THE IMPACT OF WEATHER CONDITIONS ON ECONOMIC ACTIVITY IN UKRAINE

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Abstract This article explores the impact of weather conditions on core sectors of the Ukrainian economy and the composite index of economic activity in Ukraine. We build autoregressive distributed lag (ARDL) models using statistical data provided by the Central Geophysical Observatory named after Boris Sreznevsky (CGO) and the State Statistics Service of Ukraine for the period 2004-2019. The obtained outcomes show that fluctuations in the air temperature and precipitation are significant determinants of output in different sectors (specifically agriculture, construction, manufacturing, and energy). Therefore, the inclusion of weather conditions into models may potentially improve the modeling properties and forecasting of economic activity.

JEL Codes C51, E01, O44

Keywords weather conditions, autoregressive distributed lag

1. INTRODUCTION

Is there a connection between weather conditions and economic growth? According to Financial Times analyst Gavyn Davies, the slowdown in the Eurozone and the UK was due, among other things, to adverse weather conditions (Davies, 2018). Research by Bloomberg and Reuters also confirms that economic losses are partly caused by exceptional weather conditions (Sullivan and Doan, 2012; Barlyn, 2019). In addition, central banks also take weather factors into account when preparing monetary policy analysis materials. One example is the Inflation Report of the Bank of England (Bank of England, 2018).

Weather conditions are traditionally understood as a set of meteorological indicators (air temperature, precipitation, atmospheric pressure, relative humidity, solar radiation, wind speed and direction, etc.) and atmospheric phenomena that are observed at a certain point in time at a particular point in space. Weather conditions may influence economic activity through several channels (International Monetary Fund, 2017). First, weather conditions have a significant impact on the level of labor productivity, which in turn is reflected in changes in real GDP.[1] Second, weather factors (including air temperature, precipitation, and solar radiation) have a direct impact on the volume of agricultural production, especially crop farming (Acevedo et al., 2018).

Weather factors have a notable impact on the dynamics of individual macroeconomic indicators in developing countries (including Ukraine), as potentially weather-sensitive industries (e.g. agriculture) constitute the core sectors of these countries' economies. For example, an early start to the harvesting season in Ukraine in June 2019, thanks to accelerated spring vegetation amid favorable weather conditions, resulted in an increase in early crop yields (compared to the same period a year before) harvested by Ukrainian farmers. This had a positive impact on Ukraine's real GDP growth in Q2 2019 (to 4.7% yoy).

Other economic sectors besides agriculture are influenced by weather factors. In particular, the cold spring weather in Ukraine in March 2018 fueled growth in the energy sector (+24.2% yoy), while, for example, heavy snowfall in March 2013 paralyzed motorway, rail, and air transportation. This had a noticeable, albeit short-term, impact on the dynamics of passenger and freight transportation as well as volumes of retail trade.

Thus, given the sensitivity of the Ukrainian economy to changes in weather conditions, this article aims to provide a methodology to estimate the contribution of weather to output in the core economic sectors. This approach could lay the groundwork for improving the accuracy of forecasting the current value of IKSO, the composite index of economic activity, and hence the accuracy of nowcasting quarterly real GDP.[2]

This article is structured as follows: the second section provides a review of the literature on the subject matter; the

[1] Chen (2015) notes that labor productivity decreases with the rise of air temperatures above 30°C, while low air temperatures demonstrate no effect on labor productivity.
[2] Index of Key Sectors Output (IKSO) is a composite index of economic activity calculated by the NBU. It is a key indicator of real economic growth.

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third section describes the methodology and data used in the study; the fourth section presents the results of model calculations, namely quantitative evaluation of the impact of weather conditions on the monthly indices of certain economic activities in Ukraine; and the final section contains conclusions.

2. LITERATURE REVIEW

Economic literature use both linear and nonlinear models to study the influence of weather conditions on the dynamics of macroeconomic indicators (i.e. a country's GDP, employment, economic activity, etc.). Empirical studies apply a comprehensive multiple regression analysis, where changes in the air temperature and precipitation generally serve as independent variables.

To estimate the impact of long-term changes in weather conditions on GDP, researchers traditionally use a production function which also covers the so-called “loss” function”.[3] The latter characterizes the impact of changes in the air temperature on the level of economic activity (Batten, 2018). The functional form of the loss function is such that in the absence of long-term changes in the average air temperature, GDP losses from the influence of weather factors equal to zero, while in response to rising air temperatures, GDP losses increase. To this end, the Weitzman (2009) study, for example, used the exponential “loss” function.

Dietz and Stern (2015) consider different ways of incorporating a factor that characterizes changes in weather conditions into the production function. The first way is to include this factor in the equation describing labor productivity.[4] The second way involves constructing an equation that characterizes the level of physical capital stocks in the economy[5]: that is, in each period of time, investment contributes to an increase in capital stocks, while a decrease in capital stocks depends on physical wear and weather changes.

Hissler (2010) found a statistically significant effect of weather factors (including changes in precipitation) on agricultural production in the African Sahel. The study demonstrated that agriculture in the countries analyzed remains sensitive to the variability of precipitation over time.

Bloesch and Gourio (2015) revealed a considerable, though short-term, impact of winter weather on economic activity in US economic sectors such as housing, construction, and retail, whereas for other industries this impact turned out to be insignificant.

Continuing the previous study, Gourio (2015) assessed the impact of weather conditions (air temperature and snowfall) on US GDP. The author’s calculations showed a noticeable effect of weather conditions on the dynamics of indicators in monthly terms. However, the study noted that this effect was neutralized within two months, becoming imperceptible in quarterly data. François Gourio believes that retail and industry are the most sensitive sectors as far as weather changes are concerned.

Burke et al. (2015) and Acevedo et al. (2017) emphasize the existence of a statistically significant nonlinear relationship between air temperature and real GDP per capita. According to the Acevedo et al. (2017) study, rising air temperatures reduce economic activity in countries with relatively high average annual air temperatures; however, the effect is the opposite in countries with a cold climate.

The Dell et al. (2014) study also recognizes the inverse relationship between air temperature and per capita income. However, such relationship is true only for poor countries where agriculture serves as the main driving force.

Our article is most closely related to the study presented researchers of the Bank of England (Bank of England, 2018). The latter, in particular, assesses the impact of heavy snowfalls on the performance of the economy as a whole and its individual sectors (namely electricity, construction, retail, and services provision).

The authors of the Bank of England report came to the conclusion that weather conditions have a temporary effect on total product output. That is if a change in weather causes a shortfall in economic output in a certain quarter, we should expect to make up for lost opportunities in the next quarter and, as a result, the impact of weather conditions on semi-annual and annual indicators is smoothed and becomes insignificant. In contrast to the Bank of England study, we also analyze the impact of weather on the dynamics of selected individual economic sectors, albeit focusing on the average monthly air temperature and monthly rainfall.

3. DATA AND METHODOLOGY

Estimating the impact of weather conditions on economic activity involves determining a set of meteorological elements to be included in the study (Bloesch and Gourio, 2015). Data from the Central Geophysical Observatory named after Boris Sreznevsky (CGO) served as the source of information on weather conditions for this article.[6] The CGO stores monthly measurements of many weather factors in Kyiv (in particular air temperature and humidity, soil temperature, wind direction and speed, atmospheric pressure, precipitation, cloudiness, and snow cover). The average monthly air temperature and the average monthly precipitation were the only values taken into account.[7]

In our study, we use monthly data for core sector output indices (agriculture, industry, construction, trade, and transport) from the official website of the SSSU.[8] The quality of time series of meteorological indicators was checked as follows. We analyzed both the number of deviations of weather conditions from the respective levels in the year before and from normative values. The descriptive statistics for the main variables used in this study are shown in Table 1. Note that the absence of a unit root in the time series, as evidenced by the data in Table 2, confirmed the possibility of using existing time series to build autoregressive models.

