McKinsey Global Institute

Climate risk and response: Physical hazards and socioeconomic impacts

Will the world's breadbaskets become less reliable?

Case study

May 2020

McKinsey Global Institute

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Will the world's breadbaskets become less reliable?

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Introduction to case studies

In January 2020, the McKinsey Global Institute published *Climate risk and response: Physical hazards and socioeconomic impacts*. In that report, we measured the impact of climate change by the extent to which it could affect human beings, human-made physical assets, and the natural world. We explored risks today and over the next three decades and examined specific cases to understand the mechanisms through which climate change leads to increased socioeconomic risk. This is one of our case studies, focused on breadbasket failure.

We investigated cases that cover a range of sectors and geographies and provide the basis of a “micro-to-macro” approach that is a characteristic of McKinsey Global Institute research. To inform our selection of cases, we considered over 30 potential combinations of climate hazards, sectors, and geographies based on a review of the literature and expert interviews on the potential direct impacts of physical climate hazards. We found these hazards affect five different key socioeconomic systems: livability and workability, food systems, physical assets, infrastructure services, and natural capital.

We ultimately chose nine cases to reflect these systems and based on their exposure to the extremes of climate change and their proximity today to key physiological, human-made, and ecological thresholds (Exhibit 1). As such, these cases represent leading-edge examples of climate change risk. Each case is specific to a geography and an exposed system, and thus is not representative of an “average” environment or level of risk across the world. Our cases show that the direct risk from climate hazards is determined by the severity of the hazard and its likelihood, the exposure of various “stocks” of capital (people, physical capital, and natural capital) to these hazards, and the resilience of these stocks to the hazards (for example, the ability of physical assets to withstand flooding). We typically define the climate state today as the average conditions between 1998 and 2017, in 2030 as the average between 2021 and 2040, and in 2050 between 2041 and 2060. Through our case studies, we also assess the knock-on effects that could occur, for example to downstream sectors or consumers. We primarily rely on past examples and empirical estimates for this assessment of knock-on effects, which is likely not exhaustive given the complexities associated with socioeconomic systems. Through this “micro” approach, we offer decision makers a methodology by which to assess direct physical climate risk, its characteristics, and its potential knock-on impacts.

Climate science makes extensive use of scenarios ranging from lower (Representative Concentration Pathway 2.6) to higher (RCP 8.5) CO_2 concentrations. We have chosen to focus on RCP 8.5, because the higher-emission scenario it portrays enables us to assess physical risk in the absence of further decarbonization. Such an “inherent risk” assessment allows us to understand the magnitude of the challenge and highlight the case for action. (We also choose a sea level rise scenario for one of our cases that is consistent with the RCP 8.5 trajectory). Our case studies cover each of the five systems we assess to be directly affected by physical climate risk, across geographies and sectors. While climate change will have an economic impact across many sectors, our cases highlight the impact on construction, agriculture, finance, fishing, tourism, manufacturing, real estate, and a range of infrastructure-based sectors. The cases include the following:

— For livability and workability, we look at the risk of exposure to extreme heat and humidity in India and what that could mean for that country's urban population and outdoor-based sectors, as well as at the changing Mediterranean climate and how that could affect sectors such as wine and tourism.

— For food systems, we focus on the likelihood of a multiple-breadbasket failure affecting wheat, corn, rice, and soy, as well as, specifically in Africa, the impact on wheat and coffee production in Ethiopia and cotton and corn production in Mozambique.

