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Research Article

An Overview of Global Wheat Market Fundamentals in an Era of Climate Concerns

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Wheat is a key global commodity in terms of acreage and tradeable value and as a staple in household diets. Many factors affect wheat prices including climate, yields, oil prices, lagged prices, and imports. In addition to gradually and consistently increasing global wheat demand, these market drivers are posited to impact world prices and, ultimately, food security. To investigate how these factors differentially influence wheat markets, an extensive survey of literature regarding wheat market fundamentals was conducted, as well as a trend analysis using a uniquely compiled data set specific to significant wheat-producing areas. Previous studies show that imports, climate, oil prices, and past prices, among other factors, have a significant relationship with changes in the world wheat price. This study compiles and compares these same key variables from five major wheat export countries/regions for the time frame from 1980 to 2013.

1. Introduction

The international agricultural research agenda on climate-smart agriculture (CSA) explores the intersection of climate change, the reorientation of food production systems, and food security as a core mission of its programming [1]. Such priorities are a result of tension between natural resources and food production systems due to perceptions of increasing scarcity of resources and the growing demand for food that has fueled interest in analyses that inform stakeholders on food market dynamics. Clearly, the demand for all foodstuffs grows with increases in both world population and the wealth of developing countries, whereas the supplies of natural resources are limited or, if renewable, may be maintained or increase only gradually. The tension between these markets and resource systems is heightened by concerns about how climate resiliency may impact natural resources stocks and flows. In an era of increasing climate concerns and growing focus on sustainable production, this paper summarizes how wheat is produced, consumed, and traded among partners with differential exposure to climactic shocks. The purpose of this analysis is to provide a comprehensive review of the drivers that are important to consider for food security and, more specifically for this paper, the global wheat market. Food security is a complex phenomenon and is determined by distinct dimensions driven by a complex mixture of individual forces, of which volatility plays a minor role [2]. Identifying the economic and environmental factors which exert the greatest influence on the major wheat exporters (including the factors that influence the markets and price of wheat) has important implications for any policies or interventions that are intended to address global food security. This also represents a contribution to the literature by providing a synthesis of data and trends for key wheat-exporting countries with a specific focus on the importance of climate-based factors.

Grains are currently the most important contributor to human food supplies globally. Approximately 21% of the world's food depends on annual wheat crop harvests, which often have relatively low stocks [3]. Developing countries, the majority of which are net wheat importers, consume 77% of total global wheat production. Accordingly, wheat accounts for approximately 24% of food commodities imported by developing countries [4, 5]. Many of those countries pay subsidies to stabilize and/or lower food prices so that consumers are better able to consistently meet dietary needs and, ultimately, increase the level of household food security. However, increasing wheat consumption fueled by population growth and rising incomes in developing country households puts upward pressure on wheat prices [6]. Specifically, growth of the middle class in highly populated, developing countries, particularly those in the Asian region, in tandem with changes in lifestyle and consumption patterns resulting from an increase in wealth, causes an increase in demand for food, including grains.

On the supply side, climate and oil prices are two important factors affecting wheat production. Oil prices influence the cost of inputs for wheat production, and similar patterns observed in wheat and oil price fluctuations indicate high correlation between the two. Changes in climate can influence food production in a variety of ways, as the climates of major production areas may change with respect to growing season length, as well as changes in average temperatures and rainfall. Numerous international research and policy organizations (the G20 Ag Ministers and the Consultative Group for International Agricultural Research (CGIAR) research centers) have made the impact of climate change on agriculture and food security a key priority moving forward, motivating the need to further explore how one key food staple may be influenced by efforts to make the food system more resilient [1, 7]. Specifically related to this study is the likelihood that changes in precipitation patterns will affect world wheat production.

Fluctuations and patterns in wheat prices have changed in recent years compared to earlier decades, due in large part to the previously discussed factors. With increased world wheat prices, imports have become more expensive, and, subsequently, prices of foods that are largely produced using wheat as an input have increased as well. In many developing countries, wheat-based foods are a major share of household diets, meaning that increases in wheat prices will have noticeable effects on the cost of food and food security.

Understanding how different factors influence the world wheat market is essential because of its role in food security for such a large share of the global population. So, the article begins with a broad overview of global food security issues in an era of increasing concerns about climate and then gradually narrows to explore key market drivers for one specific sector of importance to global food security, wheat.

With wheat being particularly sensitive to the consequences of changes in climate, it is essential to investigate the scope of demand and supply factors that affect the global wheat market, particularly among key production regions. To describe the differences among major stakeholders in the global wheat market, this article examines key factors affecting demand and production to determine the relative importance of each. Relevant literature on factors affecting the global wheat market, including oil prices, past prices, import trends, yields, and precipitation, is also presented. A particular focus is placed on the exploration of key market determinants that interface with climate concerns in major supply regions and trading partners. To assess these wheat market dynamics, several key sources of data were compiled and analyzed for trends.

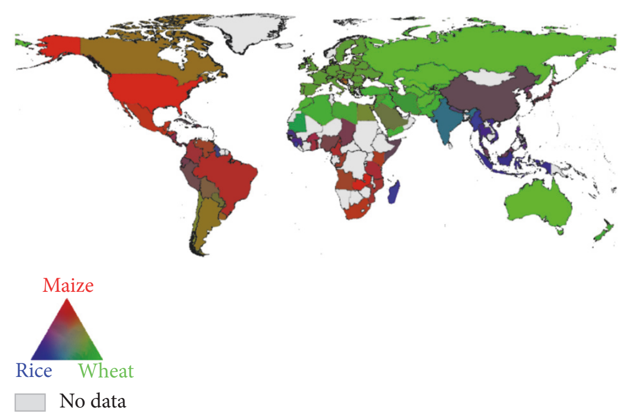


Figure 1: Global major grain consumption map. *Source*: New England Complex Systems Institute, 2011, and Bar-Yam et al. [12, 13]. *Note*. Colors represent the relative domestic consumption of corn, rice, and wheat in each country or indicate that no data is available.

1.1. Wheat Market Fundamentals. Wheat is one of the principal cereal grains produced and consumed globally. It is grown on more land area than any other commercial crop and continues to be the most important grain food source for human consumption [8]. World wheat production is ranked third in weight produced, after corn and rice [9]. This is likely due to the fact that wheat can be cultivated in many areas with heterogeneous types of weather, elevation, or soil. It is mostly cultivated between the latitudes of 30°N to 60°N and 27°S to 40°S [10], up to 3,000 meters above sea level, and in places with temperatures between 3° and 32° Celsius. Wheat is adapted to a broad range of moisture conditions from dry weather to seaside moisture. Although approximately three-fourths of the land area where wheat is grown receives an average of 375 to 875 mm of annual precipitation, wheat can be grown in a wider set of locations where precipitation ranges from 250 to 1750 mm [11]. Wheat production covers more than 240 million hectares (ha) globally and its gross world trade is greater than all other crops combined [8]. Wheat is a major food staple because of the wheat plant's agronomic adaptability, ease of grain storage, and ease of converting grain into flour for making staple food products. Wheat is the major source of carbohydrates in the diet of people from many countries, including Australia, most of Europe, Northern Asia, and Northern Africa (Figure 1).