[3] $Y_t = A_t D(\Delta T_t) F(K_t, L_t)$, where A_t – technological efficiency indicator, L_t – labor factor, K_t – capital factor, $D(\Delta T_t)$ – "loss" factor due to temperature changes.
[4] $A_{(t+1)} = (1 - D_t^A) A_t$, where D_t^A characterizes the quantitative impact of weather conditions on production efficiency indicators (including labor productivity).
[5] $K_{(t+1)} = (1 - D_t^K)(1 - \delta) K_t + I_t$, where D_t^K characterizes the degree of the losses of companies’ stocks as a result of weather factors, δ – depreciation rate, I_t – capital investment.
[6] CGO named after Boris Sreznevsky is the oldest organization among meteorological agencies in Ukraine which has been collecting and storing hydrometeorological observations since the middle of the XIX century.
[7] Calculated as the arithmetic mean of daily values.
[8] State Statistics Service of Ukraine. Retrieved from http://www.ukrstat.gov.ua

At the preliminary analysis stage, the relationship between variables that describe weather conditions and the dynamics of output in the core sectors of the Ukrainian economy was determined on the basis of matrices of correlation coefficients. Table 3 concludes that there is a moderate negative relation between output in the energy sector and the change in the average monthly air temperature in autumn and winter. Thus, energy production is sensitive to weather. Accordingly, warmer weather in the cold season has an inverse relationship with the performance of this industry. For other sectors of the economy, there is a weak correlation between changing weather conditions and their output dynamics. Therefore, the variables of weather conditions alone are not sufficient to explain the dynamics of the core sectors of the Ukrainian economy. For example, one study (Doronin, 2014) notes that the efficiency of a grain sector largely depends on the size of sown areas, the state of grain sales infrastructure, loan interest rates, budget support for the industry, etc. Another study (OECD, 2019) states that the efficiency of the energy sector in Ukraine is dependent on the negative impact of outdated technologies, strict regulation of the sector, improper management of public institutions, and declining demand. The NBU's information and analytical materials (National Bank of Ukraine, 2020) also stress the importance of the latter factor while analyzing the dynamics of energy sector output.

We consider several specifications to identify the statistical significance of the influence of weather conditions on the indicators of economic activity in the Ukrainian economy's core sectors. As dependent variables, we used monthly indices of output in the core economic sectors $y_j(t), j=\overline{1,9}$[9]:

Specification one. We used the autoregressive approach, i.e. the values of the dependent variables $y_j(t\text{-}s)(s=\overline{1,p})$ were used as lag explanatory variables, where "s" is the order of the autoregressive process. In its general form, the autoregression model $AR(p)$ can be expressed as follows:

$$y_j\,(t)=f(c,\, y_j(t\text{-}s),\, \varepsilon_j), \quad (1)$$

where: c – is constant; ε_j – is a random component.

Specification two. We built autoregressive distributed lag models with , i.e. the list of variables used in the first stage was supplemented by lags of independent variables $x(t\text{-}l)$, where l – is the length of the lag. Given below is the general form of the autoregressive distributed lag model $ARDL(l,p)$:

$$y_j(t)=f(c,y_j(t\text{-}s),\, x(t\text{-}l),\, \varepsilon_j) \quad (2)$$

And, finally, *specification three*. The list of variables used in the previous stage, was supplemented by determinants of weather conditions (namely changes in the average monthly air temperature ΔT and monthly precipitation ΔP[10]). The general form of the regression equation is written as follows:

$$y_j(t)=f(c,y_j\,(t\text{-}s),x(t\text{-}l),\Delta T_t,\Delta P_t,\, \varepsilon_j) \quad (3)$$

Table 4 presents the specifications of equations (1)-(3) for each core type of economic activity. The implementation was carried out in the Eviews 8.0 environment. The best specifications of regression equations were selected based on the results of verification: adequacy of regression equations, statistical significance of beta coefficients, absence of residual autocorrelation (verification was performed on the basis of autocorrelogram, partial autocorrelogram, and Ljung-Box Q-statistics). Also, when choosing the regression equation, the following factors were taken into account: the coefficient of determination and information criteria of Akaike and Schwarz. Conducting the augmented Dickey-Fuller test, we rejected the null hypothesis that the residuals have a unit root, while the bell-shaped histograms of the residual distribution, the statistical insignificance of Jarque-Bera statistics, and the location of the quantile residues near the 45-degree baseline confirmed their compliance with the normal distribution.

Further, we evaluate the contribution of weather conditions to the dynamics of particular industries on the basis of selected regression equations. For this purpose, we added together the products of the coefficients near variables ΔT_t, ΔP_t with the changes in weather conditions calculated on the basis of the CGO data (average monthly air temperature and monthly precipitation).

As the last step, the following equation was used to estimate the contribution of weather conditions to IKSO as the composite index of economic activity:

$$C_{IKSO_t}=\sum_{j=1}^{9} w_j \cdot v_{jt}, \quad (4)$$

where w_j – weight of the industry in the Index of Key Sectors Output (IKSO) in period t; v_{jt} – contribution of weather conditions to the dynamics of industry j $(j=\overline{1,9})$.

4. ESTIMATION RESULTS

The preliminary analysis shows that agriculture, construction, manufacturing, and energy are the most sensitive to weather conditions. Figure 1 demonstrates that these sectors account for a significant share of Ukrainian GDP (e.g. 25.6% of GDP or UAH 1,018.6 billion in 2019). While the manufacturing industry's share of GDP shrank (particularly due to the loss of production in the occupied territories) and construction's share remained insignificant during 2015-2019, agriculture's GDP share increased. The growing role of agriculture was supported, in particular, by continued state support for farmers and increasing grain and oilseed yields.

In this section, we estimate the contribution of weather conditions to output dynamics in Ukraine's core economic sectors. In particular, the results of the econometric analysis presented in Table 4 show that the last of our three specifications, one that contains changes in weather conditions, yields the results with the highest explanatory power. Therefore, it is justified to supplement the regression equation with the determinants of weather conditions in assessing Ukrainian economic sectors' production dynamics.

At the same time, the quantitative estimates (see Table 4) demonstrate statistically significant effects of the air temperature and precipitation, primarily on those sectors that involve work in the open air (including open construction sites) or in unheated premises (namely agriculture, construction, manufacturing industry, and energy).

[9] The study focused on the following core sectors: agriculture, manufacturing and mining industries, energy, construction, retail and wholesale trade, and freight and passenger transportation.
[10] The author tested two options, namely changes in weather conditions compared to: a) the same period a year earlier, b) the norm. According to the results presented in Table 4, statistical characteristics of the equations set up on the basis of deviations of weather conditions as compared with the previous year's level are better.

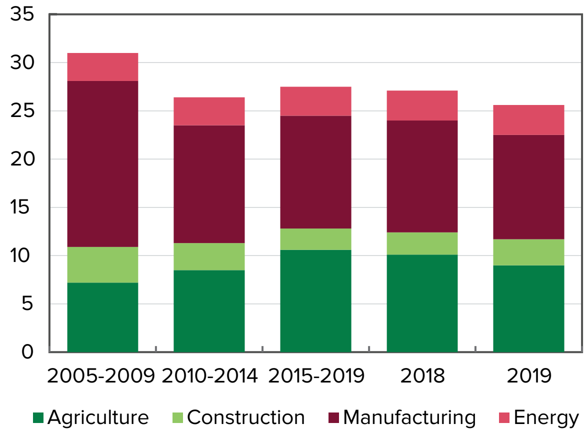

Figure 1. Core Economic Sectors' Share of GDP (in actual prices, % of total), on average for period
Note: In accordance with the SNA 2008 methodology. Starting from 2010, data exclude the temporarily occupied territory of Crimea, the city of Sevastopol, and part of the temporarily occupied territories of the Donetsk and Luhansk oblasts.
Sources: Author's calculations on the basis of SSSU data.

Given the significant role industry, agriculture, and construction play in the Ukrainian economy, we first interpret the estimation results of the impact of weather conditions for these particular sectors.

Agriculture

Weather conditions have a significant impact on agricultural production dynamics, primarily through their effect on crop farming (as measured by harvest volumes, harvest quality, and yields, among other things).[11] According to the model calculations presented in Table 4a, the absolute values of weather condition variables are marginal, but their impact is statistically significant at the 0.1 level of significance.

As shown in Table 4a, the influence of weather conditions on the growth and development of crops is multidirectional and, as noted in Yeremenko et al. (2018), depends on the phases of growth, the timing of seed formation and filling, etc. Specifically, crops require different amounts of heat and rainfall, depending on which stage they are at in their growth cycle. Higher air temperature in the fall compared to the previous year's level has been shown to have a significant positive impact on agricultural dynamics in Ukraine (through a positive effect on harvesting).[12] However, early-spring air temperature values that are lower than in the same period a year ago have a negative effect on wheat yields (including due to a phosphorus shortage in plants). More specifically, a 1°C decrease in the air temperature in March compared to the same month a year earlier cuts growth in the agricultural sector in June of the current year by an average 1.4 pp (all else held equal), according to my calculations presented in Table 4(A). At the same time, cool weather during the maize sowing period (late April through early May) limits the absorption of nutrients, slows the crop's development and reduces its yield, thus adversely affecting agricultural production dynamics in September-October (when maize is harvested).

As with temperatures, optimal precipitation levels depend on plant development phases. A rainless fall, for instance, is favorable for harvesting late grains but hinders the normal growth and development of winter crops, while scarce precipitation in winter adversely affects the volume and the quality of the future harvest. In particular, a 1 mm drop in precipitation in winter compared to a year earlier shaves 0.47 pp off growth in agriculture in the summer of the following year (all else held equal), according to my estimates.

