive and statistically significant under both high emissions scenario (HES) and low emissions scenario (LES) over the short, medium and long run. Southeastern and Eastern Anatolia, main wheat growing regions, are the most vulnerable regions to temperature changes under HES and LES (Table 7). Spring warmings are also estimated to be effective in major wheat growing regions with their impact reaching 1.1°C to 4°C depending on the region and time span. According to HES and LES temperature increase during summer is highly significant reaching a record high up to $6.5^0$C under HES across many regions.

This increased temperature is alarming by itself, yet, it can cause additional drying in the region through evapotranspiration even if precipitation changes are not significant during the same period. Unlike temperature, estimation results for precipitation suggest that not all seasonal precipitation changes over time are statistically significant.[7] The most prominent precipitation reduction is expected in summer under LES and in autumn under HES over the long-term across all regions. In particular, spring precipitation changes are significant across most of the regions under HES. Under LES, a major reduction in precipitation is expected in Central Anatolia and Mediterranean in the short and medium term under LES (Table 6). In Southeastern Anatolia precipitation change is not significant under both scenarios in the short and medium term (Table 6). However, in the long-term, spring precipitation is significant under HES.

Overall, in the regions where wheat is mostly grown, a notable temperature increase is expected with the impact being higher under high emissions scenario. Especially, spring anomalies are to be expected in Southeast Anatolia, Mediterranean and Central Anatolia regions where drying levels are also higher. The estimations for mean temperature and precipitation change are in line with the literature confirming southern parts of the country being most vulnerable to climate change.

[7] In Table 6, statistically significant value changes at the $p = 0.05$ level are marked in bold charachters.

Table 6. Estimated Precipitation Change for High Emissions Scenario (Low Emissions Scenario) (%)

| | | Marmara | Black Sea | Eastern Anatolia | Aegean | Central Anatolia | Mediterranean | Southeastern Anatolia | Average |
|---|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 0.4 (-3) | 2.8 (2.1) | 0.5 (-0.9) | -1.7 (-6.1) | -3.5 (**-6.2**) | -6.2 (**-10.6**) | -3.8 (-0.4) | -1.6 (-3.6) |
| | **Summer** | **-14.2** (-11.4) | **-10 (-12.4)** | -4.9 (**-10.5**) | -14.3 (-11.9) | -5.4 (-8.8) | -3.9 (-8.8) | 5 (1) | -6.8 (-9) |
| | **Autumn** | -7.6 (-4.6) | -7.5 (**-9.5**) | -7.3 (-5.5) | -9.4 (-5.1) | -8.6 (-6.3) | **-11.6** (-2.5) | -0.9 (-2.4) | -7.6 (-5.1) |
| | **Winter** | **9.5** (1.3) | 4.3 (1) | 2.2 (-1) | 4.8 (-0.5) | 5.2 (-1) | 1.6 (-3.6) | -3.6 (-3.3) | 3.4 (-1) |
| **2050-2070** | **Spring** | 2.5 (**-7.6**) | **4.2** (2.5) | 4.6 (-1) | -0.5 (**-10.9**) | -2.3 (**-6.4**) | -5.8 (**-12.8**) | 4 (-5.6) | 1 (-6) |
| | **Summer** | **-30.7 (-22.3)** | **-20 (-10.6)** | -5.6 (**-15.8**) | **-27.2 (-22.3)** | -9.2 (-8.7) | -10.5 (-11.6) | 11.3 (-8.1) | -13 (-14.2) |
| | **Autumn** | **-11.5** (-7) | **-9.1** (-4) | **-10.8** (1.9) | **-16.8** (-6.4) | **-10.7** (-6.6) | **-10.6** (-6.2) | -1.1 (8.4) | -10.1 (-2.8) |
| | **Winter** | 1.4 (5.7) | 2.8 (**7.4**) | 0.3 (3.8) | **-6.8** (-1.2) | -2.7 (2.5) | **-8.2** (-4.2) | -8.8 (-3) | -3.1 (1.6) |
| **2070-2100** | **Spring** | **-13.3** (-0.5) | 0.6 (**8.3**) | **-6** (2.4) | **-18** (-1.5) | **-11.7 (1.1)** | **-17.5** (-4.7) | **-13.9** (-5) | -11.4 (0) |
| | **Summer** | **-37.3 (-31.2)** | **-30.9 (-20.4)** | **-13.7 (-20.3)** | **-30.6 (-33.7)** | -9.4 (**-22.0**) | -9.3 (**-29.1**) | 21.1 (-9) | -15.7 (-23.7) |
| | **Autumn** | **-27.2** (-7.1) | **-17.6** (**-8.3**) | **-18.3** (-7.4) | **-29.6 (-12.3)** | **-25.4 (-16.4)** | **-25.5 (-17.3)** | **-18.3** (-3.8) | -23.1 (-10.4) |
| | **Winter** | 5.8 (6.4) | **9.3 (8.5)** | 4.9 (5.6) | **-9** (-0.7) | 0.4 (2.3) | **-12.5** (-5.2) | -5.6 (0.6) | -1 (2.5) |