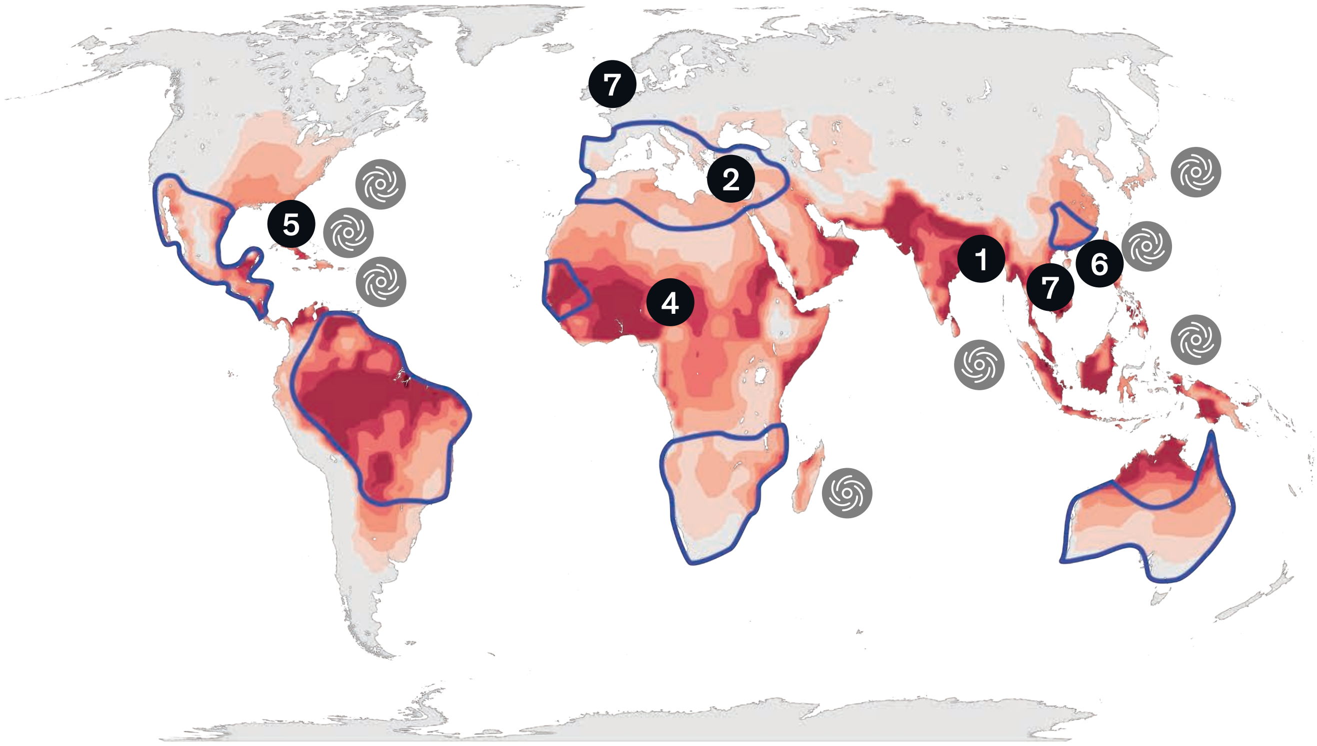
— For physical assets, we look at the potential impact of storm surge and tidal flooding on Florida real estate and the extent to which global supply chains, including for semiconductors and rare earths, could be vulnerable to the changing climate.

— For infrastructure services, we examine 17 types of infrastructure assets, including the potential impact on coastal cities such as Bristol in England and Ho Chi Minh City in Vietnam.

— Finally, for natural capital, we examine the potential impacts of glacial melt and runoff in the Hindu Kush region of the Himalayas; what ocean warming and acidification could mean for global fishing and the people whose livelihoods depend on it; as well as potential disturbance to forests, which cover nearly one-third of the world's land and are key to the way of life for 2.4 billion people.

Exhibit 1

We have selected nine case studies of leading-edge climate change impacts across all major geographies, sectors, and affected systems.



Global case studies 3 8 9

Heat stress[1] Low — High | Highest drought risk in 2050[2] | Increase in hurricane/cyclone severity

Livability and workability	1	Will India get too hot to work?
	2	A Mediterranean basin without a Mediterranean climate?
Food systems	3	Will the world's breadbaskets become less reliable?
	4	How will African farmers adjust to changing patterns of precipitation?
Physical assets	5	Will mortgages and markets stay afloat in Florida?
	6	Could climate become the weak link in your supply chain?
Infrastructure services	7	Can coastal cities turn the tide on rising flood risk?
	8	Will infrastructure bend or break under climate stress?
Natural capital	9	Reduced dividends on natural capital?

1. Heat stress measured in wet-bulb temperatures.
2. Drought risk defined based on time in drought according to Palmer Drought Severity index (PDSI).

Source: Woods Hole Research Center; McKinsey Global Institute analysis

A farmer in the Brazil-Pantanal Region holds a handful of sandy soil during dry season.

Breadbasket failure

Will the world's breadbaskets become less reliable?

Over the past few decades, people around the world have benefited from a growing supply of food, keeping prices relatively stable and reducing undernourishment to near all-time lows.[1] This positive long-term trend was briefly interrupted by one episode of globally spiking food prices between 2006 and 2008 and a smaller increase between 2010 and 2012, causing significant disruptions to markets and societies alike (see Box 1, "What can we learn from past global food price spikes?"). Relative stability in prices has been achieved primarily through continuously higher productivity (rather than major expansion of croplands) and the absence of a major event that could have caused large-scale crop failure.[2] If these trends continue, the global food supply could increase over the next decade by an estimated 20 percent, more than the 13 percent projected increase in world population.[3]

However, the global food system has underlying vulnerabilities, such as high geographical concentration of production, long supply chains and high dependency of imports in some countries, especially developing ones. The current COVID crisis has exposed some of them already. While global food supply is still strong, individual countries and regions are starting to experience shortages due to interruptions of local agricultural labor, grain export bans by some countries and interruptions in logistics services.[4] This can be compounded by weather related harvest declines, such as the locust infestation in Africa.