Overall, these calculations show that the impact of weather conditions on agricultural sector dynamics is noticeable from June through November each year, while in other months of the year it is close to zero (see Figure 5). This is due to the fact that the domestic agricultural production index begins to trace crop farming dynamics in June, complementing livestock farming. Specifically, the positive contribution of weather conditions to agricultural production in June 2018 stemmed from an early start to the harvesting season, which was enabled by low rainfall and high air temperatures. In contrast, low night temperatures in November 2018, which had an adverse impact on the harvest volume of industrial crops and oilseeds, fueled a negative contribution of weather conditions to agricultural production dynamics (-2.1 pp, according to my calculations).

Taking into account the significant impact of weather conditions on agricultural sector performance, and assuming that this impact is primarily transmitted through the crop farming sector, we also tried to quantify the contribution of weather conditions to the production of major crops in Ukraine, specifically wheat and maize. These calculations are shown in Figures 2, 3. Weather conditions made a negative contribution to growth in the wheat harvest in 2019, according to our estimates.[13] Among other things, this was a consequence of insufficient precipitation in October and early November 2018. This led to unfavorable conditions for the initial growth and development of the future harvest of winter crops. However, early crop yields were positively affected by ample precipitation in April–May 2019, while mild weather in August had a positive impact on late crop yields (maize in particular). Meanwhile, the cool April weather and excessive rainfall in June-July this year were the unfavorable factors that depressed late crop yields. Overall, weather conditions made a negative contribution to growth in last year's corn harvest, according to my estimates (see Figure 3).[14]

Figures 2, 3 demonstrate clearly how weather conditions affect the dynamics of maize and wheat production in Ukraine. This result is in line with the calculations by other

[11] While crop farming accounts for 60%-70% of gross agricultural output, livestock farming represents only 30%–40%. This explains the definitive influence of crop farming indicators on the agricultural production index.
[12] A 1°C increase in the air temperature in the fall of the current year compared to the same period a year earlier accelerates growth in the agricultural sector by an average 1.75 pp (other things being equal) (see Table 4a).
[13] Weather's contribution to the increase in the wheat harvest was estimated using a regression equation. The following explanatory variables were used: deviations from the previous year's average rainfall in April–May and October–November (the variable was lagged one period), and an increase in sown areas under grains and legumes (excluding maize). Variation in the weather and sown area variables explained 66% of the variation in the dependent variable, the regression analysis showed. These explanatory variables had a statistically significant impact (Table 4(K)).
[14] To estimate the contribution of weather conditions to growth in the maize harvest, I ran a regression with the following independent variables: deviations of average monthly precipitation in June-July and average monthly air temperatures in April and August from the respective previous-year levels, and growth in the sown area under maize. Variation in the weather and sown area variables accounted for 72% of the variation in the dependent variable, the regression analysis showed (Table 4l).

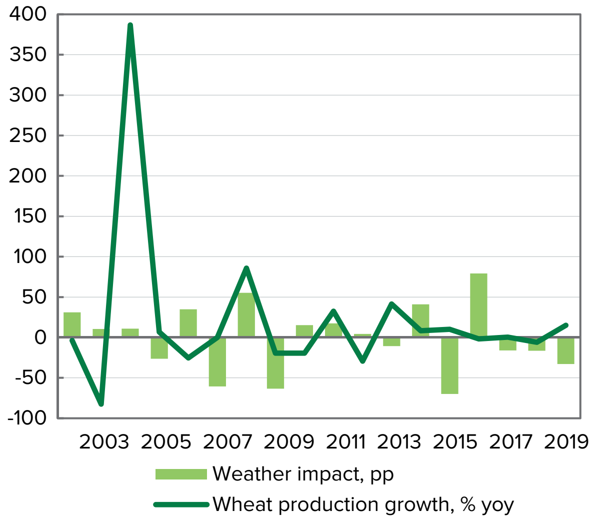

Figure 2. Weather Impact on Growth in Wheat Production, %
Sources: Author's calculations based on SSSU, NBU, and CGO data.

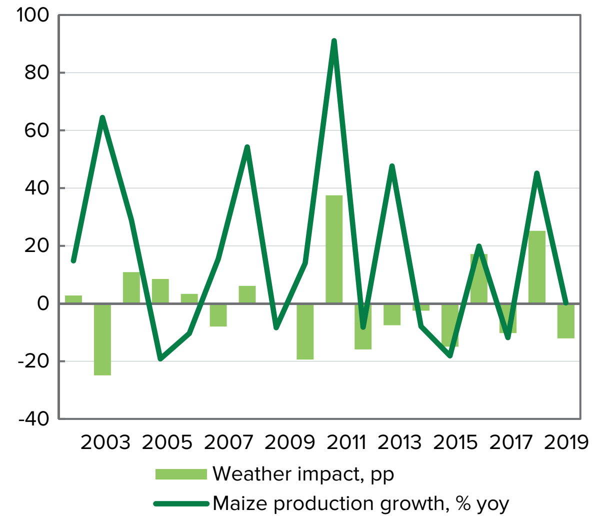

Figure 3. Weather Impact on Growth in Maize Production, %
Sources: Author's calculations based on SSSU, NBU, and CGO data.

authors, in particular Mendelsohn (2008), who writes that the crop farming sector is the main channel that transmits the impact of weather on economic activity in developing countries.

The fact that weather effects and growth in the grain harvest (Figures 2 and 3) are not closely related confirms the view, expressed in Paltasingh and Goyari (2018), that crop yields are affected not only by weather but also by a number of other factors such as soil fertility, increases in sown areas under grains and legumes, use of selected varieties of grains, use of pesticides and fertilizers, etc.

Construction

Construction is the second most weather-sensitive sector. Strong wind, dense dust or fog, high or too low air temperatures, and excessive rainfall can cause serious injuries to workers and significantly damage rigging equipment and mounting devices. Lightning endangers the personnel who operate cranes and hoists. The occurrence of force majeure due to adverse weather conditions will in turn cause additional economic costs and delay the implementation of construction projects. In general, the dependence of construction dynamics on weather conditions is direct and most noticeable during cold seasons (December through March), according to my estimates. Specifically, at a significance level of 0.1, a 1°C increase (from a year earlier) in air temperatures in winter and early spring has the effect of accelerating the pace of construction work by about 1 pp, all else held equal (Table 4b). Model calculations show that favorable weather conditions in February-March 2020 (higher air temperatures and lower precipitation relative to the previous year) made a positive contribution to the change in construction output (Figure 5). This insight is in agreement with other studies, including Bloesch and Gourio F. (2015), who find that cold weather can cause delays in construction projects.

Energy

Weather conditions also affect industrial dynamics (including the energy sector) (Stulec et al., 2012). This impact is the most pronounced between October and March, the typical heating season in Ukraine when air temperatures significantly affect the volumes of natural gas and electricity consumption. In a given year, March temperatures that are colder yoy tend to accelerate growth in the energy sector by 0.6 pp with each 1°C drop in the air temperature (other things being equal), my estimates show. This effect is somewhat stronger in the winter months, with energy production rising by 0.7 pp as the air temperature falls by 1°C (Tables 4c, 4d). These calculations are reliable at a significance level of 0.1.

It can thus be inferred from these calculations that it was the relatively warm weather that led to a negative contribution of weather conditions to energy sector dynamics in the winter of 2019–2020 and March 2020 (Figure 5). I also attempted to estimate the impact on the energy sector of changes in the average monthly air temperature during the warm period of the year. However, as shown in Tables 4c, 4d, my assumption about the statistical significance of this effect was not confirmed. This result is in line with other studies. More specifically, Staffell and Pfenninger (2018), among others, indicate that electricity demand is seasonal, with a marked peak in winter and remaining virtually unchanged in summer.

Given that part of electricity is generated by hydroelectric power plants, production in the energy sector is probably also affected by the amount of precipitation. However, this effect is not statistically significant, as seen from my estimates presented in Table 4c.

It should also be emphasized that with the energy sector gradually transitioning towards clean and safe renewable sources, its performance in Ukraine has been increasingly affected by weather factors such as wind speed and solar radiation but these issues were not addressed in this paper and require further research.[15]

Manufacturing

Cold winter weather adversely affects the performance of manufacturing companies, particularly by reducing the

[15] Specifically, the solar power plants put into operation in the first nine months of 2019 had a total capacity of 2,033.2 MW (nearly six times the level of the same period a year before), while the capacity of newly launched wind power plants totaled 399 MW (up from 57.3 MW in the first nine months of 2018), according to data from the National Commission for State Regulation of Energy and Public Utilities.

productivity of employees working in unheated buildings (Table 4e). At the same time, colder temperatures during this period of the year also have a positive effect on, for example, the clothing and footwear industry by increasing demand for warm clothes. All else held equal, a 1°C decrease in the air temperature reduces the growth rate of manufacturing by 0.2 pp, according to my calculations. Thus, in contrast to the negative impact of warm weather in the winter of 2019-2020 on energy sector output, the estimated effect on the manufacturing sector was positive (Figures 5).