Source: Bagcaci et. al. (2021)

Table 7. Estimated Temperature Change for High Emissions Scenario (Low Emissions Scenario) (ºC)

| | | Marmara | Black Sea | Eastern Anatolia | Aegean | Central Anatolia | Mediterranean | Southeastern Anatolia | Average |
|---|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 1.1 (0.9) | 1.1 (0.8) | 1.2 (1.0) | 1.1 80.9) | 1.1 (0.9) | 1.2 (1.0) | 1.2 (1.0) | 1.1 (0.9) |
| | **Summer** | 1.9 (1.6) | 1.7 (1.5) | 1.9 (1.7) | 2 (1.7) | 2 (1.7) | 2 (1.7) | 2 (1.7) | 1.9 (1.7) |
| | **Autumn** | 1.4 (1.1) | 1.5 (1.2) | 2 (1.6) | 1.5 (1.2) | 1.8 (1.4) | 1.7 (1.4) | 2 (1.6) | 1.7 (1.4) |
| | **Winter** | 0.8 (0.7) | 0.8 (0.8) | 1.3 (1.3) | 0.8 (0.7) | 0.9 (0.9) | 0.9 (0.8) | 1.2 (1.1) | 1 (0.9) |
| **2050-2070** | **Spring** | 2.1 (1.2) | 2 (1.1) | 2.6 (1.5) | 2.2 (1.3) | 2.3 (1.3) | 2.5 (1.5) | 2.7 (1.6) | 2.3 (1.4) |
| | **Summer** | 3 (2) | 2.8 (1.9) | 3.5 (2.2) | 3.4 (2.1) | 3.6 (2.2) | 3.6 (2.3) | 3.5 (2.3) | 3.3 (2.1) |
| | **Autumn** | 2.5 (1.5) | 2.6 (1.5) | 3.5 (2.1) | 2.7 (1.6) | 3.2 (1.8) | 3.1 (1.9) | 3.6 (2.2) | 3 (1.8) |
| | **Winter** | 1.7 (1) | 1.9 (1) | 2.9 (1.6) | 1.7 (1) | 2.1 (1) | 1.9 (1.1) | 2.5 (1.4) | 2.1 (1.2) |
| **2070-2100** | **Spring** | 3.4 (1.2) | 3.1 (1.1) | 3.9 (1.5) | 3.6 (1.3) | 3.6 (1.3) | 4 (1.5) | 4.2 (1.6) | 3.7 (1.9) |
| | **Summer** | 4.9 (2.7) | 4.7 (2.5) | 5.9 (3) | 5.5 (2.9) | 6 (3.1) | 5.8 (3.1) | 6 (3.1) | 5.5 (2.9) |
| | **Autumn** | 3.7 (1.9) | 3.9 (1.9) | 5.1 (2.7) | 4.1 (2.1) | 4.7 (2.4) | 4.8 (2.5) | 5.2 (2.8) | 4.5 (2.3) |
| | **Winter** | 2.8 (1.2) | 2.9 (1.3) | 4.2 (2.1) | 2.8 (1.2) | 3.1 (1.4) | 3 (1.4) | 3.7 (1.8) | 3.2 (1.5) |

Source: Bagcaci et. al. (2021)