Climate change and related acute weather events are similarly introducing new risks into the food system. While many of them may not yet be fully appreciated, they expose similar vulnerabilities to COVID. In this case study, we examine the changing likelihood of a harvest failure occurring in multiple breadbasket locations as well as the potential socioeconomic impact of such an event. We define a breadbasket as a key production region for food grains (rice, wheat, corn, and soy) and harvest failure as a major yield reduction in the annual crop cycle of a breadbasket region where there is a potential impact on the global food system. We examine the impact of a changing climate absent mitigation and adaptation. We assess the impact of climate change on the current food production system to highlight its vulnerabilities and do not assume further improvements in yields or other adaptation measures. We find that the likelihood of a multiple-breadbasket failure (which we define as a global harvest failure of more than 15 percent relative to average) occurring in a given year has increased from roughly one percent in the past 20 years to roughly two percent in the next decade to 2030, and to roughly four percent by 2050—a quadrupling in likelihood that could have significant socioeconomic impact.[5] Similarly, the probabilities of a multi-breadbasket failure occurring at least once within a 10 year period increase from 10 percent today, to 18 percent by 2030 and to 34 percent by 2050. We find that the initial 2030 impact could be an increase in global food prices (driven by a potential shock to grain commodity prices of possibly 100 percent or more), hurting the 750 million people living below the international poverty line the most. We then consider what it would take to prevent such an episode.

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1 *The state of food security and nutrition in the world 2018: Building climate resilience for food security and nutrition*, Food and Agriculture Organization of the United Nations (FAO), 2018.
2 *OECD-FAO Agricultural Outlook 2018–2027*, Organisation for Economic Co-operation and Development and FAO, 2018.
3 Ibid.; UN Department of Economic and Social Affairs, "World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100," June 21, 2017.
4 "Joint statement on COVID-19 impacts on food security and nutrition," FAO, IFAD, the World Bank and WFP on the occasion of the Extraordinary G20 Agriculture Minister's Meeting, 21 April, 2020.
5 If not indicated differently, we follow standard practice and define current and future (2030, 2050) states as average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060. Also, if not indicated differently, the climatological analyses in this case use RCP 8.5 to represent the changes in atmospheric greenhouse gas concentrations that could occur absent mitigation action. Please see technical appendix of the full report for details.

Box 1.

What can we learn from past global food price spikes?

The spike in food prices between 2006 and 2008, and a smaller but still significant increase between 2010 and 2012, are exceptions to a trend in recent decades of relative stability in the global food system. These episodes provide insight into what can drive prices significantly higher and the impact of the price increases.

Between August 2006 and March 2008, cereal prices increased by 100 percent (Breadbasket failure-1). In 2010, prices increased again by about 50 percent and remained elevated relative to the long-term average until 2013. Episodes of rapid price increases also occurred in the 1970s and 1990s.[1]

In the 2008 food price spike episode, the global production of grains barely changed, falling 0.2 percent in 2006, driven by drought in Australia and Ukraine, and even increasing 4 percent in 2007.[2] On the demand side, sustained growth in India and China and most notably a rapid expansion of the biofuels market led to a continuous decline in stock-to-use ratios from more than 30 percent in 2000 to historic lows of 21 percent in 2007–08, at which point prices spiked.[3]

There are a number of reasons that explain how a decline of stocks by ten percentage points can lead to such high price volatility and spikes.

In typical markets, price increases would lead consumers to consume less and producers to produce more, thereby countering the effect of price increases. However, the market for food grains is in this sense not typical. Given the critical importance of food for human survival, most people will reduce other spending before cutting back on food. In developed markets, the share of food expenditure is so small that most people do not react at all, even at very high food prices. At the aggregate level, the relation between the available supply and price has been difficult to model and to estimate, due to challenges in accurately measuring consumption and its response to price variations.

The market for animal feed and the biofuels sector create significant nonfood demand for corn and soy. In theory, this provides a buffer, by keeping grain prices up during years with good harvests and thereby giving farmers an incentive to keep producing, with the potential to divert grains to food use in bad years in reaction to market price signals. However, this mechanism may not work well. In the case of biofuels, there are three reasons: first, blending mandates for biofuels (in the United States, about one-third of corn production is diverted to biofuels based on federal ethanol supply mandates, limited only by the current "blending wall" of 10 percent that may or may not be relaxed during episodes of high food prices).[4] Second, since biofuel is a substitute for fossil fuel, oil prices also drive demand (the higher oil prices are, the higher the demand for biofuels). Third, farmers are often locked in to long-term offtake contracts preventing them from diverting grains to food use in response to price signals. During 2008, those factors converged, likely aggravating the crisis. Rosegrant estimated that the long-term impact of the acceleration in biofuel production from 2000 to 2007 on weighted cereal prices was a 30 percent increase in real terms.[5]

Furthermore, some countries have tried to protect domestic food supply security in the face of food price increases by implementing export bans, export tariffs, or import subsidies. In 2008, 15 countries, including Argentina, Russia, and Thailand, established such policies. The International Food Policy Research Institute estimates that those measures could explain 30 percent of price increases.[6] In addition, world market prices are not necessarily reflected in local market prices, which can differ (higher or lower) for a variety of reasons, including transportation costs, trade barriers such as tariffs, and subsidies.[7] Porteous finds that, for example, local corn prices in northern Kenya on the border with Somalia, a hard-to-reach region, were consistently higher (between 60 percent and more than 200 percent) compared with US grain trading hubs such as Minneapolis and New Orleans.[8]