Wheat production increased sharply in the 1960s and gradually afterwards, mostly as a result of higher yields per ha, in a technology shift commonly labeled the "green revolution" [14]. The green revolution resulted in the development of rust-resistant semidwarf wheat that could utilize large amounts of nitrogen fertilizer and had a higher yield. Between 1980 and 2013, the world's annual harvested area of wheat decreased by 0.24%, but yield increased by 1.41% [3].

Average annual world yields increased from 1855 kilograms per hectare (kg/ha) in 1980 to 3264 kg/ha in 2013 [3].

Most wheat is consumed within the country where it is produced, although roughly one-fifth of global annual production is exported. World wheat trade was estimated at 148 million metric tons (MMT) in 2011, most of which was imported by developing countries. Despite the increase in wheat production over the past few decades, developing countries have continued to import two-thirds of all world wheat trade flows [3].

2. Survey of the Literature and Trends

Studies which simultaneously consider the effect of global weather changes, oil prices, and imports on wheat market dynamics are somewhat rare, especially research that considers the relationship between precipitation and wheat prices on a global scale. Such an integrated analysis could provide a richer understanding of long-term wheat price fluctuations, but many studies relating to this topic consider the effect of just one of these factors at a time. Thus, a more integrated approach can help inform our discussion of cross-cutting issues for wheat markets in an era of climate change.

2.1. The Interface of Food Production, Weather Patterns, and Climate Concerns. Weather can impose a variety of changes across the climate-sensitive agricultural sector, including production challenges, global migration, economic disruption, and land use changes [15]. While positive effects may occur in some regions, drought and extreme heat [16] resulting from changes in climate in lower latitudes can reduce production yields, especially in areas with suboptimal growing conditions, subsequently increasing demand for wheat imports [5]. In recent years, Africa and the Middle East have imported approximately 45% of global wheat trade flows and are predicted to experience increases in aridity in coming decades which may drive further import needs [17]. Arid and semiarid regions account for approximately 30% of global land area and 20% of total world population, representing a large share of global wheat consumers [18]. Despite the risks of a changing climate for warmer wheat production regions, changes in climate could also have a positive effect, potentially making cold regions warmer and more suitable for wheat production [16]. While some studies forecast decreases in future production in regions such as southern Australia [19], others, such as Izaurralde et al. [20] and Zhang and Liu [21], show climate-induced increases in wheat yields in the American Northern Plains and China.

2.2. Global Food Security Policy and Programming Responses. The focus on adaptation of agriculture to climate change for food security is evident in the commitments put forward; for example, the Paris Agreement on global climate action showcased agriculture as a priority, with 94% of countries including the agricultural sector for mitigation and/or adaptation. Agriculture holds a central position in the response to climate change, as actions in this sector represent not only a political, economic, and moral imperative but also an opportunity [22]. A Brookings Institution fellow reports that, in the run up to the 21st session of the UN Conference of Parties for the Convention on Climate Change (COP 21), the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) and Farming First produced a toolkit aimed at farmers' organizations, agricultural development organizations, and negotiators [23]. More broadly, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) addresses the increasing challenge of global warming and declining food security on agricultural practices, policies, and measures [1].

The G20 Ministers of Agriculture and their food security agenda are also important: these countries represent approximately 60% of all agricultural land and about 80% of world trade in agricultural products. They emphasize that there are a number of significant challenges that must be met if stable supplies of safe, nutritious, and affordable food are to be provided for the global population, which is expected to reach 8.5 billion by 2030; these challenges include climate change, urbanization, conflict, and the limited availability of energy and natural resources, such as land and water, and their increased degradation. They promote activities and innovations, such as long-term planning, investments in technologies and practices, and ecosystem-based measures that will make the agricultural sector more resilient to water-related risks such as drought, flooding, salinization, and declining water quality, which are further compounded by climate change [7]. It is critical to note that measuring food security is difficult [24], and there is a rich literature that discusses methods for evaluating the degree of food insecurity present in countries, as well as the implications of employing different metrics for food security assessments [25].

2.3. The Role of Global Economic Factors on Commodity Markets. To find a pattern and form future expectations of food market dynamics, price information from previous years and trends in market prices, both of wheat and of substitute crops, are commonly used. Like other industries, agricultural suppliers respond to price changes by increasing or decreasing production. Due to the lag in agricultural production processes, however, these responses take a longer time to appear in the market supply [26]. Haile et al. [27] found that price volatility is also an important deterrent of supply response, with producers tempering supply response in the face of greater price risk. Wheat prices from the past three decades were compiled and analyzed for trends. Table 1 includes a summary of historical world wheat prices. All prices are deflated based on the 2013 consumer price index (CPI) reported by the US Bureau of Labor Statistics [28]. The lowest deflated price for wheat was $151.70/metric ton (MT) in 1998, for which the nominal price was $107.96/MT. The highest deflated price of wheat was $409.41/MT in 1980, with a nominal price of $148/MT. Figure 2 shows the trend for annual wheat prices during the 34-year time frame. Though ultimately only one of many factors, lagged prices are a strong basis for producer decisions related to future production and are considered an important factor in wheat price forecasting.

Table 1: Summary of data statistics: annual wheat price in USD/MT, deflated to 2013 dollars.

	Mean	Median	Maximum	Minimum	Std. dev.	Coefficient of variation	Obs.
Price ($)	252.62	236.67	409.41	151.70	67.39	0.27	34

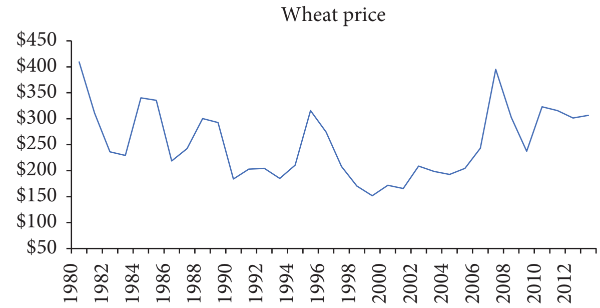


Figure 2: Annual world wheat price, deflated to 2013 dollars. *Source*: FAO, 2015 [3].

