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Agricultural production at the oblast level in post-Soviet Kyrgyzstan, 1990–2014: Implications of demographic and climate changes

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ABSTRACT

Increasing agricultural production is essential for reducing food insecurity, which continues to be a major challenge faced by many developing countries. Here, we examine agricultural production—both crop and livestock—in association with demographic and climate changes from 1990 through 2014 in Kyrgyzstan, an understudied, disadvantaged, mountainous Central Asian country that experienced dramatic changes in political and market structures, rapid demographic changes, and climatic changes during the study period. Results indicate that crop and livestock productions, which are correlated with food security, experienced dramatic changes in the study period. The total fertility rate was found to have a negative association with livestock production. Precipitation and temperature measures had statistically significant and strong correlations with both crop and livestock productions, but their significance diminished dramatically when considered together with socioeconomic factors, regional variation, and temporal change. There were strong correlations among demographic, climatic, and socioeconomic factors, making it challenging to separate their individual attributions to the changes of agricultural production. Overall, a wetter and colder climate was associated with agricultural production increases. However, the growing season from 1991 through 2014 in Kyrgyzstan has become drier and hotter, challenging future agricultural production. This study provides insights into agricultural production and food security in relation to demographic and climate changes in Central Asia.

1. Introduction

Food insecurity is a major challenge faced by many developing countries. It is exacerbated by population growth, climate change, globalization, international geopolitics, urbanization, and other factors (Dethier & Effenberger, 2012). Increasing agricultural production provides an essential pathway to increase food security (Mozumdar, 2012). While the severity of food insecurity and level of agricultural production vary greatly across developing countries, countries that fare the worst often share common characteristics such as limited arable land combined with geopolitical instability and/or dramatic changes in economic structure that impact the ability to effectively use land resources (Dethier & Effenberger, 2012; Gerber et al., 2013).

Central Asia provides a unique and important context for understanding these challenges. Many countries in Central Asia are landlocked and therefore experience higher costs and barriers to trade for basic goods. After independence from the Soviet Union in 1991, Central Asian countries transitioned from guaranteed, state-controlled agricultural markets and large-scale communal farming to family farming and private markets in an ever-globalizing world (Babu & Reidhead, 2000; Lerman et al., 2004; Tashmatov et al., 2000). Here we focus on agricultural production in Kyrgyzstan—both crops and livestock—and their association with demographic and climate changes since 1990. Kyrgyzstan is an ideal country to study stresses on agricultural production because it continues to face many significant challenges:

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- Following independence in 1991, Kyrgyzstan experienced dramatic economic reform and changes in economic structure, as the nation transitioned from a centralized economy to one that is market-based (Pankow & Jermakowicz, 1995).
- Many working-age Kyrgyz men and women migrate to Russia, Kazakhstan, or other countries, thereby reducing the local labor supply but sending home remittances that, in 2018, contributed ~33% of the country's gross domestic product (GDP) (World Bank, 2019a). This influx of liquidity further complicates agricultural practices because the remittances could either be invested in agricultural production or reduce the need to work in agriculture.
- More than 65% of Kyrgyzstan's population is rural, and it is the second poorest country in Central Asia, as measured by GDP per capita.
- It has experienced violent ethnic conflicts and dramatic changes in ethnic composition since independence (Becker & Paltsev, 2004; Ruziev & Majidov, 2013).
- Kyrgyzstan has very limited arable land—only 6.5% of the land is suitable for planting crops (Ibragimov & Asanaliyev, 1999).

Because the data for food security were not available at the oblast (province) level of Kyrgyzstan, here we focus on agricultural production in association with demographic and climate changes. The data came from the National Statistical Committee of Kyrgyzstan, the Food and Agriculture Organization (FAO) of the United Nations, the World Bank (for national-level data including both socioeconomic and climatic variables), and the National Climatic Data Center (NCDC) of the U.S. National Oceanic and Atmospheric Administration (NOAA). Our research question is: How are demographic, climatic, and socioeconomic changes associated with changes in agricultural production in Kyrgyzstan at the oblast level since independence?

This research extends previous work in Central Asia on agricultural production to incorporate subnational social, demographic, and climatic influences with agricultural production over an extended time period by utilizing descriptive statistics, geovisualization, Pearson correlation, and regression models. The combination of methods helps overcome the limitations of data availability in Kyrgyzstan, a problem common to other Central Asian countries. Examining changes to crop and livestock production over time and the various associated factors helps illuminate applicable directions for future policies. It should be noted that the demographic, climatic, and socioeconomic factors could be interacting with each other in affecting agricultural production; this study focuses on their collective effects on agricultural production rather than trying to separate their complicating contributions to the changes of agricultural production.

2. Prior research on agricultural production

Agricultural development is a critical part of global economic development as it alleviates food insecurity, provides income and acts as a social safety net for poor and rural households, and contributes jobs and resources for economic development in other sectors. In developing countries, many agricultural policies aim to reduce food insecurity of households by increasing production and agricultural efficiency (Dethier & Effenberger, 2012). One of the primary goals of agricultural development is the improvement of production efficiency, which means increasing yield. Agricultural yield is often measured as crop output through total production of specific crops and livestock, or ratios between inputs—such as fertilizer, labor, and land use—and outputs (Liverpool-Tasie et al., 2011; Zepeda, 2001). In a review of 362 manuscripts, Hamidov et al. (2016) find that most studies focused on the impacts that agricultural production and land use have on water usage and soil changes but gave less attention to their relationship with social processes. Other studies of agricultural production have noted several barriers to increased production, including soil and terrain, climate and weather extremes, financial crises and volatile markets, and access to technologies, inputs, and markets (Funk & Brown, 2009). A review of agricultural production research conducted in Central Asia found that examinations of social impacts were underrepresented across the region (Hamidov et al., 2016). We add to this body of knowledge by examining a country's

social and demographic characteristics and changing climate patterns that could influence its agricultural production.

2.1. Changing demographics

Changes to the population can affect agricultural production. Globally, since 2009 the number of people living in urban areas has surpassed the rural population (United Nations, 2009). However, in Central Asia more people still live in rural areas. In Kyrgyzstan, more than 65% of the national population lives in rural areas. Among the Central Asian countries, Kyrgyzstan is ranked the second poorest according to its GDP (World Bank, 2019c). Kyrgyz people face economic challenges and have experienced violent ethnic conflicts and changes in ethnic composition since independence (Becker & Paltsev, 2004; Ruziev & Majidov, 2013).

The most notable demographic change in Kyrgyzstan after the collapse of the Soviet Union was migration—both internal and international (Nedoluzhko & Agadjanian, 2010). Approximately one-third of the employable Kyrgyzstan population works abroad (Schmidt & Sagynbekova, 2008). Many working-age Kyrgyz migrate to Russia and Kazakhstan, reducing the local labor supply but sending money back home in the form of remittances (Nichol, 2010; World Bank, 2019a). In 2018 the valuation of remittances in Kyrgyzstan was estimated at US\$2.7 billion (World Bank, 2019a), 33% of the country's GDP, making Kyrgyzstan the world's third most remittance-dependent country after Tonga and South Sudan. This influx of liquidity further complicates agricultural practices. For example, the migrants' families and relatives could reduce their reliance on agriculture production, or these families could invest in more livestock, which could increase production or have a negative consequence on local ecology in the form of overgrazed pastures (Atamanov & Van den Berg, 2012a; Deshingkar, 2012; Herrero et al., 2009; Schoch et al., 2010; Wang et al., 2020).