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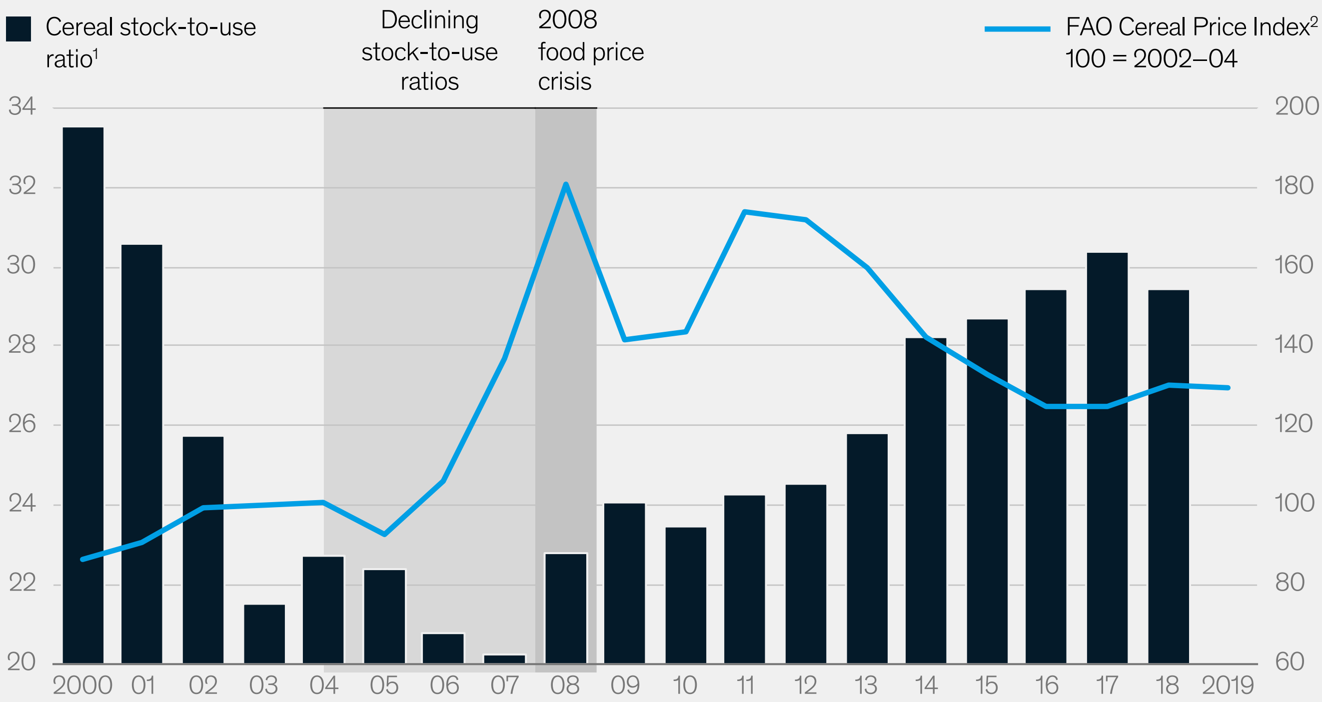
1 May Peters, Suchada Langley, and Paul Westcott, "Agricultural commodity price spikes in the 1970s and 1990s: Valuable lessons for today," *Amber Waves*, US Department of Agriculture, Economic Research Service, March 1, 2009.
2 FAOSTAT, FAO.
3 "What happened to world food prices and why?," in *The state of agricultural commodity markets 2009*, FAO, 2009.
4 Federal standards as well as car manufacturer standards require a maximum of 10 percent blending of ethanol into fuel. Brian Wright, "Global biofuels: Key to the puzzle of grain market behavior," *Journal of Economic Perspectives*, Volume 28, Number 1, pp. 73–98.
5 Mark W. Rosegrant, "Biofuels and grain prices: Impacts and policy responses," International Food Policy Research Institute (IFPRI), testimony for the US Senate Committee on Homeland Security and Governmental Affairs, May 7, 2008.
6 Maximo Torero, "Alternative mechanisms to reduce food price volatility and price spikes: Policy responses at the global level," in Matthias Kalkuhl, Joachim von Braun, and Maximo Torero, eds., *Food Price Volatility and Its Implications for Food Security and Policy*, Cham, Switzerland: Springer, 2016.
7 Elena Ianchovichina, Josef Loening, and Christina Wood, *How vulnerable are Arab countries to global food price shocks?*, World Bank Policy Research Working Paper WPS6018, March 1, 2012; Kenneth Baltzer, *International to domestic price transmission in fourteen developing countries during the 2007–08 food crisis*, WIDER working paper 2013/031, United Nations University, World Institute for Development Economics Research (WIDER), 2013.
8 Obie Porteous, "High trade costs and their consequences: An estimated dynamic model of African agricultural storage and trade," *American Economic Journal: Applied Economics*, forthcoming.

Case study Breadbasket failure-1

Declining cereal stock-to-use ratios are typically associated with higher prices.