## 1.5 Interpretation of Estimation Results

In Table 2, we presented estimation results to measure the impact of a percentage change in mean temperature and precipitation on wheat production in Türkiye. Accordingly, a 1% change in mean spring and summer temperatures would translate into 1.1% and 0.7% reduction in what production, respectively. Moreover, Table 7 projects that, based on the average temperature between 1995 and 2014, a 1.1°C, 2.3°C and 3.7°C temperature increase is expected in short, medium and long term under HES. Combining the estimation results of Table 2 with mean temperature forecasts of Table 7 would indicate that a significant amount of reduction in wheat production would be expected based on different scenarios due to increasing spring temperature (Table 8).

Table 8. Estimated Impact of Temperature Change on Wheat Production under High Emissions Scenario

| | | Projected Temperature Increase (°C)* | Historical Average Temperature (1995-2014) (°C)** | Projected Change (%) | Wheat*** | Estimated Impact (%) |
|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 1.1 | 12.1 | 9.1 | -1.1 | **-10.0** |
| | **Summer** | 1.9 | 23.8 | 8.0 | -0.7 | **-5.6** |
| **2050-2070** | **Spring** | 2.3 | 12.1 | 19.0 | -1.1 | **-20.9** |
| | **Summer** | 3.3 | 23.8 | 13.9 | -0.7 | **-9.7** |
| **2070-2100** | **Spring** | 3.7 | 12.1 | 30.6 | -1.1 | **-33.6** |
| | **Summer** | 5.5 | 23.8 | 23.1 | -0.7 | **-16.2** |

*(Bagcaci et al., 2021)
**Turkish State Meteorological Service
***Based on writers' calculations

A significant but less reduction in wheat production due to increasing temperature is projected under LES (Table 9). Moreover, the impact of a change in temperature during summer is found to be less compared to spring.

Table 9. Estimated Impact of Temperature Change on Wheat Production under Low Emissions Scenario

| | | Projected Temperature Increase (°C)* | Historical Average Temperature (1995-2014) (°C)** | Projected Change (%) | Wheat*** | Estimated Impact (%) |
|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 0.9 | 12.1 | 7.4 | -1.1 | **-8.2** |
| | **Summer** | 1.7 | 23.8 | 7.1 | -0.7 | **-5.0** |
| **2050-2070** | **Spring** | 1.4 | 12.1 | 11.6 | -1.1 | **-12.7** |
| | **Summer** | 2.1 | 23.8 | 8.8 | -0.7 | **-6.2** |
| **2070-2100** | **Spring** | 1.9 | 12.1 | 15.7 | -1.1 | **-17.3** |
| | **Summer** | 2.9 | 23.8 | 12.2 | -0.7 | **-8.5** |

*(Bagcaci et al., 2021)

**Turkish State Meteorological Service
***Based on writers' calculations

## 1.6 Conclusion

The detrimental effects of climate change on agriculture is undeniable. According to the IPCC, crop production is extremely vulnerable to climate change since production of major crops are mainly concentrated in several producing countries (IPCC, 2019). In this regard, the analysis aims to fill an important gap in the literature by quantifying the impact of climate change on wheat production in Türkiye, a major wheat producer.

Our model findings are in line with the existing literature. While precipitation in the development phase positively impacts production, the temperature increase has a negative impact during harvesting of the crop. Moreover, the results are more significant in the Central Anatolia, Mediterranean and Southeast Anatolia which are the major wheat growing regions of the country. According to the findings of the analysis, under both high and low emissions scenario, temperature increase especially during spring and summer months, would decrease wheat production significantly over the course of short, medium and long term. It is important to mention that the impact increases over time. For example, under high emissions scenario expected temperature increase during spring months is estimated to decrease wheat production by 10.0% in the short term. This number increases to 33.6% over the long term. Under the low emissions scenario, while the estimated reduction is less, it still increases over the long run.

The estimation results of our model present the alarming impact of meteorological variables on staple crop production. The analysis in this study is formed by a novel data set gathered under Food-EWS enabling us to generate relatively higher level of statistical validity through performing panel data analysis. We believe that with the availability and advancement of the data under Food-EWS, our model would improve and our results would be more scrutinized.