International commodity markets operate and adapt given fundamental ratios of supply and demand growth, but stocks can provide a buffer when historical trade patterns are disrupted. Several years of drought, including those in Europe in 2006, North America in 2006-2007, and a severe drought in Australia from 2006 to 2008, drove wheat stocks down to critical lows. This, coupled with the surge in biofuel demand, contributed to record grain prices [29] that make the scarcity of buffer stocks a concern for those who seek to stabilize world food prices.

While not directly tied to the wheat market, global events in the last three decades may have distorted markets. During the early 1980s, the economic recession in the United States, other countries' unemployment levels, energy price shocks, and corresponding monetary policies throughout the global economy may have been possible causes of changes in wheat prices that are not accounted for with the direct factors discussed previously [30–32]. Another important market distortion in the early 1980s was a US export embargo on grain trade and technology with the Soviet Union in response to the invasion of Afghanistan [33]. Though restrictions were lifted a few years later, patterns of trade changed while the embargo was in place, with the Soviet Union facing import shortages and needing to find alternative wheat suppliers. Additional domestic market interventions also followed in the US due to corresponding decreases in the world wheat price, but the long-term trade pattern implications are not clear [34].

2.4. Implications of Oil Markets for the Agricultural Sector. Oil is another factor that affects agricultural commodity prices [35–37]. The oil market affects wheat prices both directly, through production inputs, and indirectly, through demand for biofuels and the resulting substitution effects. The prices of fertilizer, farm machinery, and transportation are all affected by the crude oil price, which influences wheat production costs. Baffes and Haniotis [38] attribute the impacts of energy prices on food commodities more to these factors than to biofuels and find that the aspects of changing energy prices have exerted the greatest influence on commodity prices, including wheat, over the past few decades. Nevertheless, biofuels can also affect wheat prices as, with high oil prices, demand for biofuel increases and agricultural inputs such as land are dedicated to planting energy crops such as corn instead of wheat. This competing use of land thereby decreases wheat production, which may explain some of the volatility and upward pressure on wheat prices [39].

In addition to market dynamics, energy policy has been in a state of flux. For example, the European Union, the United States, and other countries with large agricultural sectors have been encouraging biofuels by instituting production subsidies and renewable fuel quotas, further driving up demand for biofuel input crops. Wright [40] found the impact of biofuel mandates and associated policies to have been of particular importance in driving commodity prices in recent years. Saghaian [41], Esmaeili and Shokoohi [42], Natanelov et al. [43], and Serra and Gil [44] also studied the relationship between agriculture and energy markets and described the correlation between agricultural commodities and crude oil prices.

Oil prices were collected and analyzed for trends relative to the wheat market. Annual oil price is calculated as the average of two oil prices: West Texas Intermediate oil and the Persian Gulf countries' crude oil. Oil prices are reported in US dollars per barrel and data is collected from the US Energy Information Administration [45] (Table 2). The lowest oil price during this period was $14.33/barrel in 1998, which is also the year with the lowest wheat price. The peaks in oil prices are relatively recent, occurring in 2008, 2011, and 2012, when the deflated oil price was above $100/barrel (Figure 3). When viewed in conjunction with wheat prices over time, the relationship between the two becomes apparent, though the imperfect correlation between oil and wheat prices demonstrates the complexity of the influences of energy on agricultural commodities.

2.5. Exploring the Influence of Trade on Commodity Markets. As the global population increased, wheat consumption has grown by an average of 1.6% annually over the past three decades [3]; and, as a result of increased wheat production,

TABLE 2: Average annual oil price statistics in USD/barrel, deflated to 2013 dollars.

	Mean	Median	Maximum	Minimum	Std. dev.	Coefficient of variation	Obs.
Oil price	$ 49.21	$ 34.60	$ 104.64	$ 14.33	$ 27.60	0.56	34

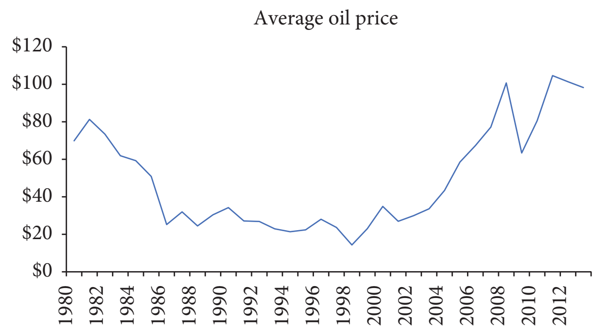


FIGURE 3: Average annual oil price in US dollars per barrel, deflated to 2013 dollars. *Source*: EIA, 2014 [45].

wheat trade has also grown over the past few decades. Wheat is purchased primarily for consumption and creating stocks as a buffer. The consumption share can be used both as human food or as a feed input for livestock production. Stockpiling creates an intertemporal buffer against shortages during large wheat consumption periods or low production years.

To eliminate market distortions, many trade agreements force countries to reduce tariffs and open the market to international trade. However, such agreements are not always fully successful or effective because many countries limit imports by imposing nontariff barriers, including import licenses and quality restrictions [46, 47]. In some cases, these nontariff barriers can be effective in stabilizing and insulating domestic prices of agricultural commodities against lower priced imports [48]. However, these insulating policies can also increase the volatility of global prices and, ultimately, nullify any domestic market insulation if many countries enact such policies [49].

Import tariff policies vary in different countries. In some major importing countries, such as Egypt, there are high tariffs on wheat products, like pasta and bakery products, which have resulted in increased wheat grain imports for input use to produce final consumption goods. However, in some countries, such as Kenya, the opposite is true and value added products that contain wheat have a lower average tariff than that placed on wheat grain [50–52].

Another important issue in the world wheat market is the effect of food aid or assistance programs. Most of these programs are donations from major world wheat exporters to developing countries and aim to fight famine but can indirectly affect the world wheat price if they modify demand (Figure 4). It should be noted that wheat does not have a simple geographic pattern of trade flows, since many countries are both exporters and importers of wheat. Trade patterns also change over time, as the quantity of wheat production, imports, and exports in different countries change and world prices drive secondary shocks in the market.

As previously mentioned, stocks-to-use ratios measure the relationship between available supply and demand by dividing the ending stock value by total annual use [54]. A low stocks-to-use ratio leads to a higher market price, because low stocks reflect scarcity. While this indicator is correlated with crop prices, there is conflicting evidence as to its importance to crop price. Daugherty and Kelly [55] found the stocks-to-use ratio to be a weak factor, while Baffes and Haniotis [38] found it to be second only to energy prices in terms of explaining long-term crop price variation.