Precipitation also appears to be a factor affecting manufacturing dynamics. For instance, heavy snowfalls cause an increase in demand for snow blowers and motor vehicle parts and accessories. This, in turn, positively affects the engineering industry. However, within the entire manufacturing sector, this impact becomes insignificant.

Other Sectors

As shown by Locke P. et al. (2011), mining performance comes under the influence of precipitation in summer, as excessive rainfall can flood mines, reducing the production of iron ore, coal, and other minerals. According to my calculations, however, the impact of rainfall on the performance of the mining sector was negligible (with a 1 mm increase in precipitation slowing growth in production by 0.01 pp) and not statistically significant (Table 4f). On the other hand, low temperatures in winter complicate the conditions for open-pit mining, with a 1°C decrease in the air temperature knocking 0.5 pp off the production growth rate, according to my estimates, with all other things being equal. These calculations are reliable at a significance level of 0.01.

Retail trade figures are also affected by weather conditions, in particular through the clothing and footwear segment, as its growth may be held back by warm weather in the fall, among other things.[16] Weather conditions also affect the traffic of stores and other retail businesses.[17] Households may find themselves "cut off" from retail stores after a heavy snowfall, for instance. In addition, inclement weather affects deliveries to grocery stores, ultimately eroding their earnings. However, the impact of weather conditions on the performance of retail trade businesses is short-lived (lasts no more than several days), dies down with every month, and is therefore statistically insignificant (Table 4g).

Adverse weather conditions (significant precipitation, excessively low air temperatures, heavy fog) affect transport industry dynamics in the short run, in particular due to disruptions in public transit schedules and delays in passenger rail services (Leviäkangas et al., 2011). A 1°C decrease in the air temperature in the winter months from the same period a year before cuts an average 0.3 pp off economic growth in passenger turnover (all else held equal), according to my calculations. Heavy clouds, thunder, and lightning can cause large-scale flight delays. All of this affects the time spent waiting for transport and the time that passengers spend on the road, which in turn affects labor productivity elsewhere in the economy. Overall, however, the influence of weather conditions on the monthly dynamics of the transport industry (and on other industries through the productivity channel) is noticeable within a few hours (rarely, days), but weakens in the course of the next few months. This is confirmed by the conclusion about the unreliability of the regression equations constructed in this paper to assess the impact of weather conditions on the transport industry's performance (Tables 5i, 5j).

Weather conditions also contribute to the dynamics of the services sector (e.g. through the impact on the activities of travel agencies, tour operators, and catering[18]), and through it affect GDP. However, as data on these particular activities are not publicly available, they (and estimation of associated weather impacts) were left outside the scope of this paper.

Therefore, the results of the calculations provided above confirmed our assumptions that the industries involving work in the open air or in unheated indoor facilities (agriculture, construction, manufacturing, energy) are more sensitive to changes in weather conditions. The impact of weather on other economic sectors is less pronounced. In general, the effect produced by the weather on the Index of Key Sectors Output (IKSO) is significant in selected months but not significant during most of the year (Figure 3). This is primarily due to the mixed effects of weather conditions on the dynamics of individual sectors (e.g. cold weather positively affects the performance of the energy sector but has a negative impact on construction and manufacturing).

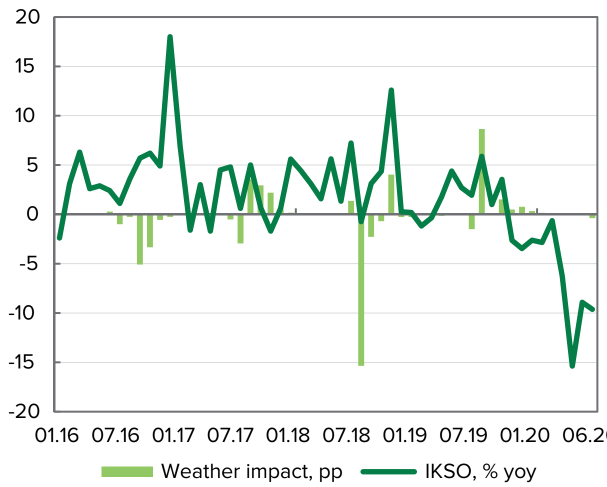

Figure 4. Ukraine's Index of Key Sectors Output, % yoy
Source: Author's calculations based on SSSU and CGO data.

5. CONCLUSIONS

This paper studies the influence of weather conditions on the core sectors of the Ukrainian economy. Overall, our findings support the view that weather has a noticeable but short-term impact on the dynamics of individual economic activities (including agriculture, construction, and industry). Weather's contributions are the most pronounced in the energy sector (during the cold season) and the agricultural sector (during harvest time).

At the beginning of each year, the opposite effects of weather factors on production in different economic

[16] In 2019, this segment accounted for 4.5% of the goods trade turnover of retail businesses, according to SSSU data.
[17] NOAA Data Helps Retail and Manufacturing Business Minimize Impacts from Weather and Climate (2017). NOAA's National Centers for Environmental Information. Retrieved from https://www.ncei.noaa.gov/news.
[18] These activities thus belong to the sections "Activities in the Field of Administrative and Support Services" and "Temporary Accommodation and Catering."

sectors, by offsetting one another, mitigate the impact of weather conditions on IKSO dynamics. However, this impact becomes more noticeable starting in June, when the agricultural production index, in addition to reflecting livestock farming, begins to trace the dynamics of crop farming, the main channel transmitting the contribution of weather to domestic economic activity. As a result, while weather makes a negligible contribution to GDP dynamics in Q1-Q2, its GDP impact increases markedly in Q3-Q4 as the harvesting season progresses.

This study offers a methodological approach to estimating the contribution of weather conditions to the dynamics of Ukraine's core economic activities. This approach lays the groundwork for improving the accuracy of forecasting current IKSO values, and thus the accuracy of nowcasting quarterly real GDP. However, this study has certain limitations.

First, we only focus on the impact of a limited number of meteorological elements (including average monthly air temperature and precipitation) on core economic activities. For the time being, we omit weather factors such as wind direction and strength, humidity, and solar radiation from the scope of this paper. As a suggestion for further research, expanding the list of meteorological elements that factor into the estimation of weather's impact on economic activity could help quantify the contribution of renewable energy sources (wind and solar power) to growth in Ukraine's real GDP.

Second, available data provided by the Central Geophysical Observatory and used in this study were collected for the city of Kyiv only. It can be assumed that conducting similar research on a regional level may produce a potential measurement error due to regional heterogeneity. Therefore, another promising direction for future studies is to perform analyses based on regional data, making separate calculations for each of the Ukrainian regions and then aggregating them to arrive at a countrywide estimate, which would produce more robust estimates of weather impact on the dynamics of core economic activities.

And finally, testing hypotheses about the asymmetrical influence of weather conditions on regional economic activities is another research area worth attention.

REFERENCES

Acevedo, S., Mrkaic, M., Novta, N., Poplawski-Ribeiro, M., Pugacheva, E., Topalova, P. (2017). The Effects of weather shocks on economic activity: How can low-income countries cope? World Economic Outlook. International Monetary Fund. http://doi.org/10.5089/9781484312490.081

Acevedo, S., Mrkaic, M., Novta, N., Pugacheva, E., Topalova, P. (2018). The effects of weather shocks on economic activity: What are the channels of impact? Working Paper, 18/144. International Monetary Fund.

Bank of England. (2018a). Quarterly Inflation Report. Retrieved from https://www.bankofengland.co.uk/inflation-report/2018/may-2018

Bank of England. (2018b). The role of temporary factors in recent output growth. Bank of England Quarterly Inflation Report, May 2018, 12-13. Retrieved from https://www.bankofengland.co.uk/inflation-report/2018/may-2018

Barlyn, S. (2019) Hurricane Dorian insured losses in Caribbean to range from $1.5 billion to $3 billion: AIR worldwide. Reuters. Retrieved from https://www.reuters.com/article

Batten, S. (2018). Climate change on the macro-economy: a critical review. Bank of England Staff Working Paper, 706. London: Bank of England. Retrieved from https://www.bankofengland.co.uk/-/media/boe/files/working-paper/2018/climate-change-and-the-macro-economy-a-critical-review.pdf

Bloesch, J., Gourio, F. (2015). The effect of winter weather on U.S. economic activity. Economic Perspectives, 39(1). Retrieved from https://www.chicagofed.org/publications/economic-perspectives/2015/1q-bloesch-gourio

Burke, M., Hsiang, S. M., Miguel, E. (2015). Global non-linear effect of temperature on economic production. Nature, 527, 235-239. https://doi.org/10.1038/nature15725

Chen, A. (2015). It's hot days, not cold, that really chill labor productivity. The Wall Street Journal.