2.2. Changing climate

Current agricultural policy in Kyrgyzstan is shifting to incorporate environmental and social impacts into research on improved crop production and agricultural efficiency. Changes in precipitation and temperature can be particularly important in Kyrgyzstan. Agriculture in mountainous regions faces multiple challenges: reduced partial pressures of CO₂ for plants and O₂ for animals (including humans); shallower, less developed soils on steeper slopes; drier, colder, and windier conditions at higher elevations; and topographic obstacles between farmers and herders and their markets. Mountainous environments in parts of Kyrgyzstan complicate the impacts on agricultural production of climatic variation and extremes as well as climatic change (Beniston, 2003; Manandhar et al., 2018; Rangwala & Miller, 2012). For example, for rainfed crops and pastures, snow cover duration and snow melt timing can affect surface climate and soil moisture availability, thereby influencing subsequent vegetation growth and development (Dye & Tucker, 2003; Groisman et al., 1994; Wang et al., 2018). There have also been significant changes and variations across Kyrgyzstan in the timing of snow onset and snow melt and the duration of snow cover (Tomaszewska & Henebry, 2018). From 2004 through 2015, more areas were experiencing earlier snow onset than earlier snow melt, and about the same number of areas were experiencing both longer and shorter durations of snow cover.

While timing of snow can affect agriculture as snow can serve as a buffered release of water (or as a source of flooding in periods of rapid melting), these snow factors were not considered in this study; rather, we focused on only the temperature and precipitation and their variabilities in the growing season. Modelers forecast that climate change may reduce snowmelt and increase reliance on rain for much of Central Asia's widespread irrigated croplands in coming years (Elliott et al., 2014). In addition, pasture degradation, including the spread of weedy and unpalatable species, is already a concern in the highlands of Kyrgyzstan (Eddy et al., 2017; Hoppe et al., 2016). Kyrgyzstan has very limited agricultural land (Ibragimov & Asanaliyev, 1999), and intensive grazing practices have already impacted the ecosystems of Kyrgyzstan's mountainous pastures (Borchardt et al., 2011).

2.3. Geopolitics and land reform

In countries that have transitioned from centralized or state-owned agricultural production to privately owned farms and liberalized market policies, there are barriers to increased agricultural production. Land reform, changes to property rights and land tenure, reallocation of agricultural inputs, and market restructuring can all result in output decline (Dorward et al., 2008; Jackson & Swinnen, 1995; Macours & Swinnen, 2000). Prices, which had previously been controlled or regulated by the state, can suffer volatility when introduced to the vagaries of the global markets. In addition, developing countries face barriers to exporting agricultural products to developed countries because of high tariffs or crop quotas that limit the amount of products that developed countries are willing to buy (Dethier & Effenberger, 2012). With such barriers, development of local institutions, infrastructure, and markets for agricultural products is important for maintaining or increasing agricultural outputs. Additionally, in post-Soviet economies, national transition policies and institutional structures can have widely varying impacts on rates of land use and land abandonment (de Beurs et al., 2017; Ioffe et al., 2004; Ioffe et al., 2012; Kuemmerle et al., 2008; Prishchepov et al., 2012).

Kyrgyzstan became independent of the former Soviet Union in 1991 and has experienced dramatic economic reform and changes in economic structure (Pankow & Jermakowicz, 1995). Notably, land policies and land ownership have changed since independence. When Kyrgyzstan was part of the Soviet Union, its agricultural production had been interconnected with other Soviet states and markets. Kyrgyzstan was once a net importer of many crops and inputs such as fertilizers and had guaranteed markets for some crops such as cotton and tobacco, but the shift to independent statehood caused an immediate need for self-sufficient production without the infrastructure or inputs to accomplish it (Babu & Reidhead, 2000). Work by Wilson (1997) documented the rapid decrease of livestock production after independence. Changes from collective to family farming meant a larger portion of the rural population began to own land, and localized markets had to be created (Tashmatov et al., 2000). Sustainable agricultural practices were recommended in earlier studies. For example, Wilson (1997) discussed implications and opportunities for more sustainable pasture usage. Sustainable agricultural practices recognized the importance of monitored experimentation on farms, malleable farm organization, and diversifying as means for keeping farms adaptable to external changes (Darnhofer et al., 2010).

2.4. Development in the agricultural sector

Development and industrialization also affect agricultural production. As countries make investments in industrial production and technology, more money is spent on construction of the built environment. As populations become increasingly more concentrated in cities, the labor required for agricultural production may be lost or substituted by technology (such as pesticides, irrigation, harvesters, etc.). Increased agricultural production through new technology and machinery can free up labor to pursue other forms of production, which can aid development (Dethier & Effenberger, 2012).

Irrigation is an important agricultural input, allowing crops to receive water to minimize the deficit between rainfall and evaporative demand. However, the infrastructure of irrigation in Kyrgyzstan, which had been designed for large Soviet farming systems, was not restructured or maintained after land was redistributed, making access to irrigation water problematic (Sabates-Wheeler, 2007). Among the land that is used for agriculture in Kyrgyzstan, usually less than 14% is irrigated. Over time, there have been increases in agricultural land that was irrigated during the post-Soviet transition years and during the global economic recession (FAO, 2012).

3. Study area and data

3.1. Study area

Kyrgyzstan (Fig. 1) is a small, landlocked country situated within the Tien Shan and Pamir mountain ranges in Central Asia. Tall peaks and

high mountain valleys dominate the landscape, with 86% of the country at more than 1500 m above mean sea level and 57% above 2500 m above mean sea level (Azykova, 2002). The mountains also influence the climate and the settlement patterns of the country's citizens. Summers are hot and dry, particularly in the southern region of the country, and winters are cold. Most people live in the southern region or in the capital city of Bishkek in the north (Atamanov & Van den Berg, 2012b; NSCKR, 2011).

Kyrgyzstan was one of the poorest Soviet states, and some have argued it was one that suffered greatest from the Soviet Union's collapse (Becker & Paltsev, 2004). In 1991, Kyrgyzstan officially withdrew from the Soviet Union and established itself as a sovereign state. Looking for rapid economic and political reform, Kyrgyzstan became one of the first former Soviet republics to establish a national currency and join the World Trade Organization (Anderson & Pomfret, 2000; Ruziev & Majidov, 2013). The impact of rapid transition and economic shocks was drastic economic decline between 1991 and 1995 (Anderson & Pomfret, 2000) as GDP fell by 60% in those four years (Becker & Paltsev, 2004).

In 1996, gold production and increased agricultural output began to turn things around, though economic development was not equally distributed across the country (Anderson & Pomfret, 2000; Atamanov & Van den Berg, 2012b; Bernabè & Kolev, 2005). Around 400 collective state farms were redistributed into thousands of private farms across the population, and crop yields increased on these private farms (Savastano & Scandizzo, 2009; Tashmatov et al., 2000). Farming families worked together to form smaller collectives to protect themselves from market fluctuations and to assist each other in the face of unequal distributions of agricultural machinery and irrigation systems (Sabates-Wheeler, 2007). Yet, even with these improvements, many farming families remain among the working poor and must subsist on their own production.

Rural and urban differences in earnings and regional differences in production led to inequalities in resource allocation and income. Poverty rates are lowest in the capital city of Bishkek and highest in the southern parts of the country (Anderson & Pomfret, 2000). By the turn of the 21st century, many Kyrgyz people began to migrate abroad to find new sources of income, sending money to family back home. There were so many migrants sending remittances that in 2018 Kyrgyzstan became the third most remittance-dependent country (measured as a percentage of the GDP) in the world (World Bank, 2019a).