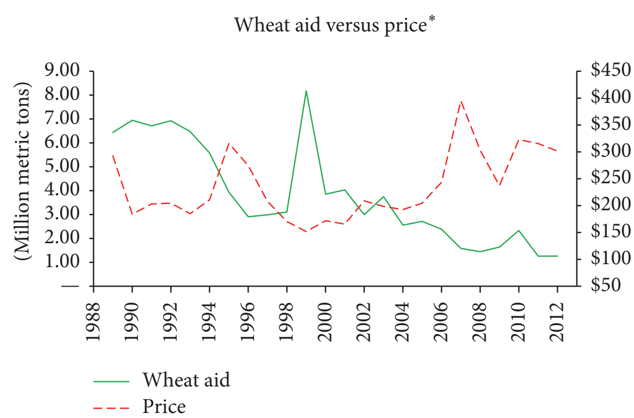


FIGURE 4: Wheat aid versus wheat price. *Source*: World Food Program and OECD, 2012 [53]. *Wheat aid is total of wheat and wheat flour provided and wheat prices are deflated in terms of 2013 dollars between 1989 and 2012.

2.6. Changing Demand in Major Wheat-Importing Countries. Demand for wheat has been relatively high and stable in North Africa and the Middle East, South Asia, East and Southeast Asia, South America, and Sub-Saharan Africa. Based on FAO and USDA reports [3, 9], these five regions are defined as the world's major wheat importers, annually accounting for nearly 90% of total wheat imported in the world [9]. Specifically, Egypt was one of the top five importing countries for the 30-year time frame from 1982 to 2011, with average wheat imports of 6 MMT/year (Figure 5) [3, 4]. Other countries, such as those in Eastern Europe, had increased demand between 1980 and 2013 because of war and political

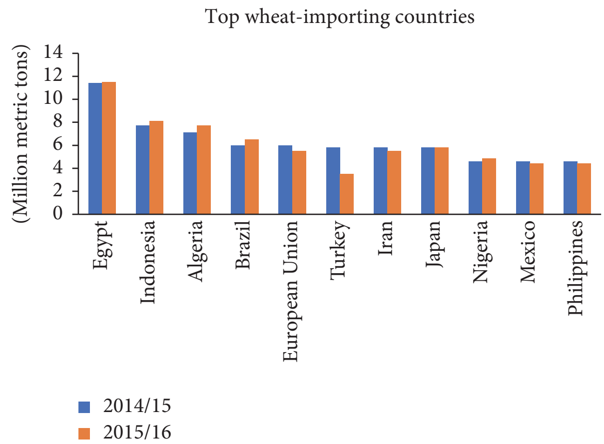


Figure 5: Principal importing countries of wheat, flour, and wheat products. *Source*: USDA, Foreign Agricultural Service, June 2015 [4].

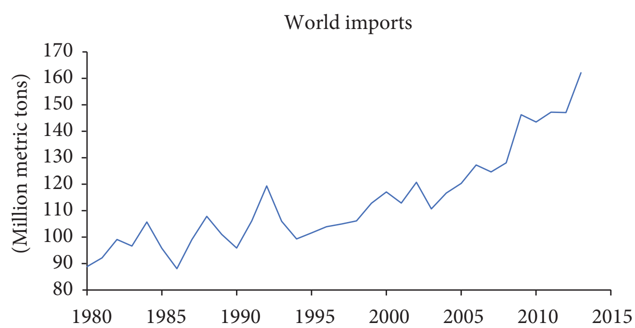


Figure 6: Annual world wheat imports. *Source*: FAO, 2015 [3].

or financial problems but, overall, were less consistently listed among the top importers [3].

Global import data is presented in millions of metric tons (MMT) and is collected from FAO statistics for the 34-year time frame [3]. During this time frame, the maximum annual world import level is 162 MMT in 2013, and the minimum is 88.06 MMT in 1986. The average world import level during the time frame is 113 MMT, and the increasing trend in annual world imports is illustrated in Figure 6. The clear upward trend of imports demonstrates the growing global demand for wheat, having nearly doubled over the timespan evaluated. The concurrent economic expectation of such upward pressure on demand is increased pressure on supply which subsequently increases prices.

3. An Overview of Supply Drivers in Major Wheat Export Countries

Although past research shows that there are a myriad of factors that influence commodity markets and food security, a more specific focus on how wheat supplies may be influenced by climate concerns is the focus of this study. Based on USDA statistics, the five largest wheat-exporting regions between 1980 and 2013 were the United States, the European Union, Canada, Australia, and the Former Soviet Union (FSU), with 30.9, 30.2, 17.9, 13.5, and 9.8 MMT of average annual wheat exports, respectively [3]. Overall trade flows increased during this 34-year time frame, despite variations in market factors such as weather shocks, domestic and international policies, and world wheat price changes. This section describes each of these key wheat-exporting countries with particular attention to the factors that past literature highlights as important.

Precipitation data is based on National Oceanic and Atmospheric Administration records [56] and was retrieved for different stations located in the high-productivity regions of each country. The stations located in Kansas, France, South Saskatchewan, and the southwest of Western Australia represent the United States, the European Union, Canada, and Australia, respectively. Krasnodar and Stavropol represent the FSU. In general, the region with the highest yield in each country on average during the 34-year time frame from 1980 to 2013 was selected to represent the country as a whole. For more accurate results, Geographic Information System (GIS) software was used to select specific data related to each region. Data from weather stations that have been active for all, or most, of the 34-year time frame (for at least 25 years) are included.

For the United States, the European Union, Canada, and the FSU, the average of May and June monthly precipitation is considered for each year. During these months, the wheat plant is in the heading and grain development stage and has the highest water needs [58]. For the same reason, the average of November and December monthly precipitation levels is

Table 3: Summary of precipitation statistics (mm).

	Kansas	France	Saskatchewan	Western Australia	Krasnodar and Stavropol
Mean	939.34	651.11	640.86	166.50	721.39
Median	916.37	651.27	624.82	144.84	705.27
Maximum	1656.04	1129.09	1022.89	449.12	1082.027
Minimum	419.27	369.25	351.05	52.00	311.67
Std. dev.	269.44	205.00	163.82	88.96	195.76
Coefficient of variation	0.29	0.31	0.26	0.53	0.27

Source: National Oceanic and Atmospheric Administration, 2015 [56].

Table 4: Summary of precipitation statistics in +/− from average (mm).