Davies, G. (2018). Global slowdown begins to look more troublesome. Financial Times. Retrieved from https://www.ft.com/content/dd485650-dcf3-11e8-9f04-38d397e6661c

Dell, M., Jones, B. F., Olken, B.A. (2014). What do we learn from the weather? The new climate-economy literature. Journal of Economic Literature, 52(3), 740–798. http://doi.org/10.1257/jel.52.3.740

Dietz, S., Stern, N. (2015). Endogenous growth, convexity of damage and climate risk: how Nordhaus' framework supports deep cuts in carbon emissions. The Economic Journal, 125(583), 574–620. https://doi.org/10.1111/ecoj.12188

Doronin, A. V. (2014). The current state of the grain market in Ukraine. Research Papers of the Institute of Bioenergy Crops and Sugar Beets, 21, 270–276.

Gourio, F. (2015). The effect of weather on first-quarter GDP. Chicago Fed Letter, 341. Retrieved from https://www.chicagofed.org/publications/chicago-fed-letter/2015/341

Hissler, S. (2010). Econometric study on the impact of rainfall variability on security in the Sahel region. SWAC Secretariat/OECD. Retrieved from https://www.oecd.org/swac/publications/44245104.pdf

International Monetary Fund. (2017). Seeking sustainable growth: Short-term recovery, long-term challenges. World Economic Outlook, October 2017. Washington: The International Monetary Fund. Retrieved from https://www.imf.org/en/Publications/WEO/Issues/2017/09/19/world-economic-outlook-october-2017#Introduction

Leviäkangas et al. (2011) Extreme weather impacts on transport systems. VTT Working Papers, 168. Retrieved from https://www.vttresearch.com/sites/default/files/pdf/workingpapers/2011/W168.pdf

Locke, P., Clifton, C., Westra, S. (2011) Extreme weather events and the mining industry. Engineering and Mining Journal, 212(3), 58-59. Retrieved from https://www.e-mj.com/departments/operating-strategies/extreme-weather-events-and-the-mining-industry/

Mendelsohn, R. (2008). The impact of climate change on agriculture in developing countries.

Journal of Natural Resources Policy Research, 1, 5-19. https://doi.org/10.1080/19390450802495882

National Bank of Ukraine. (2019). Inflation Report, April 2019. Retrieved from https://bank.gov.ua/en/news/all/inflyatsiyniy-zvit-za-kviten-2019-roku

National Bank of Ukraine. (2020). Macroeconomic and Monetary Review, March 2020. Retrieved from https://bank.gov.ua/en/news/all/makroekonomichniy-ta-monetarniy-oglyad-berezen-2020-roku

OECD. (2019). Snapshot of Ukraine's energy sector: Institutions, governance and policy framework. Retrieved from https://www.oecd.org/eurasia/competitiveness-programme/eastern-partners/Snapshot-of-Ukraines-Energy-Sector-EN.pdf

Paltasingh, K. R., Goyari, P. (2018). Statistical modeling of crop-weather relationship in India: A survey on evolutionary trend of methodologies. Asian Journal of Agriculture and Development, 15(1), 43-60. http://doi.org/10.22004/ag.econ.275688

Staffell, I., Pfenninger, S. (2018) The increasing impact of weather on electricity supply and demand. Energy, 145(15), 65-78. https://doi.org/10.1016/j.energy.2017.12.051

Stulec, I., Bakovic, T., Hruska, D. (2012). Weather risk management in energy sector. Annals & Proceedings of DAAAM International Symposium.

Sullivan, B. K., Doan, L. (2012). Sandy brings hurricane-force gusts to U.S. East Coast. Bloomberg. Retrieved from https://www.bloomberg.com/news/articles/2012-10-29/hurricane-sandy-may-push-record-storm-surge-into-manhattan

Weitzman, M. L. (2009). On modeling and interpreting the economics of catastrophic climate change. Review of Economics and Statistics, 91(1), 1–19. https://doi.org/10.1162/rest.91.1.1

Yeremenko, O. A., Todorova, L. V., Pokoptseva, L. A. (2018). Impact of weather conditions on the passage and duration of phenological phases of growth and development of oilseeds. Taurian Scientific Bulletin, 99, 45–52.

APPENDIX

Table 1. Descriptive Statistics

Variable	Mean	Median	Standard deviation	Min	Max
T	9.44	9.90	9.31	-10.00	24.60
ΔT^Y	0.15	-0.05	2.91	-8.10	9.60
ΔT^N	1.72	1.60	2.02	-5.80	7.70
P	51.38	42.00	35.68	2.00	210.80
ΔP^Y	-0.17	-0.50	49.44	-165.80	178.50
ΔP^N	-2.79	-9.85	34.91	-69.70	163.80
Δy_{agr}	4.24	1.77	17.36	-30.70	134.25
Δy_{constr}	0.68	4.85	21.67	-57.60	46.50
Δy_{energy}	-0.72	0.70	8.89	-25.94	22.80
Δy_{manuf}	0.10	1.27	12.23	-41.60	24.36
Δy_{mining}	-0.76	1.70	9.34	-31.65	22.90
Δy_{retail}	9.10	11.55	14.76	-29.00	38.10
$\Delta y_{wholesale}$	-1.13	0.15	13.34	-52.53	25.03
Δy_{pas}	1.06	1.46	9.46	-19.63	27.52
Δy_{cargo}	-1.77	0.57	11.54	-42.33	29.11

Note 1. Data cover the period from January 2004 through December 2019.
Note 2. T – actual average monthly air temperature data, °C; ΔT^Y – change in the average monthly air temperature compared to the same month of the previous year; ΔT^N – change in the average monthly air temperature compared to the norm; P – actual monthly precipitation data, mm; ΔP^Y – change in the monthly amount of precipitation compared to the same month of the previous year; ΔP^N – change in the monthly amount of precipitation compared to the norm; Δy_{agr} – change in the physical volume of agricultural production, % yoy; Δy_{constr} – change in production volume of construction products, % yoy; Δy_{energy} – change in industrial production of the energy sector, % yoy; Δy_{manuf} – change in production of industrial products in manufacturing, % yoy; Δy_{mining} – change in the volume of production of industrial products in mining,% yoy; Δy_{retail} – change in the physical volume of retail trade turnover, % yoy; $\Delta y_{wholesale}$ – change in the physical turnover of wholesale trade, % yoy; Δy_{pas} – change in passenger traffic, % yoy; Δy_{cargo} – change in the volume of freight traffic, % yoy.
Source: Author's calculations based on SSSU and CGO data.

Table 2. Results of the ADF Test to Analyze the Time Series of Meteorological Indicators (Average Monthly Air Temperature and Monthly Rainfall)

Variable	Value of τ-statistic in ADF test
T	-12.805***
ΔT^{Y}	-7.242***
ΔT^{N}	-12.231***
P	-13.783***
ΔP^{Y}	-14.377***
ΔP^{N}	-14.682***
Δy_{agr}	-11.451***
Δy_{constr}	-2.380
Δy_{energy}	-2.959**
Δy_{manuf}	-2.881**
Δy_{mining}	-3.813***
Δy_{retail}	-1.968
$\Delta y_{wholesale}$	-2.886**
Δy_{pas}	-3.068**
Δy_{cargo}	-3.704***

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Note 1. Data cover the period from January 2004 through December 2019.

Note 2. T – actual average monthly air temperature data, °C; ΔT^{Y} – change in the average monthly air temperature compared to the same month of the previous year; ΔT^{N} – change in the average monthly air temperature compared to the norm; P – actual monthly precipitation data, mm; ΔP^{Y} – change in the monthly amount of precipitation compared to the same month of the previous year; ΔP^{N} – change in the monthly amount of precipitation compared to the norm; Δy_{agr} – change in the physical volume of agricultural production, % yoy; Δy_{constr} – change in production volume of construction products, % yoy; Δy_{energy} – change in industrial production of the energy sector, % yoy; Δy_{manuf} – change in production of industrial products in manufacturing, % yoy; Δy_{mining} – change in the volume of production of industrial products in mining,% yoy; Δy_{retail} – change in the physical volume of retail trade turnover, % yoy; $\Delta y_{wholesale}$ – change in the physical turnover of wholesale trade, % yoy; Δy_{pas} – change in passenger traffic, % yoy; Δy_{cargo} – change in the volume of freight traffic, % yoy.

Source: Author's calculations in E-Views 8.0.

Table 3a. Correlation Matrix: Weather Deviations from the Previous Year's Levels and Production Dynamics in Selected Sectors of the Ukrainian Economy

	Agriculture	Construction	Energy sector	Mining	Manufacturing
	(1)	(2)	(3)	(4)	(5)
$\Delta T_{Dec,Jan,Feb}$	0.062	0.139	-0.281	0.080	0.083
$\Delta T_{Mar,Apr,May}$	0.014	0.113	-0.103	0.013	0.064
$\Delta T_{Jun,Jul,Aug}$	-0.064	-0.090	0.025	-0.079	-0.024
$\Delta T_{Sep,Oct,Nov}$	0.159	-0.075	-0.238	-0.034	-0.082
$\Delta P_{Dec,Jan,Feb}$	-0.113	-0.098	-0.127	-0.112	-0.017
$\Delta P_{Mar,Apr,May}$	0.009	-0.005	0.204	0.143	0.088
$\Delta P_{Jun,Jul,Aug}$	0.092	0.175	0.107	0.030	0.167
$\Delta P_{Sep,Oct,Nov}$	-0.208	0.051	0.121	0.147	0.081

Source: Author's calculations in E-Views 8.0.