Example: 2008 food price crisis



1. Weighted average of wheat, corn, and rice; excludes other crops to match composition of FAO Cereal Price Index.
2. Average of various global and regional wheat, corn, and rice price quotations.
Source: FAO

Given that supply shortages are difficult to predict on an annual basis, a larger safety stock reserve is one potential solution. Our analysis suggests that stock-to-use ratios of 35 to 40 percent, compared with today's typical 30 percent, would be required to mitigate the impact of these shortfalls when they occur. We estimate the costs for the required additional storage to be a total of $5 billion to $11 billion a year. The second approach would be to expand private and public research. For instance, an area of interest could be technologies making crops more resistant to abiotic and biotic stresses. This may include conventional breeding, gene editing, or other biological or physical approaches, over and above ongoing efforts to increase agricultural yields and productivity. Third, increasing adoption of modern, efficient irrigation technologies could help reduce the risk from drought significantly.

The global food system is vulnerable as a growing population depends on four key crops with high geographic concentration of production

Climate change could affect food production through both continuous changes—for example, increasing temperatures and changes to precipitation patterns—and more frequent episodes of acute stress, such as heat waves and excessive precipitation. We find that the global food system is vulnerable to climate change as a growing population depends on four key crops with high geographic concentration of production.

The human diet is highly dependent on just four grains: rice, wheat, corn, and soy. They make up almost half of the calories of an average global diet, with rice and wheat contributing 19 percent and 18 percent, respectively (Breadbasket failure-2). Corn and soy, contributing only 5 percent and 3 percent to human diets directly, are mainly used in animal feed, through which they help supply the 15 percent of calories coming from animal products such as meat, dairy, and eggs.

Sixty percent of global food production occurs in just five countries: China, the United States, India, Brazil, and Argentina (Breadbasket failure-3). Even within these countries, food production is highly concentrated in a few regions. For example, 88 percent of Indian wheat production comes from five states in the northern part of the country.[6] In China, the eight largest grain-producing provinces, accounting for 57 percent of production, are all in the eastern part of the country.[7] In the United States, five Midwestern states account for 61 percent of corn production, according to the Department of Agriculture. In Brazil, a single state, Mato Grosso, produces 8 percent of all corn and 30 percent of all soy.[8] While this concentration of production (often in the form of monocultures) creates significant efficiencies through, for example, economies of scale, it also creates vulnerability for the global food system, because a few geographically concentrated extreme weather events in those production regions could affect a large portion of global production.

6 Government of India, Ministry of Statistics and Programme Implementation, 2017, mospi.gov.in/statistical-year-book-india/2017/177.
7 China Statistical Yearbook 2018,statista.com/statistics/242335/grain-production-in-china-by-province/
8 *Corn and soybean production costs and export competitiveness in Argentina, Brazil, and the United States*, US Department of Agriculture, Economic Research Service, June 2016.

Furthermore, the population that relies most on these grains is growing (Breadbasket failure-4). In particular, developing countries tend to be importers of grain, mostly because competitive disadvantages in growing grains make buying from the world markets cheaper than producing domestically. For example, Algeria, Egypt, Mexico, and Saudi Arabia are net importers of grain, and China is highly dependent on soy imports.[9] Dependency on grain imports can change. In 2018, for the first time in many years, China was not able to meet its demand for corn with domestic production.[10]

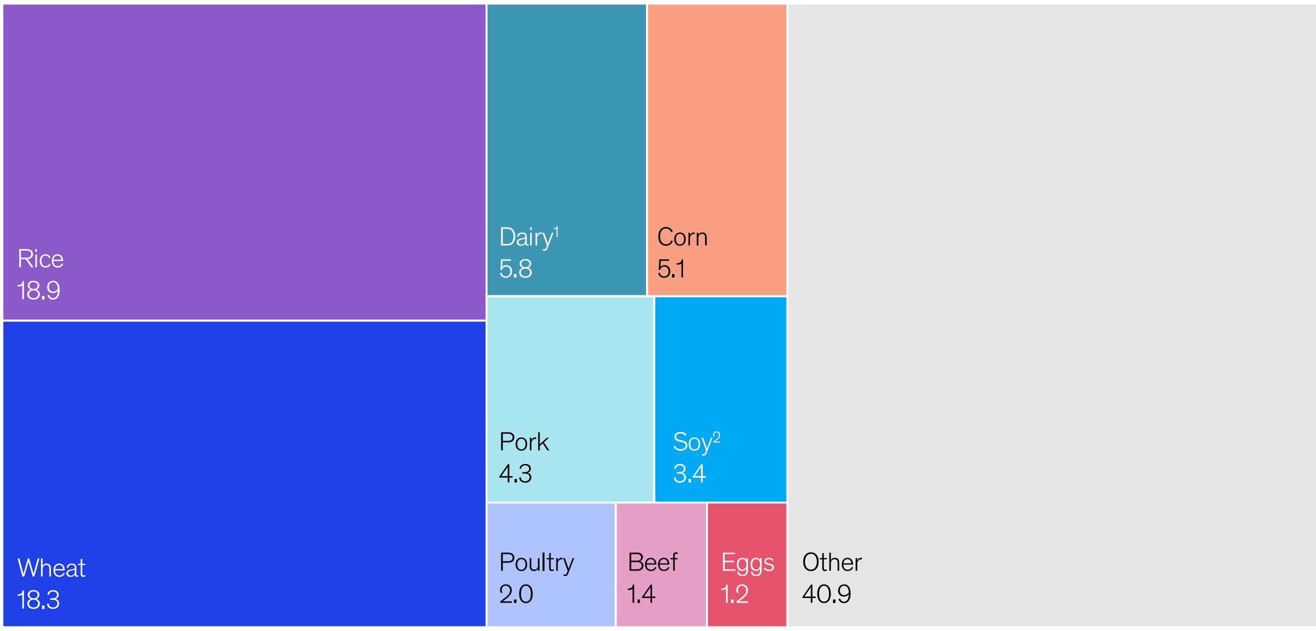
This import dependency creates a further vulnerability as it relies on the continued functioning of organized global trade relationships and geopolitical stability.