	USA	European Union	Canada	Australia	FSU
Mean	0.0	0.0	0.0	0.0	0.0
Median	−23	0.2	−16	−22	−16
Maximum	717	478	382	283	361
Minimum	−520	−282	−290	−115	−410
Std. dev.	269.44	205.00	163.82	88.96	195.76

Source: National Oceanic and Atmospheric Administration, 2015 [56], and authors' calculations.

Table 5: Summary of yield data statistics (MT/ha).

	USA	Canada	European Union	Australia	FSU
Mean	2.66	2.27	4.77	1.61	1.73
Median	2.65	2.25	4.82	1.63	1.65
Maximum	3.17	3.18	5.68	2.15	2.39
Minimum	2.20	1.23	3.63	0.76	1.27
Std. dev.	0.28	0.43	0.51	0.38	0.30
Coefficient of variation	0.11	0.19	0.11	0.24	0.17

Source: OECD-FAO 2015 Agricultural Outlook and the USDA Statistical Bulletin [57].

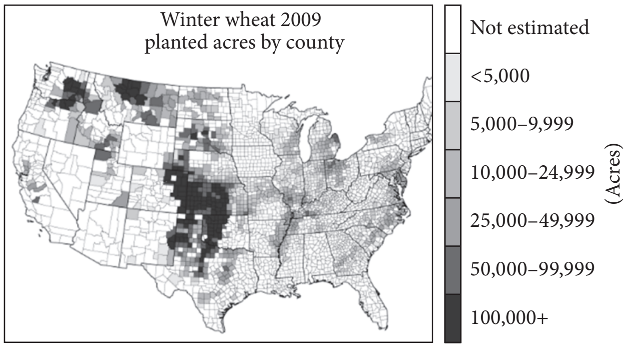
considered for each year in Australia since it is located in the southern hemisphere and has a countercyclical agricultural season relative to the other regions [59]. Precipitation data is reported in millimeters (mm) and the average is calculated for the agricultural production year (Table 3). Among the five regions, the state of Kansas in the United States has the highest average precipitation levels and the state of Western Australia has the lowest average precipitation during the 34-year time frame. Annual precipitation in the state of Western Australia, on average, is 166 mm compared to other regions that have average annual precipitation of more than 640 mm.

To facilitate interpretation, precipitation for each year is compared to the average precipitation of that region to show how that year varied from the longer-term norm. The long-term average precipitation for every region is calculated over the 34-year time frame from 1980 to 2013 and subtracted from the raw precipitation data of that region. Therefore, the data has been converted to plus/minus the average index value (Table 4).

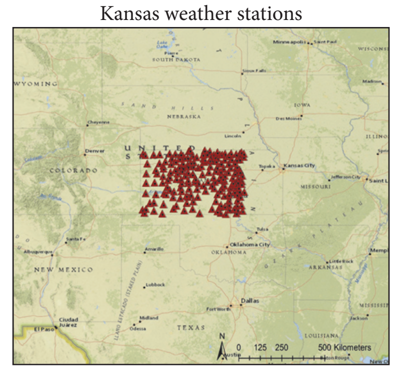
Annual yield data is in metric tons per hectare (MT/ha) and was retrieved from the OECD-FAO 2015 Agricultural Outlook and the USDA Statistical Bulletin [57]. After 1992, the sum of Russia, Ukraine, Kazakhstan, and Uzbekistan production and exports is used to represent the Former Soviet Union (FSU). Yield was, on average, highest in the European Union, approximately two times more than the yield in other regions, while Australia had the lowest yield during the 34-year time frame (Table 5).

The following section shows greater detail on each key wheat-exporting country to complement the discussion of factors affecting price behavior. Charts and maps accompanying the information for each country/region better demonstrate wheat production trends over time in the five major export regions and are presented in the country profiles below.

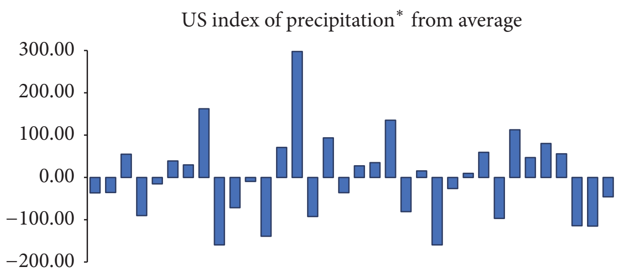
3.1. United States (Kansas). Wheat production and yield levels in the United States remained relatively stable during the 34-year time frame from 1980 to 2013. Wheat yields have increased, but, due to decreases in harvested area, total production declined by an average of 0.48% annually [3]. The US was the largest exporter for almost all of the 34-year period, with gradual narrowing of the gap from the second



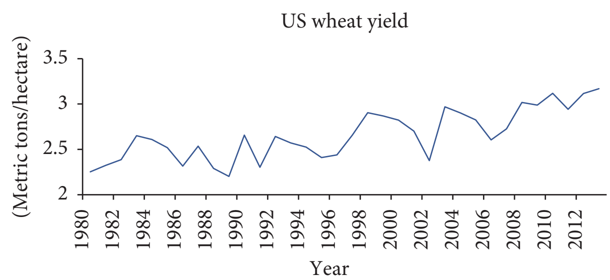
(a) United States wheat production map. *Source*: USDA ERS, 2014



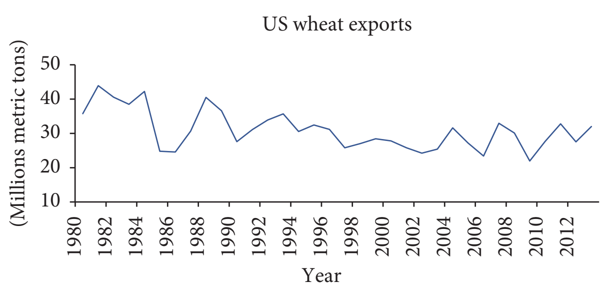
(b) Map of Kansas weather stations from which precipitation data is collected. *Source*: NOAA, 2015



(c) United States Index of Precipitation annual deviations from average, 1980 to 2013. *Source*: NOAA, 2015. *Precipitation is shown in +/− from average index



(d) Annual United States wheat yields (MT/ha), 1980 to 2013. *Source*: OECD-FAO, 2015

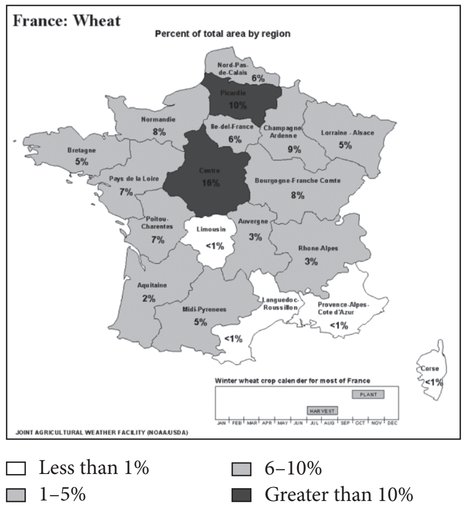


(e) Annual United States wheat exports (MMT), 1980 to 2013. *Source*: FAOSTAT, 2015

Figure 7: United States.