Two instances of political unrest and violence have occurred in the 21st-century history of Kyrgyzstan. The first, in 2005, is known as the Tulip Revolution, where protests against government corruption led to a regime change, with the overthrow of the president. Then in June 2010, violence erupted between ethnic Kyrgyz and Uzbek people in the southern part of the country. That event, coupled with repercussions from the global financial crisis, slowed the country's economic growth (Ruziev & Majidov, 2013).

Kyrgyzstan remains a country in transition. Its development strategies and long-term plans for the future are unclear (Shadymanova et al., 2014). Compared with its much larger or more populous neighbors, Kyrgyzstan's agricultural economy and dependence on imports for energy, machinery, and even food products put it in a precarious situation. Though the country has experienced significant economic, political, and social change in the past quarter century, its future trajectory will be influenced by demographic and climate changes as well as continuing institutional changes.

3.2. Variables and data

We pooled multiple sources of data to construct time series panel data at the oblast level (Table 1). Kyrgyzstan is divided into seven subnational regions called *oblasts* (i.e., provinces), as well as two independent cities: the capital city of Bishkek near the northern border with Kazakhstan, and the city of Osh on the western border with Uzbekistan. We used two variables to capture agricultural production: total crop production (tonnes of grains, vegetables, and fruits) and total livestock production (tonnes of meat). The data were obtained from the Annual Agricultural Statistics of the Kyrgyz Republic, 1990–2014. Aside from agricultural production, we also

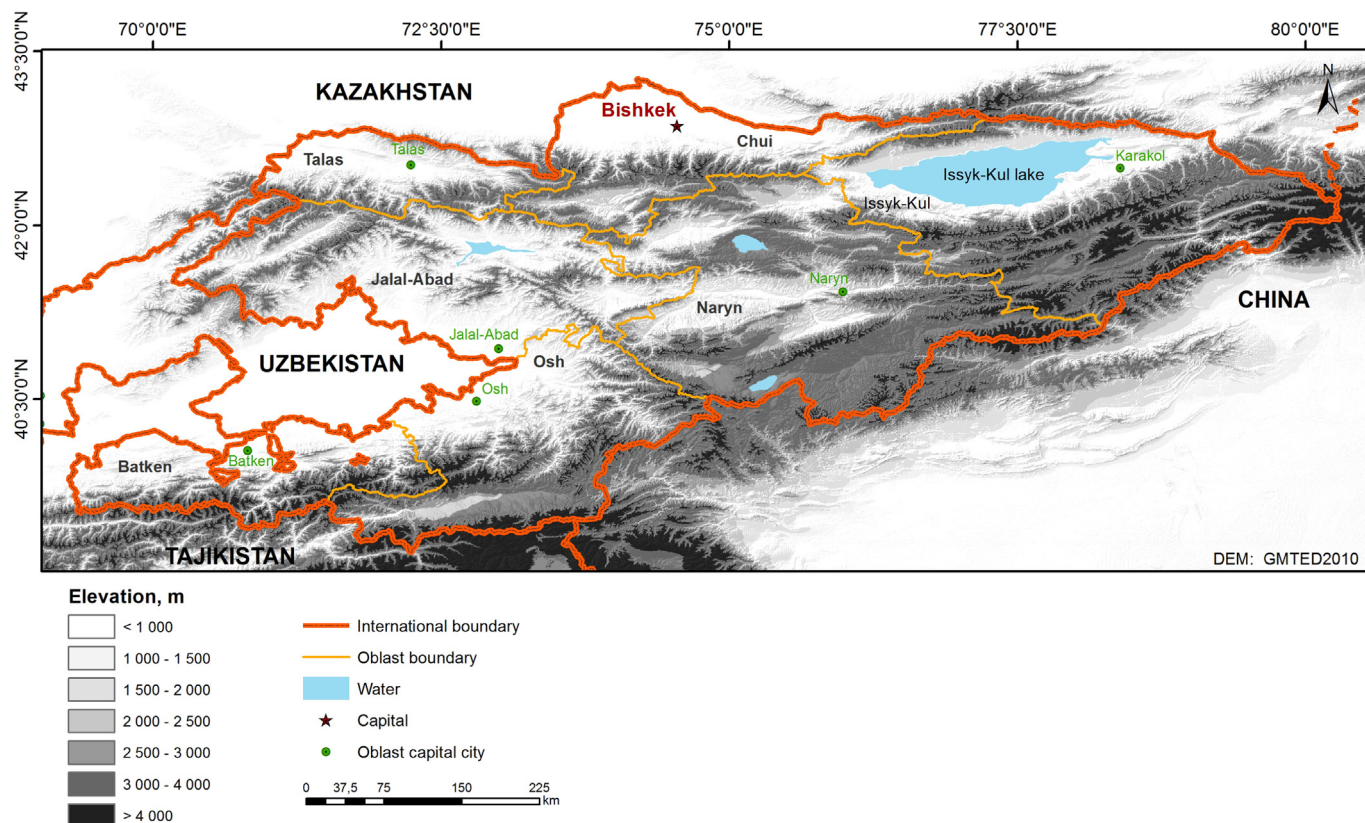


Fig. 1. Kyrgyzstan and its oblasts.

examined the trends of an array of demographic, climatic, and socioeconomic indicators. The demographic variables include total population size, percentage of rural population, total fertility rate, and life expectancy. The data were from the Demographic Yearbook of the Kyrgyz Republic, 1990–2014 and the United Nation's 2015 Population Prospectus.

Five climate variables were measured: precipitation, extreme precipitation, temperature, extreme cold, and extreme hot. We obtained country-level monthly average temperature and total precipitation data from the Climate Change Knowledge Portal (World Bank, 2019b), which were derived from the CRU high-resolution gridded time-series product (Harris et al., 2014). We obtained oblast-level annual average and extreme temperature and precipitation data from the Weather Station Observation Archive (WSOA) of the National Climatic Data Center of the U.S. National Oceanic and Atmospheric Administration (NCDC, 2019). There is roughly one weather station with archived observations per oblast in Kyrgyzstan. We extracted data for each oblast from the weather station located within it. For missing records (e.g., when a single variable in a single year is missing), we used available data from the nearest station with an elevation as similar as possible to the oblast's station to fill the blanks. When searching for the nearest neighboring weather station, we examined not only weather stations within Kyrgyzstan but also those located in bordering countries with similar landscapes. For a number of weather stations within the region, the records after 2006 including temperature, precipitation, and extreme precipitation can sometimes be absent for a few consecutive years. The gaps were of limited scope (in terms of the number of years, locations, or variables missing), and when filling them in, we tried to preserve patterns shown by observed data as much as possible: to fill any temporally consecutive oblast-level data gaps, we derived each oblast's average deviations from national averages/totals using the years when oblast-level data were available and added the deviations to national averages/totals for the years for which oblast-level data were missing. With these data, we were able to examine the association between agricultural production and

climatic variables concerning both average and extreme conditions at the oblast level.

The socioeconomic-related variables included agricultural employment, GDP per capita, construction spending, and percentage of private land; the data came from the Annual Economic Statistics of the Kyrgyz Republic, 1990–2014. Detailed descriptions of each variable and the data sources are displayed in Table 1.

3.3. Analytical strategy

Our analytical strategy was composed of multiple exploratory and confirmatory analysis methods. First, we used graphs to illustrate the trends of agricultural production from 1990 to 2014 at the national level. Second, we mapped the percentage change of agricultural production at the oblast level, comparing the difference between 1990 and 1995 (the transition period) and 1995–2014 (the post-transition period). Third, we analyzed demographic changes between rural and urban areas. Fourth, we examined climate change in terms of precipitation and temperature. Fifth, we calculated Pearson correlations between agricultural production and variables measuring demographic and climate changes. Sixth, we fitted ordinary least squares (OLS) regression models to examine the association of agricultural production with demographic and climatic changes. We used dummy variables to control for the time trends and regional differences across oblasts.