# Appendix

Table 10. Baseline Model Estimation Results

| Variables | Baseline Model |
|---|---|
| $log(Prod)_{i,t-1}$ | 0.631*** |
| | (0.0274) |
| $log(MP)_{i,t,1}$ | 0.0347 |
| | (0.0230) |
| $log(MP)_{i,t,2}$ | -0.0305* |
| | (0.0176) |
| $log(MP)_{i,t,3}$ | 0.0598*** |
| | (0.0208) |
| $log(MP)_{i,t,4}$ | -0.00189 |
| | (0.0172) |
| $log(MP)_{i,t,5}$ | 0.0380*** |
| | (0.0143) |
| $log(MP)_{i,t,6}$ | -0.0461*** |
| | (0.0145) |
| $log(MP)_{i,t,7}$ | -0.000505 |
| | (0.00789) |
| $log(MP)_{i,t,8}$ | 0.00447 |
| | (0.00748) |
| $log(MP)_{i,t,9}$ | -0.0272*** |
| | (0.00953) |
| $log(MP)_{i,t,10}$ | -0.0102 |
| | (0.0131) |
| $log(MP)_{i,t,11}$ | -0.0115 |
| | (0.0122) |
| $log(MP)_{i,t,12}$ | -0.0346*** |
| | (0.0132) |
| $log(MT)_{i,t,1}$ | -0.0251 |
| | (0.0249) |
| $log(MT)_{i,t,2}$ | 0.0697** |
| | (0.0292) |
| $log(MT)_{i,t,3}$ | -0.354* |
| | (0.199) |
| $log(MT)_{i,t,4}$ | 3.321** |
| | (1.377) |
| $log(MT)_{i,t,5}$ | -7.906* |
| | (4.306) |
| $log(MT)_{i,t,6}$ | -3.592 |
| | (6.974) |
| $log(MT)_{i,t,7}$ | -4.448 |
| | (10.95) |
| $log(MT)_{i,t,8}$ | 17.30* |
| | (10.28) |
| $log(MT)_{i,t,9}$ | -4.125 |
| | (6.424) |
| $log(MT)_{i,t,10}$ | 1.118 |
| | (2.177) |
| $log(MT)_{i,t,11}$ | -0.101 |
| | (0.171) |
| $log(MT)_{i,t,12}$ | 0.0116 |
| | (0.0292) |
| $log(MT)_{i,t,1}$^2 | -0.0208 |
| | (0.0133) |
| $log(MT)_{i,t,2}$^2 | 0.0266* |
| | (0.0140) |
| $log(MT)_{i,t,3}$^2 | 0.0908 |
| | (0.0703) |
| $log(MT)_{i,t,4}$^2 | -0.734** |
| | (0.292) |
| $log(MT)_{i,t,5}$^2 | 1.303* |
| | (0.768) |
| $log(MT)_{i,t,6}$^2 | 0.361 |
| | (1.151) |
| $log(MT)_{i,t,7}$^2 | 0.509 |
| | (1.728) |
| $log(MT)_{i,t,8}$^2 | -2.611 |
| | (1.620) |
| $log(MT)_{i,t,9}$^2 | 0.888 |

| | |
|---|---|
| | (1.083) |
| $log(MT)_{i,t,\mathbf{10}}$**^2** | -0.154 |
| | (0.417) |
| $log(MT)_{i,t,\mathbf{11}}$**^2** | -0.0106 |
| | (0.0552) |
| $log(MT)_{i,t,\mathbf{12}}$**^2** | 0.00118 |
| | (0.0178) |
| $P_{Wheat,i,t-1}$ | 0.00463 |
| | (0.00573) |
| $P_{Barley,i,t-1}$ | 0.00167 |
| | (0.00222) |
| $P_{Commodity,t-1}$ | 0.699 |
| | (1.306) |
| $P_{Fertilizer,t-1}$ | -0.661 |
| | (0.577) |
| Constant | 4.896 |
| | (20.93) |
| Observations | 889 |
| Number of Province | 69 |
| Year FE & Province FE | YES |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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TÜRKİYE CUMHURİYET
MERKEZ BANKASI

# The Impact of Precipitation and Temperature on Wheat Production in Türkiye


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May 6-7, 2024

**CBRT-IFC Workshop, İzmir**



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# Outline



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(*) The contents of this study do not reflect the view of Central Bank of the Republic of Türkiye.