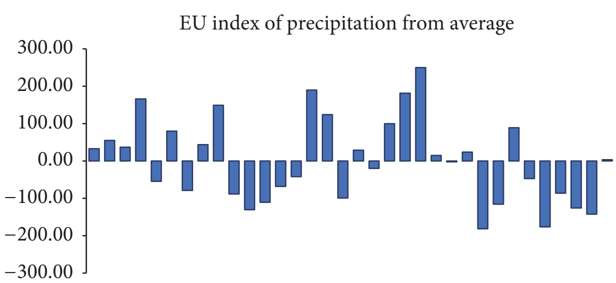
largest exporter, the European Union [3]. In some years, such as 1994 and 2008, the US produced 10% of all wheat in the world [9]. In 2001, for instance, approximately 19.6 million ha of wheat was planted in the US and about 50% of the wheat produced was exported at a value of $9 billion [9, 60]. US wheat exports decreased over the 34-year time frame, even though yields increased gradually from 2 MT/ha to more than 3 MT/ha, and precipitation varied from the average in no discernable pattern without any long wet or dry periods. The major growing areas for hard red winter wheat are located in the Midwest, centering on Kansas. The largest wheat-producing states in the US are Kansas and North Dakota, with 10.4 MMT of wheat harvested in Kansas in 2012 alone [9]. US wheat yields, exports, and maps of production and weather stations are presented in Figure 7.

3.2. European Union (France). The European Union, which now includes 28 countries, was the second highest wheat-producing region between 1980 and 2013. The average total wheat-planted land area in this region has increased by an average of 500,000 ha every year over the time frame analyzed. In 2013, 26 million ha was planted and 139 MMT was harvested [9]. France, Germany, and Romania are the top three wheat exporters in the EU, with 66%, 15%, and 5.2% of total wheat exports, respectively. France has the highest yield,

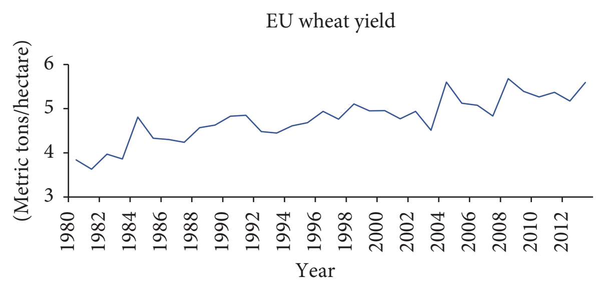


(a) France wheat production map. *Source*: USDA ERS, 2014

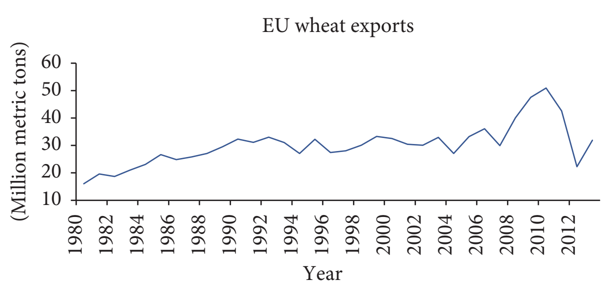
(b) Map of France weather stations from which precipitation data is collected. *Source*: NOAA, 2015



(c) European Union Index of Precipitation annual deviations from average, 1980 to 2013. *Source*: NOAA, 2015. *Precipitation is shown in +/− from average index



(d) Annual European Union wheat yields (MT/ha), 1980 to 2013. *Source*: OECD-FAO, 2015



(e) Annual European Union wheat exports (MMT), 1980 to 2013. *Source*: FAOSTAT, 2015

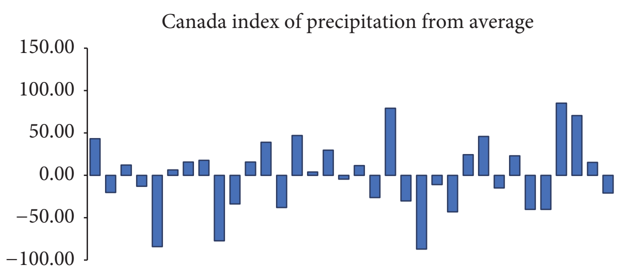
Figure 8: European Union.

with an average of 7.5 MT/ha [61]. The French administrative region, Centre, leads the production of wheat in France [9]. EU wheat exports increased over time, as did wheat yields. The EU has the highest average yields in the world totaling more than 5 MT/ha. Compared to other regions, precipitation patterns in the EU appear to exhibit periodic dry and wet years during the time frame of this analysis. EU wheat yields, exports, and maps of production and weather stations are presented in Figure 8.

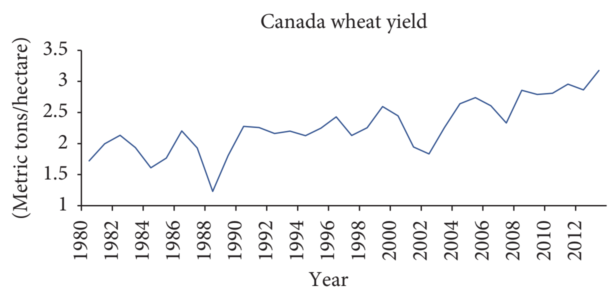
3.3. Canada (Saskatchewan). Canada, the third largest wheat exporter from 1980 to 2013, produces approximately 25 MMT of wheat annually, with the majority of production taking place in the provinces of Saskatchewan, Manitoba, and Alberta. Saskatchewan alone accounts for about 60% of Canada's wheat production, most of which is exported [62]. The planting and growing period is longer in Canada due to its high latitude and colder weather. The changes in exports from Canada varied during the time frame considered, while

(a) Canada wheat production map. *Source*: Wheat Atlas, 2014

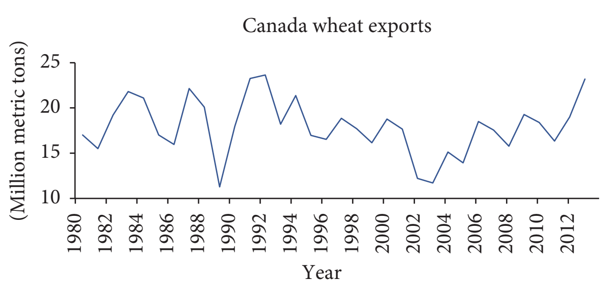
(b) Map of Saskatchewan weather stations from which precipitation data is collected. *Source*: NOAA, 2015