4. Results

4.1. Agricultural production in Kyrgyzstan

Table 1 shows basic descriptive information for each variable, including the mean, standard deviation, and data sources. We used two variables to capture elements of agricultural production: total crop production and

Table 1

Descriptions of variables at the oblast level and data sources.

Variable	Description	Mean	Std. Dev.	CV%	Data source
Agricultural production variables					
Total crop production	Including grains, vegetables, and fruits (in tonnes)	443.5	340.5	76.8	Annual Agricultural Statistics of the Kyrgyz Republic, 1990–2014
Total livestock production	Including meat and poultry (in tonnes)	210.0	161.1	76.7	Annual Agricultural Statistics of the Kyrgyz Republic, 1990–2014
Demographic factors					
Total population	Total population (in thousand)	619.4	305.3	49.3	Demographic Yearbook of the Kyrgyz Republic, 1990–2014
Percent rural	Percentage of rural population	67.0	27.0	40.3	Demographic Yearbook of the Kyrgyz Republic, 1990–2014
Total fertility rate (TFR)	Total fertility rate (# children per women)	2.9	0.4	12.5	United Nation's 2015 Population Prospectus
Life expectancy	Life expectancy at birth (years)	64.1	1.3	2.0	United Nation's 2015 Population Prospectus
Climate factors					
Precipitation	Annual precipitation (mm)	487.2	223.3	45.8	Weather Station Observation Archive (WSOA) of the National Climatic Data Center (NCDC)
Extreme precipitation	The single extreme precipitation (mm)	29.1	10.3	35.2	WSOA of the NCDC
Temperature	Average temperature (°C)	11.7	4.6	39.2	WSOA of the NCDC
Extreme cold	# days with max temperature below 0 °C (32 °F)	40.1	42.0	104.7	WSOA of the NCDC
Extreme hot	# days with max temperature exceeding 32 °C (90 °F)	38.8	33.5	86.4	WSOA of the NCDC
Socioeconomic factors					
Agricultural employment	Percentage of agricultural employment to total employment	0.4	0.1	20.0	Annual Economic Statistics of the Kyrgyz Republic, 1990–2014
GDP per capita	GDP per capita in inflation-adjusted U.S. dollars	487.7	90.4	18.5	Annual Economic Statistics of the Kyrgyz Republic, 1990–2014
Construction spending	The price-adjusted output in construction industry (in soms)	1240.5	2933.5	236.5	Annual Economic Statistics of the Kyrgyz Republic, 1990–2014
Private land	Percentage of agricultural land that is privately owned	0.1	0.1	100.0	Annual Agricultural Statistics of the Kyrgyz Republic, 1990–2014

Note: The means are calculated at the oblast-year level.

total livestock production. The total agricultural production from 1990 to 2014 for Kyrgyzstan is shown in Fig. 2, along with a measure of the portion of GDP contributed by agriculture.

In the years immediately preceding and following Kyrgyz independence and the collapse of the Soviet Union, both crop and livestock production declined. Livestock production declined sharply to its lowest—375,268 tonnes—in 1994; crop production reached its nadir (409,265 tonnes) in 1995, before production began to rise. Economic, political, social, and institutional changes can largely account for these production declines. As stated previously, Kyrgyzstan's agricultural production during the Soviet period was interconnected with other Soviet republics and the markets were controlled. Kyrgyzstan had been dependent on importing many inputs such as fertilizers and pesticides, and without these production inputs or infrastructure to generate them, Kyrgyzstan was unable to achieve self-sufficiency as a newly independent country (Babu & Reidhead, 2000). During the transition, agriculture occupied an increasing share of Kyrgyzstan's GDP: it accounted for almost half of the GDP in 1996, reflecting the importance of even low production levels in the transitioning economy.

Agricultural production began to rise after 1995 and continued to rise until the global economic recession started in 2008. Crop production dipped during the recession and continues to fluctuate between 1,350,000 and 1,800,000 tonnes in the years after the recession. Livestock production leveled off during the recession years but has since continued on an upward trend. In 2013, livestock production surpassed crop production, a trend not seen since the formation of the independent state of Kyrgyzstan. At the same time, the share of GDP occupied by agriculture declined to less than 20% in 2014. This trend indicates economic development in other sectors, suggesting that increased agricultural production might have freed labor to pursue other forms of production.

4.2. Agricultural production changes from 1990 through 2014 at the oblast level

Subnational differences in agricultural production can impact the distribution of goods across a country. We examined crop and livestock production across seven oblasts and Bishkek. While recent data collection separates Bishkek and the city of Osh from the oblasts because of the cities'

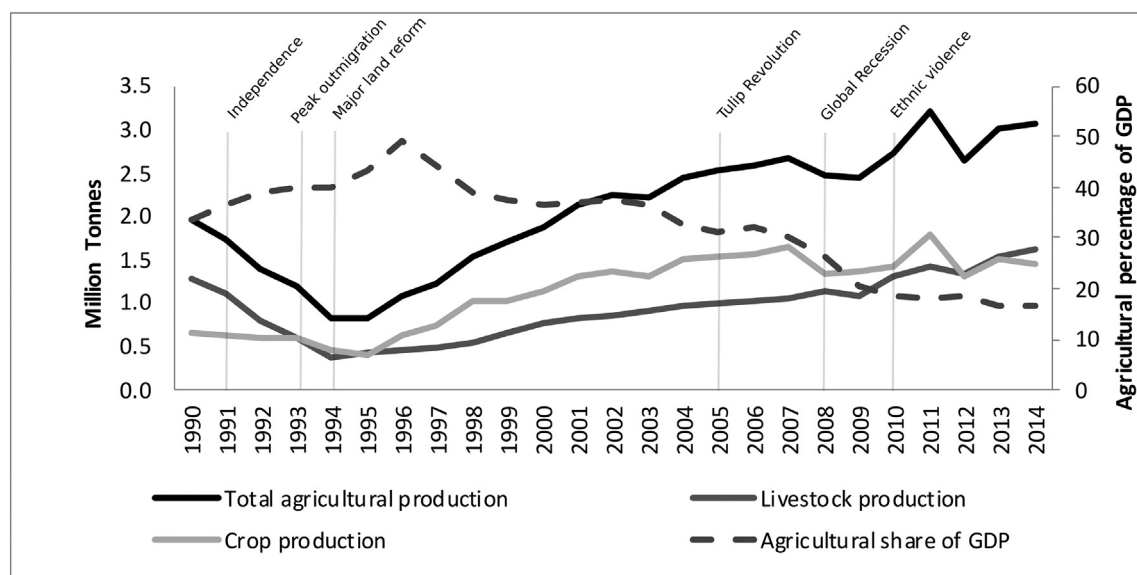


Fig. 2. Agricultural production (million tonnes) and agricultural share of GDP (Percentage), 1990–2014, Kyrgyzstan. Data source: Annual Agricultural Statistics of the Kyrgyz Republic, 1990–2014.

large, concentrated populations, in our analysis the city of Osh was incorporated into the surrounding oblast of Osh so that comparisons could be made to earlier data collections when it was not differentiated. The oblasts of Kyrgyzstan differ greatly in regional size, population size and density, and geographical characteristics, which all can play a role in their agricultural production and adaptations to changes over time. We mapped changes to agricultural production at the oblast level from 1990 through 2014, as shown in Fig. 3. These results suggest regional specialization in certain modes of production over time. To better understand the nuance of the changes to both crop and livestock production, we separated the analysis into two time periods: Fig. 3A and C represent the earlier period (1991–1995) when Kyrgyzstan was transitioning, and Fig. 3B and D represent a later period (1995–2014) after the initial shocks. Fig. 3A and B show crop production, while Fig. 3C and D show livestock production. Large differences in both crop and livestock production emerged between the two time periods.