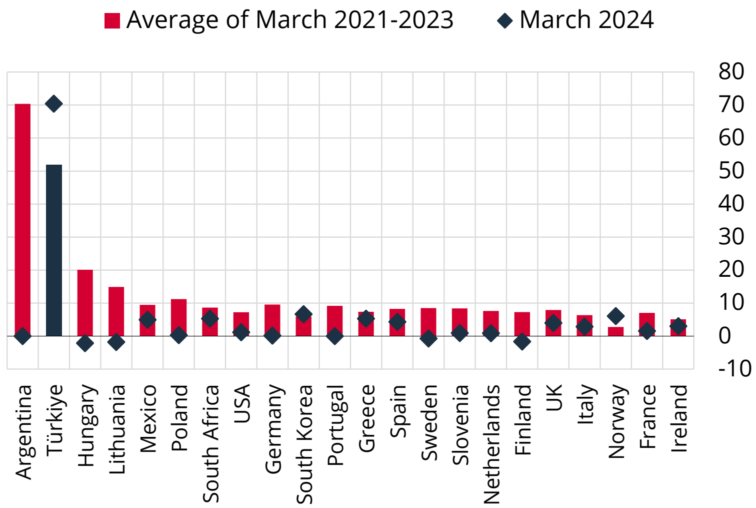
# Purpose

- Attaining price stability is one of the main responsibilities of the CBRT. Inflation especially food inflation plays crucial role for the Turkish economy when high share of minimum waged households together with high share of food expenditures are considered.
- With the aim of monitoring food and agricultural products markets more closely in our country, the Food Committee was established in 9 December 2014.
- In 2021, to identify structural problems and develop solutions for price instability due to food inflation, CBRT- Food and Agricultural Product Markets Analysis Department was established and works closely with relevant institutions and organizations.
- One of the top priority tasks of our department is the construction of Early Warning System (EWS) which aims to provide policy makers timely information about risks on agriculture and food markets.
- This warehouse allows the analysis of data on food and agricultural product prices, critical for price stability, in a detailed and timely manner also enables the implementation of necessary precautionary measures.

# Purpose

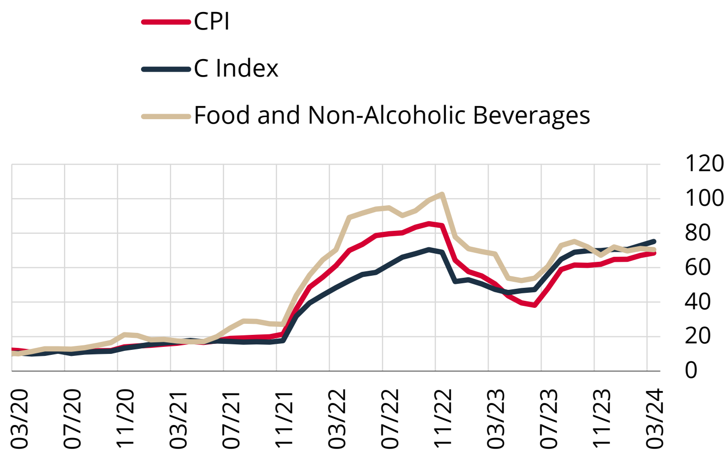
- The divergence between Turkish and international food price levels has been increasing.
- At the same time, Türkiye's food prices have been increasing faster and displaying higher volatility than overall prices in the domestic market.
- The behavior of domestic food prices, when compared to non-food prices, suggest that there are underlying domestic factors that are exerting upward pressure on food price levels and volatility.

**Food and Non-Alcoholic Beverages Prices** (Annual, %)




Source: OECD,TURKSTAT

**CPI, C Index, Food and Non-Alcoholic Beverages*** (Annual, %)




Source: TURKSTAT
*C index: CPI excluding food and non-alcoholic beverages, energy, alcohol-tobacco and gold.