Table 3a (continued). Correlation Matrix: Weather Deviations from the Previous Year's Levels and Production Dynamics in Selected Sectors of the Ukrainian Economy

	Retail trade	Wholesale trade	Passenger transport	Freight transport
	(6)	(7)	(8)	(9)
$\Delta T_{Dec,Jan,Feb}$	0.048	0.092	0.123	0.032
$\Delta T_{Mar,Apr,May}$	0.075	-0.031	0.101	-0.021
$\Delta T_{Jun,Jul,Aug}$	-0.026	-0.035	0.005	-0.062
$\Delta T_{Sep,Oct,Nov}$	-0.053	-0.118	-0.079	-0.062
$\Delta P_{Dec,Jan,Feb}$	-0.046	-0.042	-0.043	-0.148
$\Delta P_{Mar,Apr,May}$	0.051	0.060	-0.103	0.096
$\Delta P_{Jun,Jul,Aug}$	0.076	0.072	0.112	0.091
$\Delta P_{Sep,Oct,Nov}$	0.112	0.129	0.147	0.196

Source: Author's calculations in E-Views 8.0.

Table 3b. Correlation Matrix: Weather Deviations from the Norm and Production Dynamics in Selected Sectors of Ukrainian Economy

	Agriculture	Construction	Energy sector	Mining	Manufacturing
	(1)	(2)	(3)	(4)	(5)
$\Delta T_{Dec,Jan,Feb}$	0.046	0.058	-0.260	-0.036	-0.003
$\Delta T_{Mar,Apr,May}$	-0.056	0.057	-0.088	-0.046	0.011
$\Delta T_{Jun,Jul,Aug}$	0.048	-0.026	0.061	-0.018	-0.028
$\Delta T_{Sep,Oct,Nov}$	0.100	-0.066	-0.110	0.023	-0.074
$\Delta P_{Dec,Jan,Feb}$	-0.063	-0.073	-0.014	-0.027	0.001
$\Delta P_{Mar,Apr,May}$	0.005	-0.027	0.098	0.047	0.002
$\Delta P_{Jun,Jul,Aug}$	0.149	0.088	0.156	0.140	0.167
$\Delta P_{Sep,Oct,Nov}$	-0.098	-0.013	0.030	0.032	0.020

Source: Author's calculations in E-Views 8.0.

Table 3b (continued). Correlation Matrix: Weather Deviations from the Norm and Production Dynamics in Selected Sectors of Ukrainian Economy

	Retail trade	Wholesale trade	Passenger transport	Freight transport
	(6)	(7)	(8)	(9)
$\Delta T_{Dec,Jan,Feb}$	-0.006	0.037	0.079	-0.039
$\Delta T_{Mar,Apr,May}$	0.004	-0.064	0.066	0.001
$\Delta T_{Jun,Jul,Aug}$	-0.038	0.002	-0.013	0.001
$\Delta T_{Sep,Oct,Nov}$	-0.045	-0.063	-0.041	-0.011
$\Delta P_{Dec,Jan,Feb}$	-0.035	-0.026	-0.107	-0.053
$\Delta P_{Mar,Apr,May}$	-0.011	0.028	-0.123	0.052
$\Delta P_{Jun,Jul,Aug}$	0.198	0.058	0.129	0.073
$\Delta P_{Sep,Oct,Nov}$	0.030	0.059	0.085	0.088

Source: Author's calculations in E-Views 8.0.

Table 4a. Estimated Weather Impact on Output: Agriculture

	$\Delta y_{agr}(t)$			
	(1)	(2)	(3)	(4)
$\Delta_{y_1}(t\text{-}1)$	0.70***	0.99***	0.08	0.28
	(0.145)	(0.072)	(0.156)	(0.175)
$\Delta_{y_1}(t\text{-}5)$	0.02	-0.11	-0.47***	-0.26*
	(0.088)	(0.083)	(0.141)	(0.158)
$\Delta_{y_1}(t\text{-}10)$	-0.11*	-0.01	-0.36***	-0.34**
	(0.072)	(0.050)	(0.121)	(0.147)
$GRAIN(t)$		0.05*	0.11***	0.10***
		(0.035)	(0.025)	(0.037)
$POTATOES(t)$		0.28**	0.48***	0.38***
		(0.120)	(0.077)	(0.109)
$\Delta T^{Y}_{Mar,Apr,May}(t\text{-}3)$			-1.43**	
			(0.639)	
$\Delta T^{Y}_{Sep,Oct,Nov}(t)$			1.75*	
			(1.021)	
$\Delta P^{Y}_{Sep,Oct,Nov}(t)$			-0.11**	
			(0.052)	
$\Delta P^{Y}_{Dec,Jan,Feb}(t\text{-}7)$			-0.47***	
			(0.093)	
$\Delta T^{N}_{Mar,Apr,May}(t\text{-}3)$				-2.65***
				(0.750)
$\Delta T^{N}_{Sep,Oct,Nov}(t)$				0.99
				(0.960)
$\Delta P^{N}_{Sep,Oct,Nov}(t)$				0.22***
				(0.062)
$\Delta P^{N}_{Dec,Jan,Feb}(t\text{-}7)$				-0.39**
				(0.149)
C	2.13	2.41	-0.68	1.72
N	60	60	60	60
R^2(adjusted)	0.11	0.26	0.48	0.39
F	2.09	3.34	5.12	3.95
DW	1.93	1.99	1.83	1.93
AIC	8.04	7.89	7.60	7.74
SIC	8.32	8.23	8.08	8.23

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{agr}(t)$ – change in the physical volume of agricultural production in month *t*, % yoy; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (3), and compared to the norm $\Delta T^{N}(t)$, column (4); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (3), and compared to the norm $\Delta P^{N}(t)$, column (4); $GRAIN(t)$ – growth rates of grain and legume production in month *t*, % yoy; $POTATOES(t)$ – growth rate of potato production in month *t*, % yoy.
Source: Author’s calculations based on SSSU and CGO data.

Table 4b. Estimated Weather Impact on Output: Construction

	$\Delta y_{constr}(t)$		
	(1)	(2)	(3)
$\Delta y_{constr}(t\text{-}1)$	0.56***	0.59***	0.58***
	(0.067)	(0.069)	(0.069)
$\Delta y_{constr}(t\text{-}2)$	0.41***	0.38***	0.39***
	(0.068)	(0.070)	(0.070)
$\Delta y_{constr}(t\text{-}12)$	-0.13***	-0.12***	-0.12***
	(0.032)	(0.031)	(0.032)
$\Delta T^{Y}_{Dec,Jan,Feb}(t)$		0.83***	
		(0.260)	
$\Delta T^{Y}_{March}(t)$		0.78*	
		(0.415)	
$\Delta T^{N}_{Dec,Jan,Feb}(t)$			0.51
			(0.363)
$\Delta T^{N}_{March}(t)$			0.46
			(0.517)
C	0.55	0.46	0.24
N	180	180	180
R^2(adjusted)	0.84	0.85	0.84
F	308.40	199.90	185.95
DW	2.00	2.04	2.00
AIC	7.18	7.13	7.19
SIC	7.25	7.23	7.29

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{constr}(t)$ – change in the physical volume of production of construction products in month t, % yoy; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (2), and compared to the norm $\Delta T^{N}(t)$, column (3); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (2), and compared to the norm $\Delta P^{N}(t)$, column (3).
Source: Author's calculations based on SSSU and CGO data.

Table 4c. Estimated Weather Impact on Output: Energy

	$\Delta y_{energy}(t)$			
	(1)	(2)	(3)	(4)
$\Delta y_{energy}(t\text{-}1)$	0.67***	0.83***	0.83***	0.83***
	(0.099)	(0.076)	(0.078)	(0.077)
$Electricity_{prod}(t)$		1.03***	0.81***	0.96***
		(0.104)	(0.127)	(0.113)
$\Delta T^{Y}_{Dec,Jan,Feb}(t)$			-0.73***	
			(0.194)	
$\Delta T^{Y}_{March}(t)$			-0.61*	
			(0.320)	
$\Delta P^{Y}_{Dec,Jan,Feb}(t)$			-0.03	
			(0.023)	
$\Delta T^{N}_{Dec,Jan,Feb}(t)$				-0.68**
				(0.293)
$\Delta T^{N}_{March}(t)$				-0.47
				(0.362)
$\Delta P^{N}_{Dec,Jan,Feb}(t)$				0.01
				(0.030)
C	-3.22	0.73	-0.18	1.02
N	59	59	59	59
R^2(adjusted)	0.43	0.78	0.83	0.79
F	45.40	104.18	56.22	44.91
DW	2.04	1.72	1.66	1.69
AIC	6.49	5.56	5.37	5.56
SIC	6.56	5.66	5.58	5.77

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{energy}(t)$ – з change in the physical volume of production of industrial products in the energy sector in month t, % yoy; $\Delta T(t)$– change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (3), and compared to the norm $\Delta T^{N}(t)$, column (4); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (3), and compared to the norm $\Delta P^{N}(t)$, column (4); $Electricity_{prod}(t)$ – electricity production (according to monthly data from Ukrenergo NPC), % yoy.
Source: Author's calculations based on SSSU and CGO data.