(c) Canada Index of Precipitation annual deviations from average, 1980 to 2013. *Source*: NOAA, 2015. *Precipitation is shown in +/− from average index



(d) Annual Canadian wheat yields (MT/ha), 1980 to 2013. *Source*: OECD-FAO, 2015

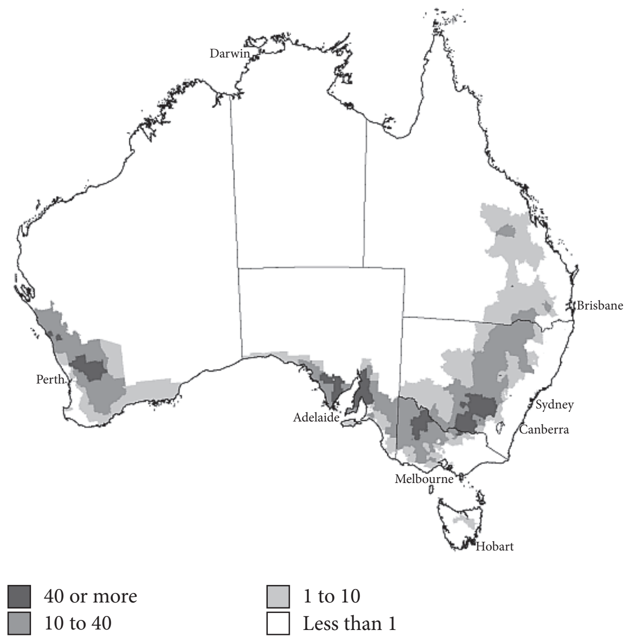


(e) Annual Canadian wheat exports (MMT), 1980 to 2013. *Source*: FAOSTAT, 2015

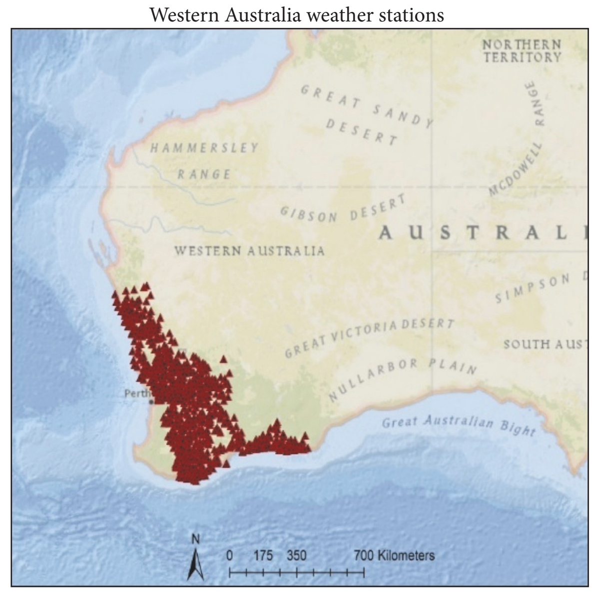
Figure 9: Canada.

precipitation levels were less variable. Like the US, yields have increased slowly over time in Canada from 1 MT/ha to 3 MT/ha. Canadian wheat yields, exports, and maps of production and weather stations are presented in Figure 9.

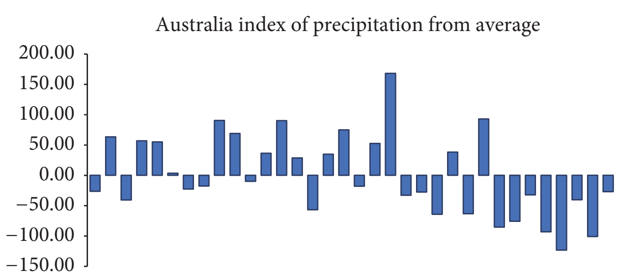
3.4. Australia (Western Australia). Australia's total harvested wheat-producing acreage in 2013 was 13.5 million ha, yielding 27 MMT of wheat, 18.6 MMT of which was exported. The main producing state is Western Australia; and, subsequently, the majority of Australian wheat is sold overseas from this state's supplies [63]. Australia's exports and yield have both increased gradually over time. With an average annual precipitation of 166.5 mm, Australia had the lowest precipitation levels compared to the other four key regions. Precipitation levels in recent years represent a long period of drought in the Western Australia region. Australian wheat yields, exports, and maps of production and weather stations are presented in Figure 10.



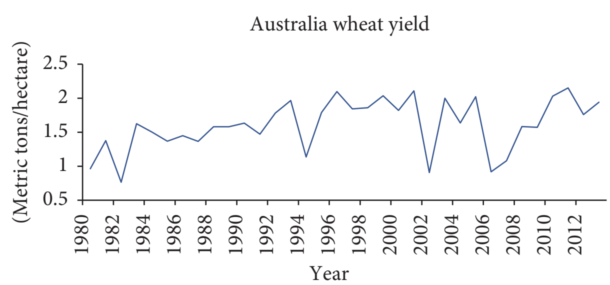
(a) Australia wheat production map. *Source*: AGDA, 2015



(b) Map of Western Australia weather stations from which precipitation data is collected. *Source*: NOAA, 2015



(c) Australia Index of Precipitation annual deviations from average, 1980 to 2013. *Source*: NOAA, 2015. *Precipitation is shown in +/− from average index

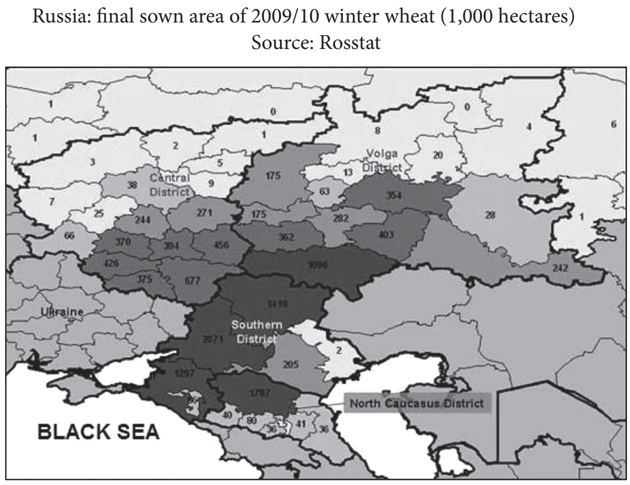


(d) Annual Australian wheat yields (MT/ha), 1980 to 2013. *Source*: OECD-FAO, 2015

(e) Annual Australian wheat exports (MMT), 1980 to 2013. *Source*: FAOSTAT, 2015

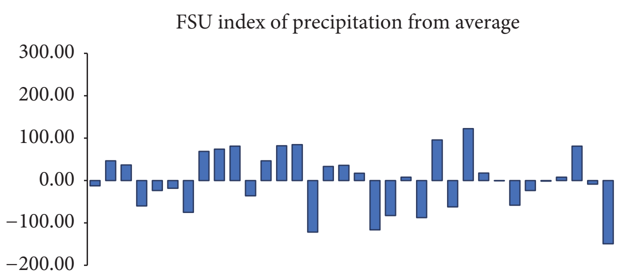
Figure 10: Australia.