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# Purpose

- Agriculture is one of the most vulnerable sector to climate change.
- Climate change poses a significant threat for Turkish economy through agricultural production which is crucial with respect to its contribution to employment, exports and national income.
- Wheat, which is the most produced, harvested and consumed crop across the world is particularly very sensitive to precipitation and temperature changes.
- Türkiye was ranked as the $12^{th}$ largest wheat producer in the world (FAOSTAT, 2022). According to 2023 national statistics 22 million tonnes of wheat production constitutes 54.3% of total crop production in Türkiye (TurkStat, 2023).
- The impact of climate change on wheat production is investigated for Türkiye at province-level with **unique, up-to-date and comprehensive dataset** that is constructed by CBRT under the Early Warning System (EWS) Project.
- The results indicate a significant reduction in wheat production in the short, medium and long-term. The impact is found to be increasing over time depending on various climate scenarios.

# Data

The study utilizes a wide range of micro-level data from the Early Warning System Project of Central Bank of the Republic of Türkiye.

The analysis covers 2000-2023 period.

| Data | Time Span | Frequency | Source |
|---|---|---|---|
| **Production** | 1991-2023 | Annual | Ministry of Agriculture and Forestry |
| **Meteorological Data (Temperature & Precipitation)** | 1990-2024 | Daily | Turkish State Meteorological Service |
| **Wheat and Barley Prices** | 1980-2022 | Monthly | TURKSTAT (TL/kg) |
| **Agricultural PPI** | 1991-2024 | Monthly | TURKSTAT (Index) |
| **Fertilizer Prices** | 2000-2024 | Monthly | Ministry of Agriculture and Forestry (Index) |
| **Commodity Prices** | 2000-2024 | Daily | International Grains Council (Index) |
| **Climate Scenarios** | 2030-2050 / 2050-2070 / 2070-2100 | Seasonal | IPCC Interactive Atlas (IPCC, Gutiérrez, et al., 2021) / (Bağçaci et al., 2021) |

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# Methodology

Monthly average temperature and precipitation across provinces over time are used separately as explanatory variables.

All models are estimated with fixed effect panel regression.

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**1. Baseline Model:**

$$\log(Prod_{i,t}) = \beta_0 + \beta_1 \log(Prod_{i,t-1}) + \sum_{k=1}^{11} \gamma_{ik} \log(MP_{i,k,t-1}) + \sum_{l=1}^{11} \gamma_{il} \log(MT_{i,l,t-1}) + \alpha_1 \Delta PD_{Wheat,i,t-1} + \alpha_2 \Delta PD_{Barley,i,t-1} + \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4 \Delta P_{Commodity,t-1} + \gamma_i + \Omega_t + e_{i,t}$$

**2. Reduced Form Baseline Model:**

$$\log(Prod_{i,t}) = \beta_0 + \beta_1 \log(Prod_{i,t-1}) + \beta_2 \log(MP_{March_{i,t}}) + \beta_3 \log(MP_{April_{i,t}}) + \beta_4 \log(MP_{May_{i,t}}) + \beta_5 \log(MP_{June_{i,t}}) + \beta_6 \log(MP_{October_{i,t}}) + \beta_7 \log(MP_{November_{i,t}}) + \beta_8 \log(MT_{February_{i,t}}) + \beta_9 \log(MT_{March_{i,t}}) + \beta_{10} \log(MT_{April_{i,t}}) + \beta_{11} \log(MT_{May_{i,t}}) + \beta_{12} \log(MT_{June_{i,t}}) + \beta_{13} \log(MT_{July_{i,t}}) + \alpha_1 \Delta PaD_{Wheat,i,t-1} + \alpha_2 \Delta PD_{Barley,i,t-1} + \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4 \Delta P_{Commodity,t-1} + \gamma_i + \Omega_t + e_{i,t}$$

**3. Model With Composite Climate Variables**

$$\log(Prod_{i,t}) = \beta_0 + \beta_1 \log(Prod_{i,t-1}) + \beta_2 \log(PCP_{i,t}) + \beta_3 \log(PCT_{i,t}) + \alpha_1 \Delta PD_{Wheat,i,t-1} + \alpha_2 \Delta PD_{Barley,i,t-1} + \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4 \Delta P_{Commodity,t-1} + \gamma_i + \Omega_t + e_{i,t}$$