Table 4d. Estimated Weather Impact on Output: Energy (no variable $\Delta P_{Dec,Jan,Feb}$)

	$\Delta y_{energy}(t)$			
	(1)	(2)	(3)	(4)
$\Delta y_{energy}(t\text{-}1)$	0.67***	0.83***	0.82***	0.83***
	(0.099)	(0.076)	(0.079)	(0.076)
$Electricity_{prod}(t)$		1.03***	0.82***	0.97***
		(0.104)	(0.128)	(0.111)
$\Delta T^{Y}_{Dec,Jan,Feb}(t)$			-0.75***	
			(0.195)	
$\Delta T^{Y}_{March}(t)$			-0.63*	
			(0.328)	
$\Delta T^{N}_{Dec,Jan,Feb}(t)$				-0.68**
				(0.290)
$\Delta T^{N}_{March}(t)$				-0.46
				(0.358)
C	-3.22	0.73	-0.18	1.02
N	59	59	59	59
R^2(adjusted)	0.43	0.78	0.83	0.79
F	45.40	104.18		44.91
DW	2.04	1.72	1.66	1.69
AIC	6.49	5.56	5.37	5.56
SIC	6.56	5.66	5.58	5.77

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Note 1. Standard errors are in parentheses.

Note 2. $\Delta y_{energy}(t)$ – з change in the physical volume of production of industrial products in the energy sector in month t, % yoy; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (3), and compared to the norm $\Delta T^{N}(t)$, column (4); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (3), and compared to the norm $\Delta P^{N}(t)$, column (4); $Electricity_{prod}(t)$ – electricity production (according to monthly data from Ukrenergo NPC), % yoy.

Source: Author’s calculations based on SSSU and CGO data.

Table 4e. Estimated Weather Impact on Output: Manufacturing

	$\Delta y_{manuf}(t)$			
	(1)	(2)	(3)	(4)
$\Delta y_{manuf}(t\text{-}1)$	0.65***	0.82***	0.85***	0.83***
	(0.099)	(0.099)	(0.099)	(0.020)
$\Delta y_{manuf}(t\text{-}2)$	0.09	-0.14	-0.17*	-0.15*
	(0.102)	(0.103)	(0.103)	(0.104)
$\Delta y_{manuf}(t\text{-}5)$	0.14**	0.15**	0.15**	0.15**
	(0.070)	(0.067)	(0.067)	(0.068)
$Food_{exp}(t)$		7.41***	7.09***	7.33***
		(1.654)	(1.626)	(1.643)
$Real_{wage}(t)$		0.36***	0.35***	0.36***
		(0.101)	(0.101)	(0.101)
$\Delta T^{Y}_{Dec,Jan,Feb}(t)$			0.22*	
			(0.125)	
$\Delta T^{N}_{Dec,Jan,Feb}(t)$				0.22
				(0.181)
C	-5.03	-14.50	-14.10	-14.60
N	103	103	103	103
R^2(adjusted)	0.73	0.79	0.80	0.80
F	91.01	79.01	67.69	66.43
DW	1.97	1.97	1.96	1.97
AIC	5.63	5.37	5.36	5.37
SIC	5.73	5.52	5.53	5.55

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{manuf}(t)$ – change in the volume of industrial production in manufacturing in month t, % yoy; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (3), and compared to the norm $\Delta T^{N}(t)$, column (4); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (3), and compared to the norm $\Delta P^{N}(t)$, column (4); $Food_{exp}(t)$ – food exports, % yoy; $Real_{wage}(t)$ – real wage, % yoy.
Source: Author's calculations based on SSSU and CGO data.

Table 4f. Estimated Weather Impact on Output: Mining

	$\Delta y_{mining}(t)$		
	(1)	(2)	(3)
$\Delta y_{mining}(t\text{-}1)$	0.85***	0.87***	0.86***
	(0.038)	(0.037)	(0.038)
$\Delta y_{mining}(t\text{-}12)$	-0.09***	-0.08**	-0.08**
	(0.038)	(0.037)	(0.037)
$\Delta T^{Y}_{Dec,Jan,Feb}(t)$		0.48***	
		(0.134)	
$\Delta P^{Y}_{Jun,Jul,Aug}(t)$		-0.01	
		(0.011)	
$\Delta T^{N}_{Dec,Jan,Feb}(t)$			0.40**
			(0.193)
$\Delta P^{N}_{Jun,Jul,Aug}(t)$			-0.01
			(0.015)
C	-1.14	-1.21	-1.36
N	180	180	180
R^2(adjusted)	0.74	0.76	0.74
F	256.82	140.78	131.29
DW	2.01	1.94	1.98
AIC	6.00	5.94	6.00
SIC	6.05	6.03	6.09

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{mining}(t)$ – change in the volume of industrial production in mining in month t, % yoy; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (2), and compared to the norm $\Delta T^{N}(t)$, column (3); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (2), and compared to the norm $\Delta P^{N}(t)$, column (3).
Source: Author's calculations based on SSSU and CGO data.

Table 4g. Estimated Weather Impact on Output: Retail Trade

	$\Delta y_{retail}(t)$		
	(1)	(2)	(3)
$\Delta y_{retail}(t\text{-}1)$	0.57***	0.56***	0.58***
	(0.100)	(0.099)	(0.020)
$\Delta y_{retail}(t\text{-}3)$	0.37***	0.38***	0.36***
	(0.101)	(0.020)	(0.101)
$\Delta T^Y(t)$		0.21	
		(0.206)	
$\Delta T^N(t)$			0.56**
			(0.301)
C	2.30	2.34	0.85
N	72	72	72
R^2(adjusted)	0.79	0.79	0.79
F	131.50	88.09	91.93
DW	2.07	1.99	2.03
AIC	6.39	6.40	6.37
SIC	6.49	6.53	6.50

p-values $^*p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{retail}(t)$ – change in the physical volume of retail trade turnover in month t, % 2; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^Y(t)$, column (2), and compared to the norm $\Delta T^N(t)$, column (3); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^Y(t)$, column (2), and compared to the norm $\Delta P^N(t)$, column (3).
Source: Author's calculations based on SSSU and CGO data.

Table 4h. Estimated Weather Impact on Output: Wholesale Trade

	$\Delta y_{wholesale}(t)$		
	(1)	(2)	(3)
$\Delta y_{wholesale}(t\text{-}1)$	0.56***	0.58***	0.57***
	(0.064)	(0.064)	(0.064)
$\Delta T^{Y}_{Sep,Oct,Nov}(t)$		-1.21**	
		(0.614)	
$\Delta T^{Y}_{Mar,Apr,May}(t)$		-0.75	
		(0.471)	
$\Delta T^{N}_{Sep,Oct,Nov}(t)$			-0.96
			(0.714)
$\Delta T^{N}_{Mar,Apr,May}(t)$			-1.02
			(0.630)
C	-0.98	-0.91	-0.17
N	167	167	167
R^2(adjusted)	0.31	0.33	0.32
F	76.50	28.33	27.30
DW	2.44	2.46	2.45
AIC	7.66	7.65	7.66
SIC	7.70	7.72	7.73

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{wholesale}(t)$ – change in the physical volume of wholesale trade turnover in month t, % 2; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (2), and compared to the norm $\Delta T^{N}(t)$, column (3); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (2), and compared to the norm $\Delta P^{N}(t)$, column (3).
Source: Author's calculations based on SSSU and CGO data.

Table 4i. Estimated Weather Impact on Output: Passenger Transportation

	$\Delta y_{pas}(t)$		
	(1)	(2)	(3)
$\Delta y_{pas}(t\text{-}1)$	0.84***	0.85***	0.84***
	(0.042)	(0.041)	(0.043)
$\Delta T^{Y}_{Dec,Jan,Feb}(t)$		0.32**	
		(0.146)	
$\Delta T^{N}_{Dec,Jan,Feb}(t)$			0.16
			(0.214)
C	0.57	0.60	0.52
N	155	155	155
R^2(adjusted)	0.73	0.73	0.73
F	410.13	212.75	204.70
DW	2.38	2.35	2.38
AIC	6.01	5.99	6.02
SIC	6.05	6.05	6.08

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{pas}(t)$ – change in the volume of passenger transport in month t, % yoy; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (2), and compared to the norm $\Delta T^{N}(t)$, column (3); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (2), and compared to the norm $\Delta P^{N}(t)$, column (3).
Source: Author's calculations based on SSSU and CGO data.