In the early years, crop production declined across the city of Bishkek and all Kyrgyz oblasts except for Talas. However, in the years following the initial transition, the trend reversed and almost all oblasts experienced large increases. The percentage of change in crop production in Naryn declined only slightly and at much lower rates than in the initial period. However, crop production in Bishkek was significantly reduced. The dramatic fluctuation in crop production in that urban area may reflect its relatively small portion of agricultural activity.

Livestock production plummeted in the early transition years. This lower production reflected the trends of shifting diets and production toward more basic and affordable sources of calories during times of economic distress. The only increase in livestock production during the period 1991–1995 was in the capital, which again may reflect its small agricultural portion or its protected status. Once the initial transition was over, livestock production increased in all oblasts.

4.3. Demographic changes

The population changes in Kyrgyzstan before, during, and after the transition to independent statehood could have had effects on agricultural production. Population growth, fertility (measured by the crude birth rate), mortality (measured by the crude death rate), and net migration rates are illustrated in Fig. 4. Between 1990 and 1994, the population growth rate plummeted, largely due to a big net out-migration in addition to a declining birth rate and an increasing death rate. After 1994, the annual population growth rate remained above 1% and began to rise in 2008. The crude birth rate bottomed out in 2003, and the death rate peaked around the same time period due to ethnic conflicts between the Kyrgyz and the Uzbek.

Fig. 5 shows urban and rural populations, by percentage, in Kyrgyzstan. Although the number of people living in urban areas has surpassed the rural population globally since 2009 (UN, 2009), Kyrgyzstan is one of the few countries with a majority-rural population and whose rural population has grown more quickly than its urban population. The percentage of the rural population in Kyrgyzstan (Fig. 5A) greatly increased in almost all oblasts in the period between 1991 and 2015, and every oblast also experienced a moderate decline in urban population (Fig. 5B). The city of Bishkek is an exception, unsurprisingly, because the population within its territorial bounds became increasingly urban. Interestingly, Talas oblast experienced declines in both rural and urban populations, indicating that the overall population of Talas declined.

4.4. Climatic changes

Fig. 6 provides a visualization of the country-level data for total precipitation (in millimeters) and average temperature (in degrees Celsius) for March through August, the growing season, during the period 1990–2014. We focus on these six months of the year because they are the critical growing season during which more than 60% of annual precipitation occurs. As shown, despite short-term interannual variabilities, the trend lines of the two variables over 25 years indicate that Kyrgyzstan's growing season has become hotter

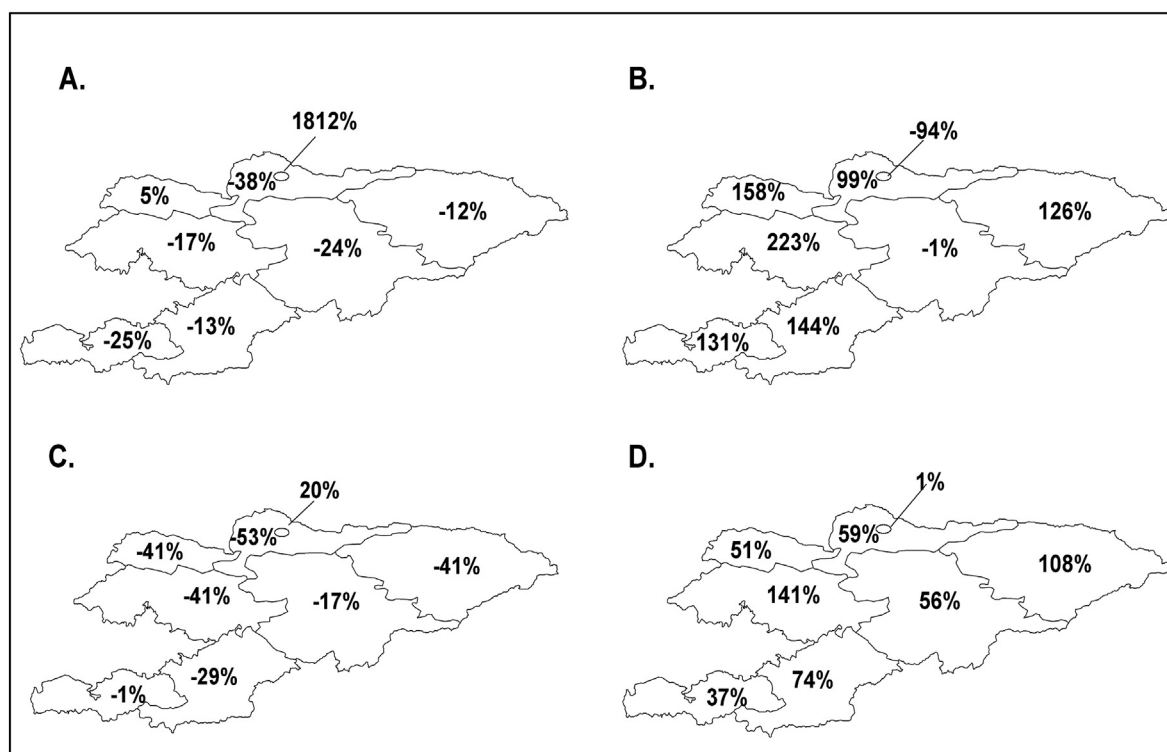


Fig. 3. Percent changes in crop and livestock productions, 1990–1995 and 1995–2014, Kyrgyzstan. Notes: A – Percent change of crop production (1991–1995); B – Percent change of crop production (1995–2014); C – Percent change of livestock production (1991–1995); D – Percent change of livestock production (1995–2014). Data source: Annual Agricultural Statistics of the Kyrgyz Republic, 1990–2014.

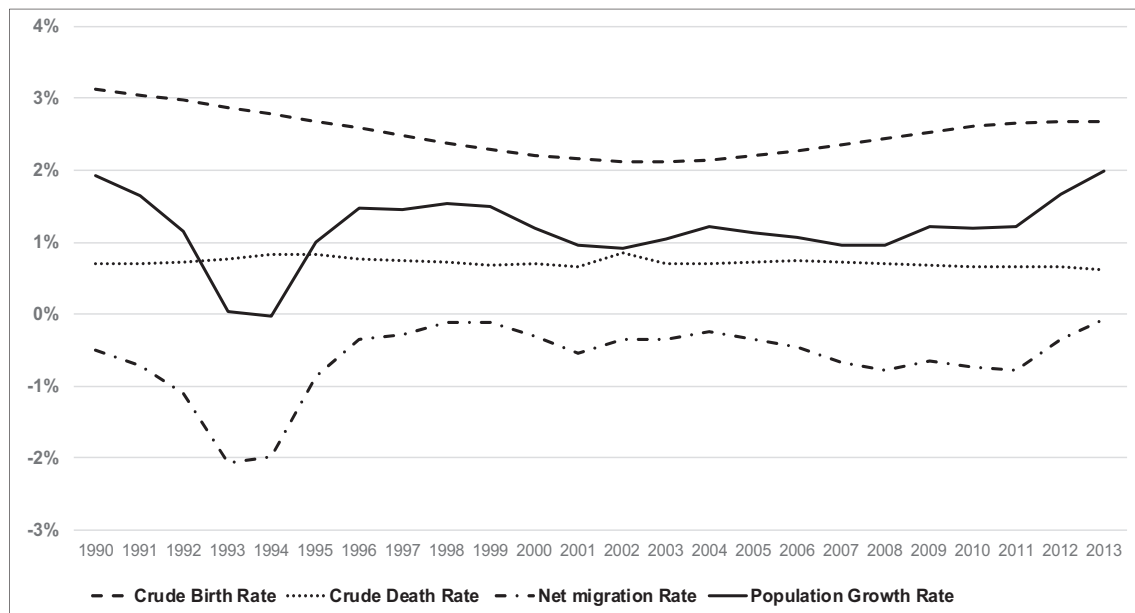


Fig. 4. Population growth, fertility, mortality, and migration, 1990–2014, Kyrgyzstan. Data source: 2015 World Development Indicator by the World Bank. <https://data.worldbank.org/products/wdi>