# Estimation Results

## Reduced Form Baseline Model:

| VARIABLES | (1) Reduced form baseline model |
|---|---|
| $\log(Prod)$ | 0.577*** |
| $log(MP_{March})$ | 0.0565*** |
| $log(MP_{April})$ | 0.0167 |
| $log(MP_{May})$ | 0.00457 |
| $log(MP_{June})$ | -0.0322*** |
| $log(MP_{October})$ | -0.0134 |
| $log(MP_{November})$ | -0.0224** |
| $log(MT_{February})$ | 0.0578*** |
| $log(MT_{March})$ | -0.100** |
| $log(MT_{April})$ | -0.124 |
| $log(MT_{May})$ | -1.065*** |
| $log(MT_{June})$ | -0.692** |
| $log(MT_{July})$ | -0.325 |
| $\Delta PD_{Wheat}$ | 0.00842* |
| $\Delta PD_{Barley}$ | 0.00347 |
| $\Delta P_{Commodity}$ | 0.266 |
| $\Delta P_{Fertilizer}$ | -0.247 |
| Constant | 12.89*** |
| Observations | 1,330 |
| Number of Province | 76 |
| Year FE & Province FE | YES |

## Principal Component Analysis:

| VARIABLES | (b) Reduced form baseline model |
|---|---|
| *log(Prod)* | 0.586*** |
| | (0.0221) |
| *PCP* | 0.0380*** |
| | (0.00991) |
| *PCT* | -0.106*** |
| | (0.0150) |
| $\Delta PD_{Wheat}$ | 0.00929* |
| | (0.00513) |
| $\Delta PD_{Barley}$ | 0.00327 |
| | (0.00218) |
| $\Delta P_{Commodity}$ | 1.510*** |
| | (0.497) |
| $\Delta P_{Fertilizer}$ | -0.693*** |
| | (0.240) |
| Constant | 6.042*** |
| | (0.366) |
| Observations | 1,330 |
| Number of Province | 76 |
| Year FE & Province FE | YES |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

# Climate Scenarios

Climate scenarios released by IPCC utilizing Global Circulation Models are widely accepted in climate literature.

With the advancement of data, the regional performance of GCMs has improved significantly especially in simulating temperature and precipitation changes.

**Estimated Temperature Change for High Emissions Scenario (Low Emissions Scenario) (ºC)**

| | | Marmara | Black Sea | Eastern Anatolia | Aegean | Central Anatolia | Mediterranean | Southeastern Anatolia | Average |
|---|---|---|---|---|---|---|---|---|---|
| 2030-2050 | Spring | 1.1 (0.9) | 1.1 (0.8) | 1.2 (1.0) | 1.1 80.9) | 1.1 (0.9) | 1.2 (1.0) | 1.2 (1.0) | **1.1 (0.9)** |
| | Summer | 1.9 (1.6) | 1.7 (1.5) | 1.9 (1.7) | 2 (1.7) | 2 (1.7) | 2 (1.7) | 2 (1.7) | **1.9 (1.7)** |
| | Autumn | 1.4 (1.1) | 1.5 (1.2) | 2 (1.6) | 1.5 (1.2) | 1.8 (1.4) | 1.7 (1.4) | 2 (1.6) | **1.7 (1.4)** |
| | Winter | 0.8 (0.7) | 0.8 (0.8) | 1.3 (1.3) | 0.8 (0.7) | 0.9 (0.9) | 0.9 (0.8) | 1.2 (1.1) | **1 (0.9)** |
| 2050-2070 | Spring | 2.1 (1.2) | 2 (1.1) | 2.6 (1.5) | 2.2 (1.3) | 2.3 (1.3) | 2.5 (1.5) | 2.7 (1.6) | **2.3 (1.4)** |
| | Summer | 3 (2) | 2.8 (1.9) | 3.5 (2.2) | 3.4 (2.1) | 3.6 (2.2) | 3.6 (2.3) | 3.5 (2.3) | **3.3 (2.1)** |
| | Autumn | 2.5 (1.5) | 2.6 (1.5) | 3.5 (2.1) | 2.7 (1.6) | 3.2 (1.8) | 3.1 (1.9) | 3.6 (2.2) | **3 (1.8)** |
| | Winter | 1.7 (1) | 1.9 (1) | 2.9 (1.6) | 1.7 (1) | 2.1 (1) | 1.9 (1.1) | 2.5 (1.4) | **2.1 (1.2)** |
| 2070-2100 | Spring | 3.4 (1.2) | 3.1 (1.1) | 3.9 (1.5) | 3.6 (1.3) | 3.6 (1.3) | 4 (1.5) | 4.2 (1.6) | **3.7 (1.9)** |
| | Summer | 4.9 (2.7) | 4.7 (2.5) | 5.9 (3) | 5.5 (2.9) | 6 (3.1) | 5.8 (3.1) | 6 (3.1) | **5.5 (2.9)** |
| | Autumn | 3.7 (1.9) | 3.9 (1.9) | 5.1 (2.7) | 4.1 (2.1) | 4.7 (2.4) | 4.8 (2.5) | 5.2 (2.8) | **4.5 (2.3)** |
| | Winter | 2.8 (1.2) | 2.9 (1.3) | 4.2 (2.1) | 2.8 (1.2) | 3.1 (1.4) | 3 (1.4) | 3.7 (1.8) | **3.2 (1.5)** |