Another factor that makes the global food system vulnerable to episodes of climate stress is limited grain storage. The amount of stored grain influences how well the food system is equipped to respond to any shortage of food production because it provides a buffer that can be built in years with low prices and released in years with higher prices. Grain storage costs consist of the working capital cost of holding large amounts of grain, the direct costs of storage, distribution costs, and potential shrinkage.

Case study Breadbasket failure-2

Four grains—rice, wheat, corn, and soy—make up almost half of the daily calories of the average global diet.

% of average daily calorie consumption, 2011–13



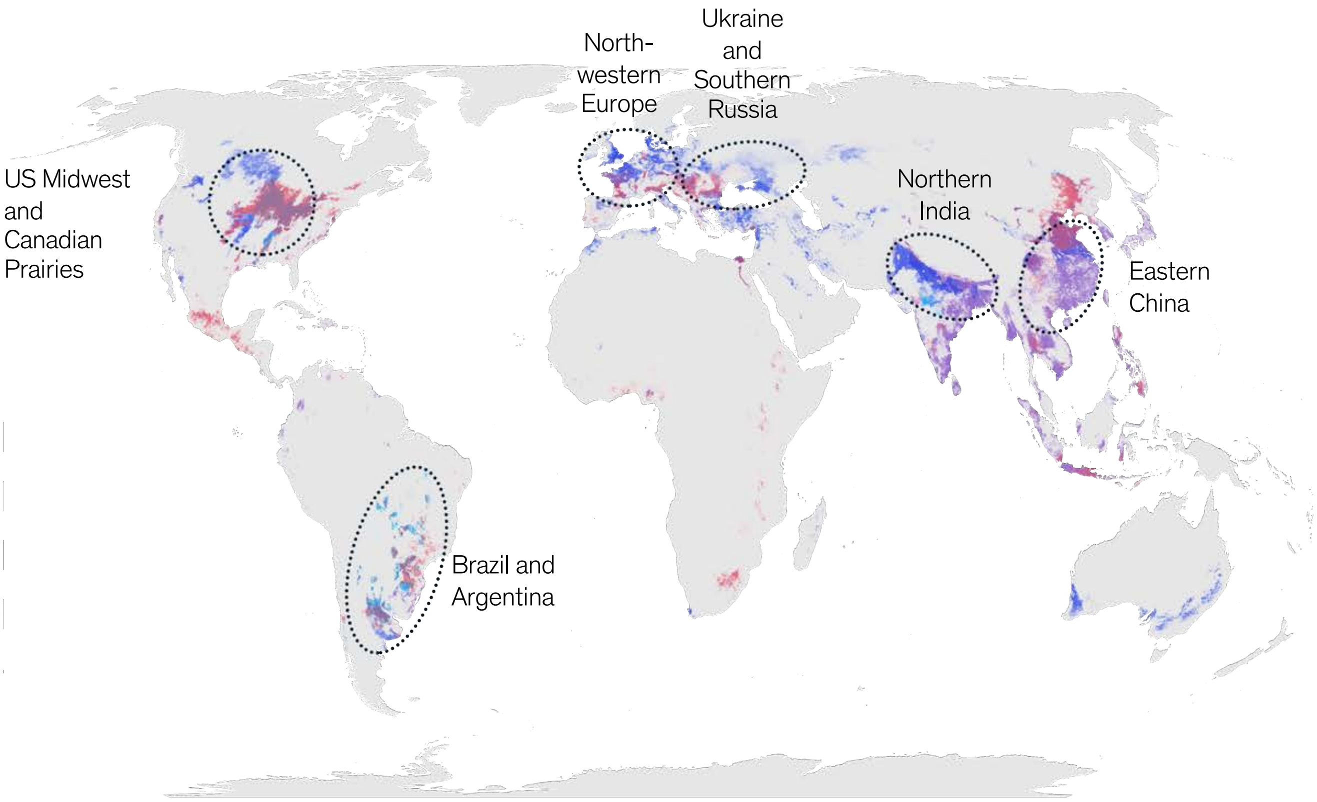
1. Milk and butter.
2. Soybeans and oil.
Source: FAO

[9] Nikos Alexandratos and Jelle Bruinsma, *World agriculture toward 2030/2050: The 2012 revision*, ESA working paper number 12-03, Agricultural Development Economics Division, FAO, June 2012.
[10] Lucy Craymer, "How high are corn prices in China? You won't believe your ears," *Wall Street Journal*, June 6, 2019.