and drier. This suggests the observed increase in the use of irrigation over the same time period (FAO, 2012) is likely environmentally motivated. Increased need for irrigation may alter demand for labor and/or technological renovation. Because these climatic trends are anticipated to continue, the necessity of irrigation may further expand and interact with socioeconomic trends (e.g., labor migration) to shape future agricultural production. Considering that Kyrgyzstan's environmental conditions show strong spatial variations, the associations among climate change, demographic shifts, and agricultural production merit careful examinations at the subnational level, such as the investigations that we discuss below.

4.5. Correlation analysis

To understand the associations between agricultural production and demographic and climatic changes, we calculated Pearson correlations (Table 2). The units of analysis are oblasts by years. We standardized agricultural productions using 1991 as a base year (i.e., the values in 1991 = 100). This standardization allowed us to compare production across production types and see broader trends. Our analysis included 192 observations, corresponding to the standardized productions from 1991

through 2014 for the seven oblasts and Bishkek (24 years \times 8 oblast-level spatial units = 192 observations). The results suggest that total population and rural population are positively correlated with both crop and livestock productions. The associations between rural population and the agricultural production variables are particularly strong. Precipitation is positively correlated with both crop and livestock productions, and the correlations are strong. The extreme precipitation also has a positive correlation with the agricultural production but not as strong as precipitation does. All three temperature measures are strongly correlated with both crop and livestock productions, with a negative correlation between production and average temperature and extreme hot, along with a positive correlation between production and extreme cold. Overall, a wetter and colder climate is associated with agricultural production increases. However, the growing season from 1991 to 2014 in Kyrgyzstan has become drier and hotter (Fig. 6), challenging future agricultural production.

It should be noted that there were significant correlations between demographic and climate changes and socioeconomic factors in the study period. For example, agricultural employment has a statistically significant and negative association with total fertility rate and life expectancy. We

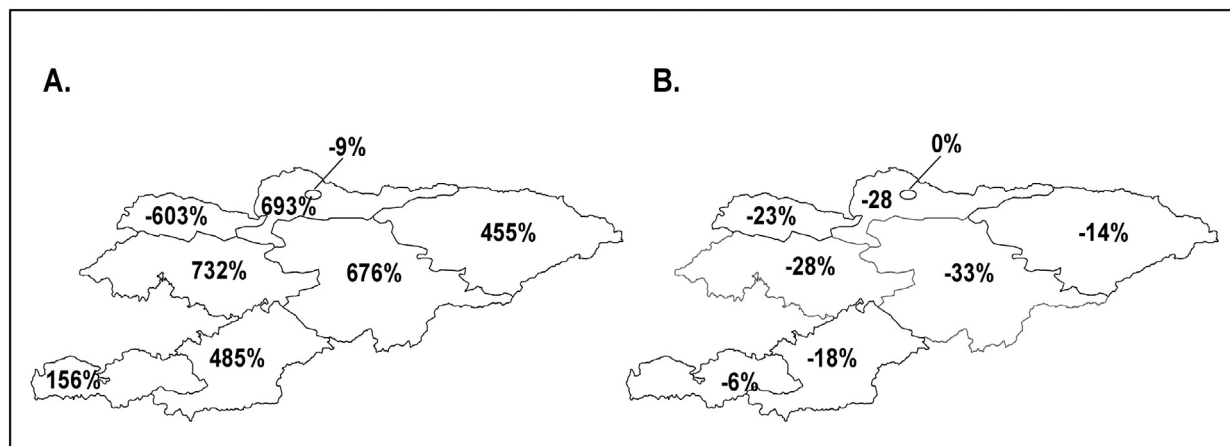


Fig. 5. Percent population change by Oblast, 1990–2014, Kyrgyzstan. Notes: A – Percent change of rural population; B – Percent change of urban population. Data source: Demographic Yearbook of the Kyrgyz Republic, National Statistical Committee of the Kyrgyz Republic.

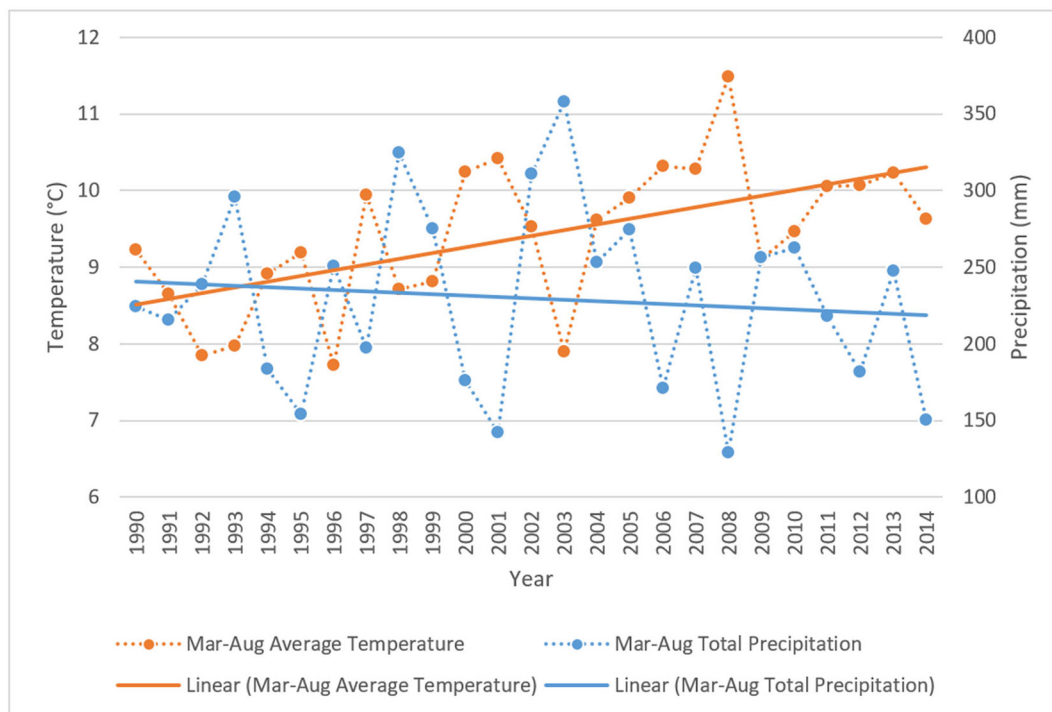


Fig. 6. March through August average temperature and total precipitation, trend lines 1990–2014, Kyrgyzstan. Data source: The Climate Change Knowledge Portal of the World Bank (2019b).

find correlations between higher GDP and longer life expectancy, and between GDP and lower agricultural employment—GDP per capita has a substantial and positive correlation with life expectancy ($r = 0.75$) but a substantial and negative correlation with agricultural employment ($r = -0.85$). Construction spending is correlated negatively with the percentage of rural population and agricultural employment but positively with GDP per capita. The high correlations among the demographic, climatic, and socioeconomic factors make it difficult to attribute changes in agricultural production changes to any specific set of factors.