3.5. Former Soviet Union (Southern). The Former Soviet Union (FSU) countries are the fifth largest wheat-exporting region during this 34-year time frame. Their exports have increased consistently from 1991 by an average of 1.58 MMT annually. More than 90% of wheat production in the FSU occurs in Russia, Ukraine, Kazakhstan, and Uzbekistan [9]. These four countries also account for 99% of the FSU wheat exports [64]. In 2013, 47.7 million ha of wheat was planted, with 103.9 MMT of production. Total exports that year were 37.1 MMT [9]. Almost no exports were reported for the region before the dissolution of the Soviet Union. After 1992, the region's annual exports grew to nearly 40 MMT, most of which was developed after the year 2000. Also, average yields increased over time from less than 1.5 to 2 MT/ha.

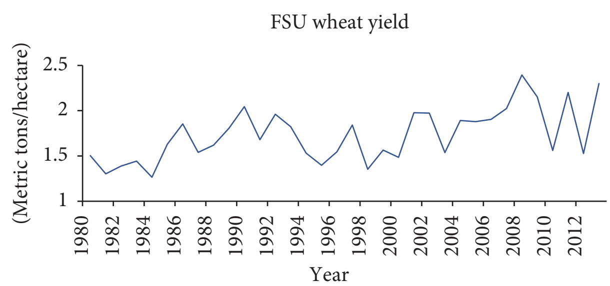


(a) Former Soviet Union wheat production map. *Source*: USDA ERS, 2014

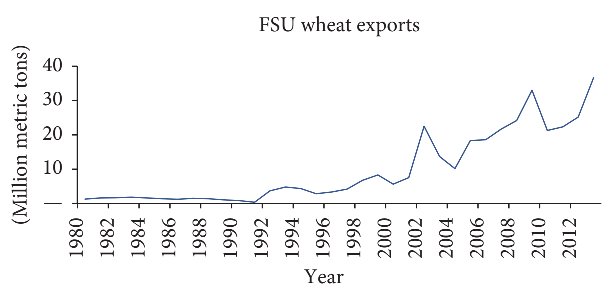
(b) Map of Former Soviet Union Southern weather stations from which precipitation data is collected. *Source*: NOAA, 2015



(c) Former Soviet Union Index of Precipitation annual deviations from average, 1980 to 2013. *Source*: NOAA, 2015. *Precipitation is shown in +/− from average index



(d) Annual Former Soviet Union wheat yields (MT/ha), 1980 to 2013. *Source*: OECD-FAO, 2015



(e) Annual Former Soviet Union wheat exports (MMT), 1980 to 2013. *Source*: FAOSTAT, 2015

Figure 11: Former Soviet Union.

The highest levels of wheat production in the FSU were in Southern Russia. The FSU wheat yields, exports, and maps of production and weather stations are presented in Figure 11.

4. Summary and Conclusions

Global food security efforts increasingly focus on adaptation of agriculture to climate concerns, but it is clear that there are also political, economic, and cultural considerations for the effectiveness of such adaptation strategies [22, 65]. As agricultural development organizations and the countries and agribusinesses that make key management and policy decisions address the increasing challenge of declining or uncertain food security, there appear to be a few key drivers to consider if one values a systems approach.

This study explores the factors that impact wheat prices in the international market, focusing on what may have contributed most to the rapid growth in world wheat prices through 2008, as well as subsequent price fluctuations. The key contributions of this work include a comprehensive summary of global supply and demand factors that affect the wheat market. We include data and trends for wheat prices, oil prices, trade and food aid, and demand in key import countries, as well as detailed country profiles for key wheat suppliers. Increases in global wheat consumption are largely driven by population growth and rising household income in developing and emerging economies. Our work highlights that climate variability, fueled by precipitation patterns, differs among key wheat-producing regions. Past wheat prices, oil prices, and global stocks have substantial effects on wheat price determination, while policy measures including food aid and other market distortions impact wheat price variability across regions as well. Trend analyses indicate a general increase in both wheat yields and exports in the major wheat-producing regions of the world. In many cases, these increases occurred largely independent of any changes in precipitation patterns, demonstrating the influence of the other factors evaluated herein.

This paper reinforces that the G20 Ministers of Agriculture, who represent approximately 60% of all agricultural land and 80% of world trade in agricultural products, will be key players in addressing this aspect of food security [7]. Their intentions to promote activities and innovations that will make the agricultural sector more resilient are important but will only be effective if systematically framed to consider the factors and drivers that influence commodity markets in an era of globalization with complex policy dimensions.

While this study evaluates a variety of the key factors affecting wheat production and prices, limitations remain. Climate change is a complex phenomenon and merits continued study and the inclusion of factors beyond precipitation patterns when investigating climate resiliency in the wheat market. Moreover, lack of accessibility to historical data from different countries limits the scope of this analysis. For example, weather station locations have changed during the time frame, limiting access to continuous weather data. Furthermore, deeper quantitative analysis of both supply and demand factors in future work is merited.

This study explores the various factors of wheat price determination, which is an integral component of providing information for market development and improvement. This study demonstrates that past market prices, weather, and other direct influences on the wheat market are among a suite of factors policymakers must consider. Indeed, the far-reaching impacts of a changing climate, the increasing demand for fuels, both traditional and renewable, and the implications of an integrated global economy all play a part in wheat price determination. In an era of great concern about climate resiliency and food security, an understanding of global wheat market fundamentals allows policymakers and producers to plan more effectively and better prepare for potential shortages or price fluctuations. Accordingly, this work contributes to the literature and provides policy relevance by creating a synthesis of information and data regarding the aforementioned key factors in an international context. While volatility plays a minor role in the complex phenomenon of food security, recognizing how all countries interact in the global wheat market further informs the discussion regarding future dynamics in this sector.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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