Production of the world's major grains is highly concentrated in a few growing regions.

Rice Corn Wheat Soy[1] Major grain production areas

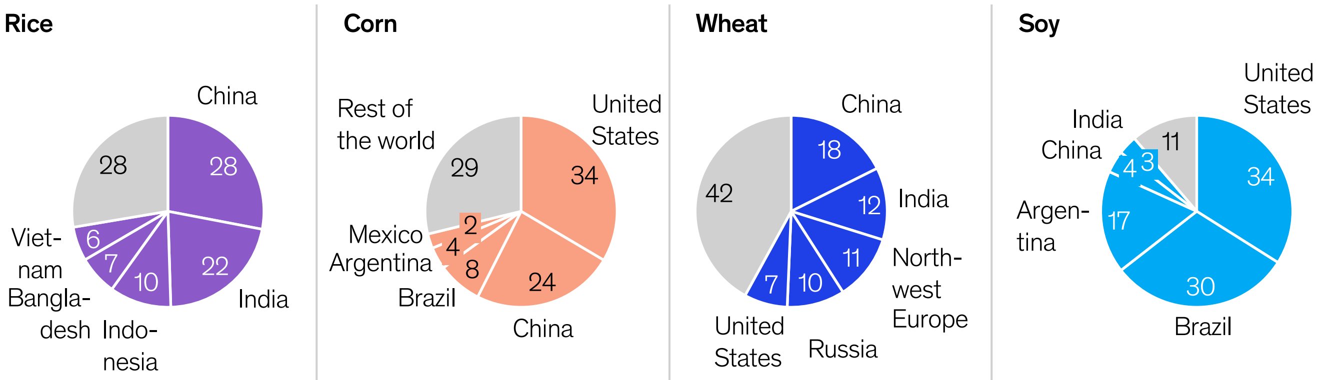
Global agricultural production[2]



Share of grain production by country, 2015–17

% of average annual production

Rest of world



1. Soybeans and oil.
2. Colors indicate where particular grain is produced. Darker shading within each color indicates higher density of production, lighter (more transparent) shading indicates lower density of production.

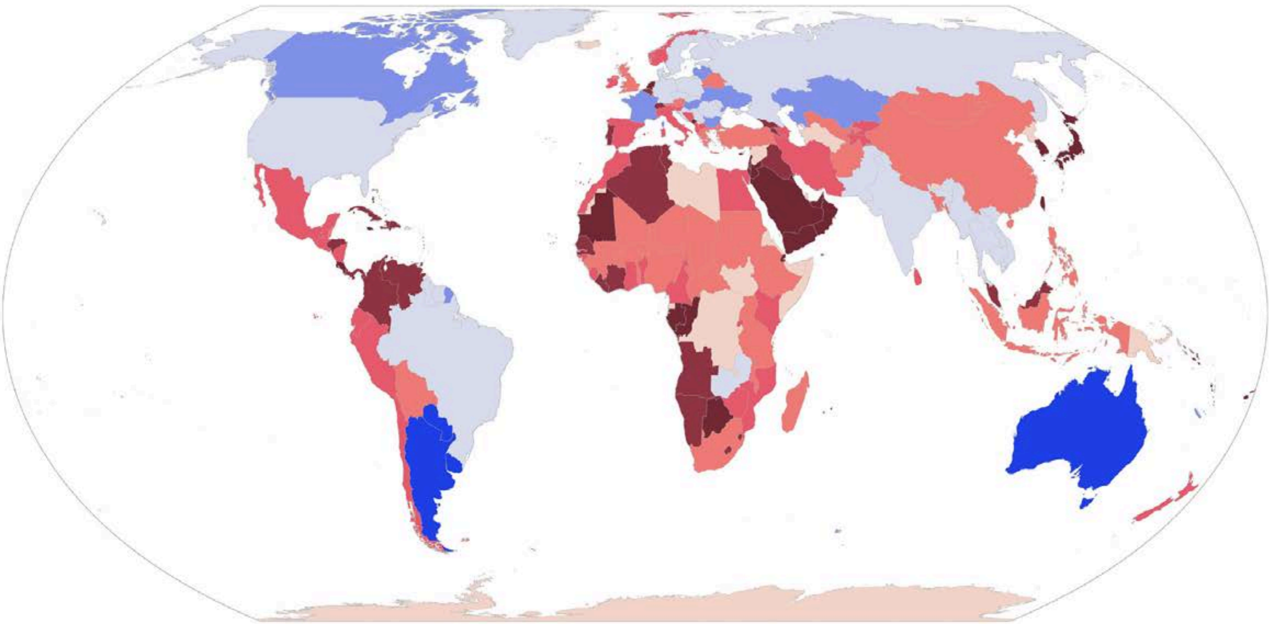
Source: FAOSTAT; Earth Stat, 2000; McKinsey Global Institute analysis

Most countries rely on grain imports.