4.6. Regression analysis

We used OLS regression models (Table 3) to examine the associations between the two agricultural production variables (standardized crop production, standardized livestock production) and the demographic, climatic, and socioeconomic factors. We also included oblast dummy variables to control for regional differences and the year dummy variable to control for the time trend. We included standardized coefficients for the purpose of comparing them across explanatory variables.

Among the demographic variables, increases in the total fertility rate are associated with decreased livestock production with each additional child per woman being associated with a 52.5 tonnes decrease in mean livestock production. The percentage of the population living in rural areas and the life expectancy of the population do not have statistically significant associations with any measures of agricultural production.

Although all the five climatic factors have statistically significant and strong correlations with the two agricultural production variables, the regression results show otherwise. Only extreme hot has a statistically significant association with crop production, with each additional day in number of days with temperatures $> 32^{\circ}\text{C}$ being associated with a 4.05 tonnes higher crop production ($p < 0.01$). This is likely because other factors, such as socioeconomic factors and regional and temporal variations, play stronger roles. In addition, the small number of observations ($N = 192$) reduces the statistical significance of 21 explanatory variables.

Increases in the number of people employed in the agricultural sector are associated with increased crop production, with each 1% rise in

agricultural employment being associated with a 2294.75 tonnes higher mean crop production ($p < 0.01$). Increases in construction spending are strongly associated with both crop and livestock production. As spending on construction increased across the country, both crop production and livestock production decreased. This pattern may be an indicator of economic development, where spending on new construction in cities or on the creation of other industries decreases local agricultural production by incentivizing workers to seek employment in construction. Crop production exhibits strong regional variations. Batken and Jalalabad oblasts have lower crop production than Bishkek has, all other factors being equal; Issyk-Kul oblast has higher crop production than Bishkek has; and Talas oblast has both higher crop and livestock productions than Bishkek has. The year trend is associated with increases in crop production, indicating that it grew over time.

5. Discussion

In this descriptive study, we examined agricultural production in Kyrgyzstan, an understudied and disadvantaged, land-locked Central Asian country that has experienced dramatic changes in political and market structures, rapid demographic changes, and climatic changes. Specifically, we examined the association of agricultural production with demographic and climatic changes from 1990 through 2014. The results suggest that both crop and livestock production experienced dramatic changes in the study period. Fertility level had a negative association with livestock production, and agricultural employment had a positive association with crop production. It is possible that there is some unmeasured change in the population that would affect livestock production—perhaps a population with more unmarried young men and late marriage ages could support livestock production, but could be associated with lower fertility. It is reasonable that higher agricultural employment is associated with higher production, but it would be interesting to try to ascertain whether higher employment follows as a result of a successful growing season, or whether hiring more workers at the start of the season supports a more productive year of agricultural production.

Table 2
Pearson correlation matrix.

	Crop production	Livestock production	Total population	Percent rural	TFR	Life expectancy	Precipitation	Extreme precipitation	Temperature	Extreme cold	Extreme hot	Agricultural employment	GDP per capita	Construction spending
Livestock production	0.86***													
Total population	0.31***	0.40***												
Percent rural	0.41***	0.40***	-0.18**											
TFR	-0.17**	0.05	-0.02	0.03**										
Life expectancy	0.20***	0.17*	0.12	0.04	-0.05									
Precipitation	0.53***	0.50***	0.40***	-0.07	-0.16	0.1								
Extreme precipitation	0.36***	0.33***	0.30***	-0.12	-0.12	0.02	-0.44***							
Temperature	-0.67***	-0.77***	-0.54***	-0.09	-0.05	0.02	-0.60***	0.79***						
Extreme cold	0.52***	0.66***	0.56***	0.01	0.07	0.02	-0.84***	0.32***	0.45***					
Extreme hot	-0.46***	-0.48***	-0.55***	0.33***	-0.03	-0.03	0.72***	-0.46***	-0.58***	-0.69***				
Agricultural employment	-0.11***	-0.17***	-0.12***	-0.09***	-0.46***	-0.53***	0.05***	0.05***	-0.05***	-0.09***	0.05			
GDP per capita	0.16**	0.20***	0.12	0.07	0.34***	0.75***	-0.04	-0.07	0.05	0.06	-0.02	-0.85***		
Construction spending	-0.08**	-0.08	0.34	-0.46***	0.02	0.33***	0.04	0.02	0.01	0.09	-0.27	-0.34***	0.36***	
Private land	0.42***	0.44***	0.06	0.37***	0.07	-0.11***	0.06	0.01	-0.31***	0.25	-0.11	-0.03***	-0.08***	-0.11

Values of agricultural productions are transformed into indices relative to the base year (that is, the values in 1991 = 100).

* Significant at $\alpha = 0.05$ level.

** Significant at $\alpha = 0.01$ level.

*** Significant at $\alpha = 0.001$ level.

Table 3
Regression results.

	Crop production			Livestock production		
	USC	SC	SE	USC	SC	SE
Demographic factors						
Total population	−0.21	[−0.18]	(0.21)	0.04	[0.15]	(0.04)
Percent rural	760.20	[0.56]	(509.41)	−33.73	[−0.11]	(89.51)
Total fertility rate	213.24	[0.21]	(114.24)	−52.50**	[−0.23]	(20.07)
Life expectancy	−10.79	[−0.04]	(30.06)	4.60	[0.07]	(5.28)
Climate factors						
Precipitation	−0.02	[−0.01]	(0.20)	−0.03	[−0.08]	(0.04)
Extreme precipitation	0.65	[0.02]	(3.31)	−0.54	[−0.07]	(0.58)
Temperature	16.87	[0.21]	(14.91)	1.48	[0.08]	(2.62)
Extreme cold	−0.43	[−0.05]	(1.30)	0.19	[0.10]	(0.23)
Extreme hot	4.05**	[0.37]	(1.39)	−0.24	[−0.10]	(0.24)
Socioeconomic factors						
Agricultural employment	2294.75**	[0.47]	(735.82)	3.19	[0.00]	(129.30)
GDP per capita	0.21	[0.05]	(0.60)	0.13	[0.14]	(0.11)
Construction spending	−0.06***	[−0.45]	(0.01)	−0.01***	[−0.34]	(0.00)
Private land	48.07	[0.01]	(517.62)	−0.55	[−0.00]	(90.95)
Oblast dummy (reference group: Bishkek)						
Batken	−508.47**	[−0.46]	(190.65)	19.99	[0.08]	(33.50)
Chuy	−77.53	[−0.07]	(110.86)	5.78	[0.02]	(19.48)
Issyk-Kul	−562.31**	[−0.50]	(213.82)	37.60	[0.15]	(37.57)
Jalalabad	181.22	[0.16]	(142.33)	−39.78	[−0.16]	(25.01)
Naryn	−391.08	[−0.35]	(205.32)	−23.71	[−0.09]	(36.08)
Osh	1356.81***	[1.21]	(373.51)	185.61**	[0.74]	(65.63)
Talas	361.82*	[0.32]	(174.79)	−22.67	[−0.09]	(30.71)
Year trend	23.68**	[0.44]	(7.28)	0.77	[0.06]	(1.28)
R ²	0.54			0.72		

Notes: USC = unstandardized coefficients; SC = standardized coefficients; SE = standard errors.

N = 192.

Values of agricultural productions are transformed into indexes relative to the base year (that is, the values in 1991 = 100).