Table 4j. Estimated Weather Impact on Output: Freight Transportation

	$\Delta y_{cargo}(t)$		
	(1)	(2)	(3)
$\Delta y_{cargo}(t\text{-}1)$	0.84***	0.85***	0.84***
	(0.044)	(0.044)	(0.044)
$\Delta T^{Y}_{Dec,Jan,Feb}(t)$		0.33*	
		(0.190)	
$\Delta T^{Y}_{Mar,Apr,May}(t)$		-0.48**	
		(0.238)	
$\Delta T^{N}_{Dec,Jan,Feb}(t)$			-0.07
			(0.284)
$\Delta T^{N}_{Mar,Apr,May}(t)$			-0.41
			(0.334)
C	-1.96	-1.89	-1.73
N	155	155	155
R^2(adjusted)	0.70	0.71	0.70
F	357.90	125.47	119.38
DW	2.21	2.26	2.22
AIC	6.55	6.53	6.56
SIC	6.59	6.61	6.64

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{cargo}(t)$ – change in the volume of freight transport in month t, % yoy; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (2), and compared to the norm $\Delta T^{N}(t)$, column (3); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (2), and compared to the norm $\Delta P^{N}(t)$, column (3).
Source: Author's calculations based on SSSU and CGO data.

Table 4k. Estimated Weather Impact on Output: Wheat Production

	$\Delta y_{wheat}(t)$		
	(1)	(2)	(3)
$Sown_{area}(cereals\&legumes)(t)$	6.72***	8.01***	6.99***
	(1.495)	(1.378)	(1.389)
$\Delta P^{Y}_{Oct,Nov}(t\text{-}1)$		1.22*	
		(0.709)	
$\Delta P^{Y}_{Apr,May}(t)$		0.53	
		(0.362)	
$\Delta P^{N}_{Oct,Nov}(t\text{-}1)$			2.12**
			(0.962)
$\Delta P^{N}_{Apr,May}(t)$			0.37
			(0.583)
C	40.70	42.06	31.09
N	17	17	17
R^2(adjusted)	0.55	0.66	0.63
F	20.17	11.45	10.08
DW	2.17	1.51	1.53
AIC	11.37	11.17	11.26
SIC	11.47	11.36	11.45

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{wheat}(t)$ – change in the volume of wheat production in month t, % yoy; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (2), and compared to the norm $\Delta T^{N}(t)$, column (3); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (2), and compared to the norm $\Delta P^{N}(t)$, column (3); $Sown_{area}(cereals\&legumes)(t)$ – the growth rate of the sown area under cereals and legumes (excluding maize) in year t.
Source: Author's calculations based on SSSU and CGO data.

Table 4I. Estimated Weather Impact on Output: Maize Production

	$\Delta y_{maize}(t)$		
	(1)	(2)	(3)
$Sown_{area}(maize)(t)$	0.52***	0.69***	0.64***
	(0.183)	(0.132)	(0.195)
$\Delta T^{Y}_{Apr}(t)$		4.60	
		(2.859)	
$\Delta T^{Y}_{Aug}(t)$		-3.54**	
		(1.217)	
$\Delta P^{Y}_{Jun,July}(t\text{-}1)$		0.24*	
		(0.131)	
$\Delta T^{N}_{Apr}(t)$			6.87
			(5.411)
$\Delta T^{N}_{Aug}(t)$			-3.06
			(4.244)
$\Delta P^{Y}_{Jun,July}(t\text{-}1)$			0.44**
			(0.204)
C	11.01	7.70	9.66
N	17	17	17
R^2(adjusted)	0.31	0.72	0.47
F	8.03	11.16	4.57
DW	2.91	1.97	2.83
AIC	9.55	8.78	9.41
SIC	9.65	9.03	9.65

p-values $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Note 1. Standard errors are in parentheses.
Note 2. $\Delta y_{maize}(t)$ – change in the volume of maize production in month *t*, % yoy; $\Delta T(t)$ – change in the average monthly air temperature compared to the same month of the previous year $\Delta T^{Y}(t)$, column (2), and compared to the norm $\Delta T^{N}(t)$, column (3); $\Delta P(t)$ – change in the monthly amount of precipitation compared to the same month of the previous year $\Delta P^{Y}(t)$, column (2), and compared to the norm $\Delta P^{N}(t)$, column (3); $Sown_{area}(maize)(t)$ – the growth rate of the sown area under maize in year *t*, % yoy.
Source: Author's calculations based on SSSU and CGO data.

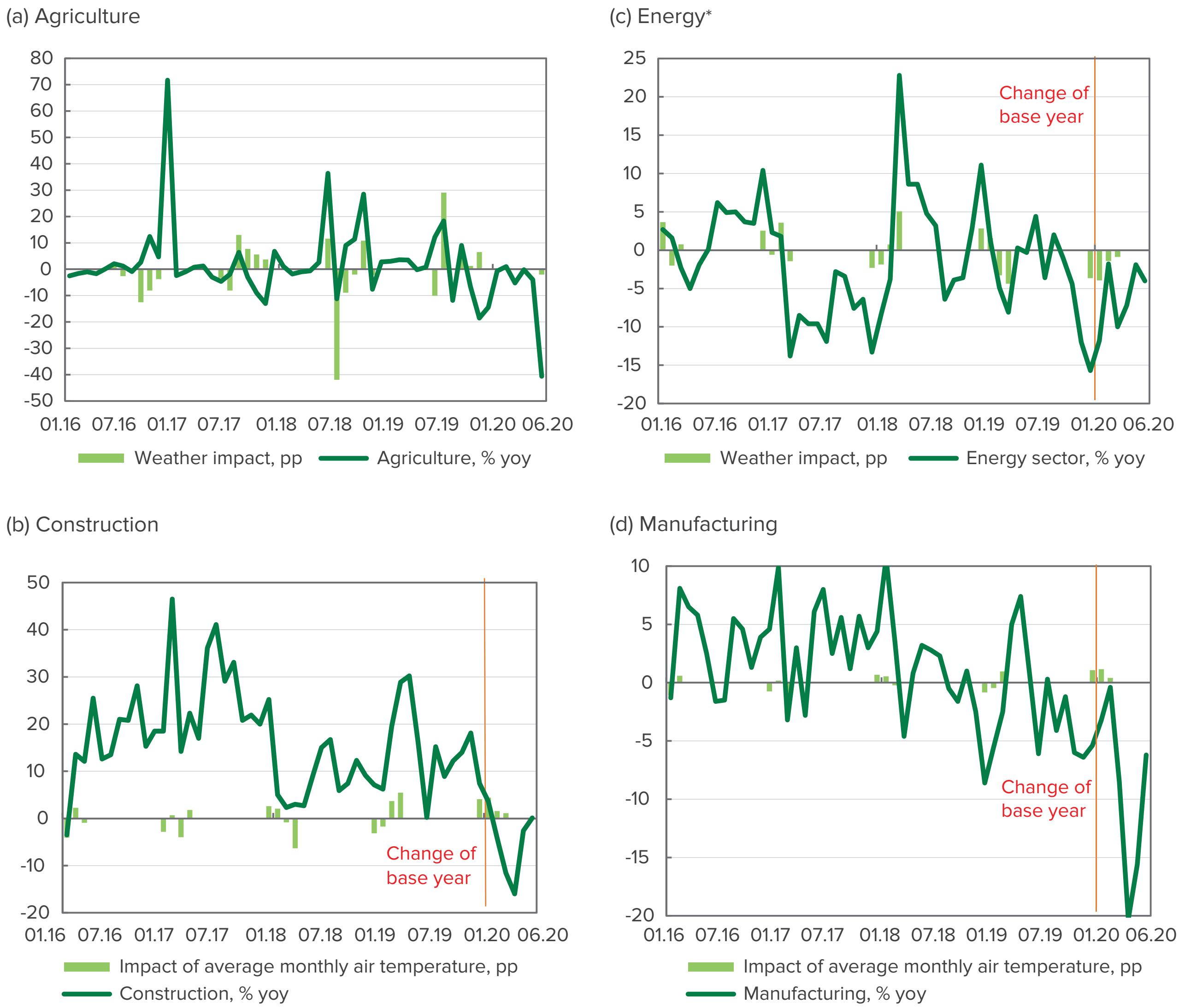

Figure 5. Production dynamics in selected sectors of Ukrainian economy, % yoy. (From January 2020, the base year i s 2016)
*Includes electricity, gas, steam, and air conditioning supplies.
Source: Author's calculations based on SSSU and CGO data.