Source: Bagcaci et. al. (2021)

# Conclusion

Almost 11% to 36% reduction in wheat production would be expected based on different scenarios due to increasing spring temperature in Türkiye.

**Estimated Impact of Temperature Change on Wheat Production under High Emissions Scenario**

| | | Projected Temperature Increase (°C)* | Historical Average Temperature (1995-2014) (°C)** | Projected Change (%) | Wheat*** | Estimated Impact (%) |
|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 1.1 | 12.1 | 9.1 | -1.2 | **-10.6** |
| | **Summer** | 1.9 | 23.8 | 8.0 | -0.7 | **-5.5** |
| **2050-2070** | **Spring** | 2.3 | 12.1 | 19.0 | -1.2 | **-22.2** |
| | **Summer** | 3.3 | 23.8 | 13.9 | -0.7 | **-9.6** |
| **2070-2100** | **Spring** | 3.7 | 12.1 | 30.6 | -1.2 | **-35.8** |
| | **Summer** | 5.5 | 23.8 | 23.1 | -0.7 | **-15.9** |

**Estimated Impact of Temperature Change on Wheat Production under Low Emissions Scenario**

| | | Projected Temperature Increase (°C)* | Historical Average Temperature (1995-2014) (°C)** | Projected Change (%) | Wheat*** | Estimated Impact (%) |
|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 0.9 | 12.1 | 7.4 | -1.2 | **-8.7** |
| | **Summer** | 1.7 | 23.8 | 7.1 | -0.7 | **-4.9** |
| **2050-2070** | **Spring** | 1.4 | 12.1 | 11.6 | -1.2 | **-13.5** |
| | **Summer** | 2.1 | 23.8 | 8.8 | -0.7 | **-6.1** |
| **2070-2100** | **Spring** | 1.9 | 12.1 | 15.7 | -1.2 | **-18.4** |
| | **Summer** | 2.9 | 23.8 | 12.2 | -0.7 | **-8.4** |

*(Bagcaci et al., 2021)
**Turkish State Meteorological Service
***Based on writers' calculations

# Conclusion

- Under both high and low emissions scenario, temperature increase especially during spring and summer months, would decrease wheat production significantly over the course of short, medium and long term.
- The estimation results of our model present the alarming impact of meteorological variables on staple crop production.
- The analysis in this study is formed by a novel data set gathered under Food-EWS of CBRT enabling us to generate relatively higher level of statistical validity through performing panel data analysis.
- We believe that with the availability and advancement of the data under Food-EWS, our model would improve and our results would be more scrutinized.
    - More timely and higher frequency production data can help to make reliable and healthy analysis about the climate impact on economic activity.
    - In addition to temperature and precipitation, in order to be able to evaluate climate risk thoroughly, humidity data needed.

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