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

Five climatic factors had statistically significant correlations with both crop and livestock production. A wetter and colder climate was associated with agricultural production increases. However, the statistical significance of the climatic factors diminished dramatically when considered together with other socioeconomic factors and regional and temporal variations. This finding is not surprising given the topographic complexity of the country, the sparsity of the weather station network, the high interannual variation in precipitation and temperature due to the continental climate, and the coarse levels of analysis. Additionally, these measures of temperature and precipitation do not account for specific timing of heat/cold or precipitation/drought. For instance, extreme cold and high precipitation might represent conditions that lead to high winter snowfalls, which in turn provide steady spring water from snowmelt, helping production. Or extreme cold and high precipitation might result in late frosts, and heavy rain that delays planting or harvests to the detriment of production. In addition, it might be that climatic factors were not as important as these other factors in the study period in Kyrgyzstan. In part, this was because the regression models included a large number of explanatory variables (21) but a small number of observations (192). Further, it is possible that the climatic variables that showed correlations (e.g. precipitation, temperature) but non-significant regression results may suggest non-linear (u-shaped)

associations that are beyond the scope of this study. This can be explored in future research when sufficient data are available.

In addition, the results showed a strong regional difference and temporal change of crop and livestock production across oblasts. It should be noted that there were strong correlations among the demographic, climatic, and socioeconomic factors, making it challenging to separate their attributions to the changes of agricultural production. In addition, food security, as measured by available foodstuffs, had a uptrend from 1991 to 2014 (Fig. 7). This uptrend was generally correlated with the increase of total agricultural production. Also, the 2019 Global Hunger Index notes an overall improvement in indicator scores with approximately 50% reduction from 2000 to 2019 in proportion undernourished and prevalence of stunting in children under five (Concern Worldwide and Welthungerhilfe, 2019). These observations support the importance of increasing agricultural production when dealing with food insecurity.

Our research fills the gap in the literature on agricultural production and food insecurity in Kyrgyzstan, a country that characterizes many developing countries but is also unique in many ways: it has a highly limited amount of arable land, dramatic economic changes and reform, high elevations that make it relatively more sensitive to climatic variation and change, an unusual pattern of out-migration, violent ethnic conflicts and changes in ethnic composition, and a population that is predominantly rural. In addition, we conducted our regression analysis at the oblast level, which had not been done in the existing research on food insecurity in Central Asian countries. This study provides insights into agricultural production and food insecurity as they relate to demographic and climate changes as well as to socioeconomic changes. Although we focused on Kyrgyzstan for this research, the results may be generalizable to Tajikistan, another montane Central Asian country, or even the montane nations of the Caucasus, such as Georgia and Armenia, which have experienced challenges similar to those of Kyrgyzstan. This study provides a framework for describing complex issues surrounding food productivity and the factors that might affect it, using measures that can be applied across geographic and political boundaries. While the variables used in this study are simple, and available in many geographies, they could be modified for more specific work exploring the inter-relationships among the factors explored in this study, and to support research and policy making involving the interrelated factors of climate mitigation, immigration, and food production. While the small number of observations makes it challenging to assess non-linear associations and potential interactions that might inform models, this descriptive paper highlights a set of variables related to agricultural production, and sheds light on some of the interplay between them.

That said, there are many directions for future research that pertains to agricultural production. One major direction is to collect a wide range of data at the oblast and rayon (district) levels related to agricultural production and food insecurity. These data include but are not limited to demographic changes (e.g., population change and age, gender, ethnic group, migration, mortality, and urban and rural differences), social changes (e.g., norms and values, marriage patterns, and crime), and economic changes (e.g., remittances, income, employment, housing quality, and industrial composition). The other major direction is to focus on groups at risk of social disadvantage—such as children, the elderly, women, and ethnic groups—within the context of food insecurity. Because of limited access to data below the national level, it is essential to collect primary data. Doing so would enable us to address specific questions and test specific hypotheses related to food insecurity among socially disadvantaged groups, which is a critical issue not only in developing countries but in developed countries as well.

CRediT authorship contribution statement

Guangqing Chi: Conceptualization, Methodology, Writing, Project administration, Funding acquisition. **Jing Gao:** Formal analysis, Data, Curation. Writing - Original Draft, Visualization. **Donghui Wang:** Formal analysis, Data Curation, Resources, Visualization. **Annelise Hagedorn:** Writing - Original Draft. **Kamilya Kelgenbaeva:** Resources, Data Curation.

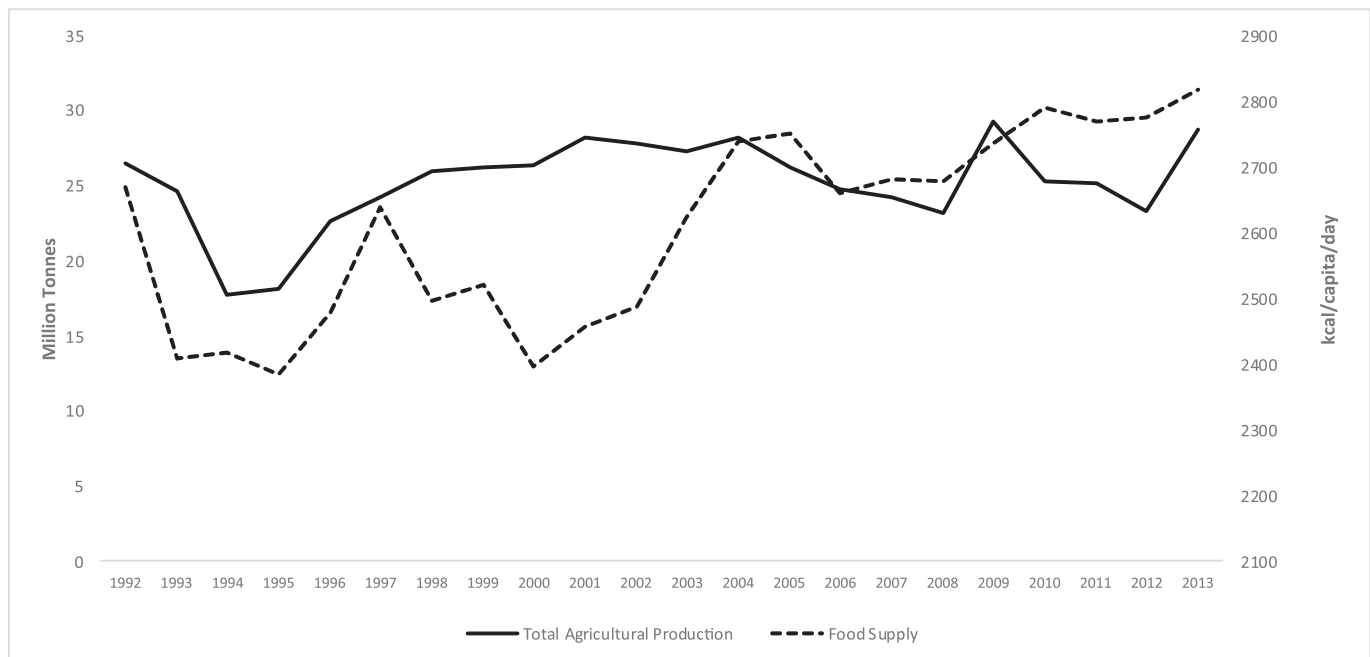


Fig. 7. Agricultural production (million tonnes) and food supply (kcal/capita/day), 1990–2014, Kyrgyzstan. Data sources: Annual Agricultural Statistics of the Kyrgyz Republic, 1990–2014; United Nations Food and Agriculture Organization (FAO) (2019), Food Balance Sheets.

M. Luke Smith: Writing – Editing, Visualization. **Geoffrey M. Henebry:** Writing - Original Draft, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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