Reliance on grain imports per country today[1]

Net imports as % of consumption

<-150 | -149 to -50 | -49 to -1 | n/a | 0–1 | 2–10 | 11–25 | 26–50 | 51–75 | >75



1. Grain imports per country = (cereal imports – cereal exports) ÷ (cereal production + cereal imports – cereal exports) × 100. Cereal refers to rice, wheat, and corn. Today defined as 2011-2013.

Source: FAO

We estimate the likelihood of a multiple-breadbasket failure occurring to be about 18 percent by 2030, and about 34 percent by 2050

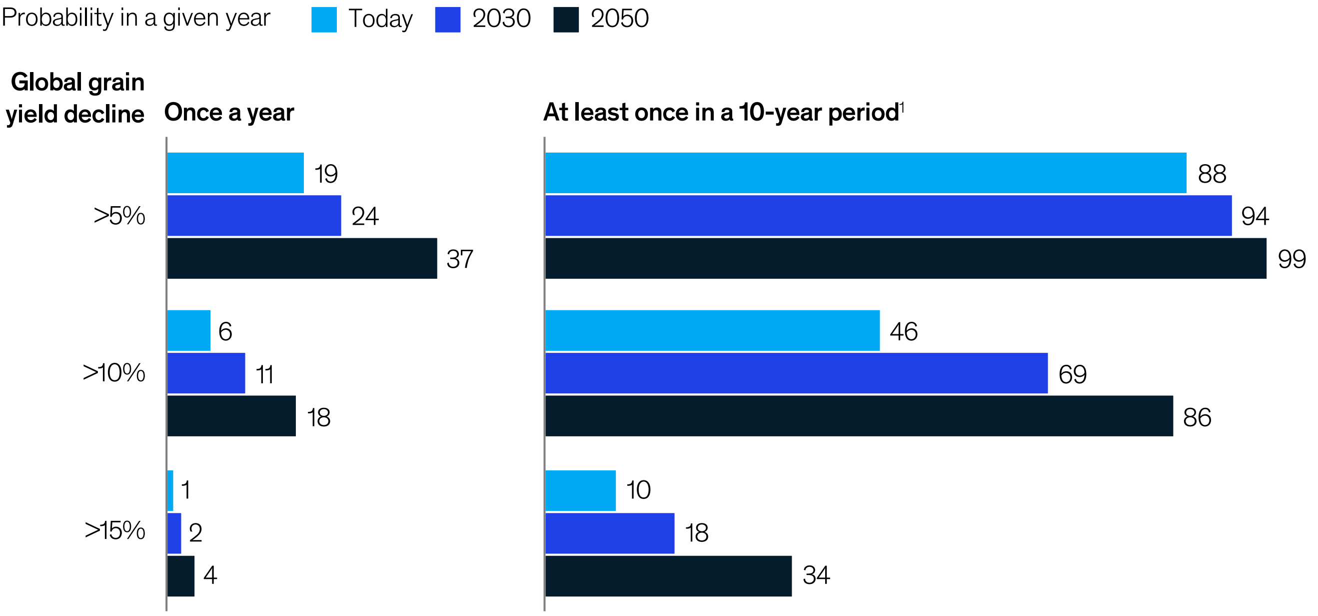
We estimate the likelihood of an episode of climate stress causing a multiple-breadbasket failure by 2030 as well as 2050. We define harvest failure as a major yield reduction in the annual crop production cycle of a region where there is a potential impact on the global food system.

To estimate the likelihood, we employ crop models from the AgMIP model library that translate outputs from climate models including temperature and precipitation into crop yields for each modeled grid cell area of the planet.[11] Using all available climate models over a period of 20 years, we construct a probability distribution of yields for each crop in each grid cell (Breadbasket failure-5). For the purpose of this analysis, we focus on grid cells in the five largest producing breadbasket regions for each crop.[12] Based on that, we can compute probability distributions for yields for each of the crops within each breadbasket, as well as global distributions per crop and across crops. Note that we are taking into account potentially positive effects on plant growth from higher CO_2 levels ("CO_2 fertilization"). However, those benefits could be reduced as increased CO_2 levels could lead to a reduction in the protein and micronutrient content of crops, which in turn would require humans to eat more volume to achieve the same level of nutrition (an effect we do not take into account).[13]

Case study Breadbasket failure-5

In our inherent risk assessment, the annual risk of a more than 15 percent global yield failure is projected to double by 2030 and quadruple by 2050.

Based on RCP 8.5



1. Calculated as a cumulative probability assuming independence between years.

Note: See the Technical Appendix of the full report for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Following standard practice, we define current and future (2030, 2050) states as average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

Source: Woods Hole Research Center; McKinsey Global Institute analysis

[11] By nature of the choice of agricultural models used, these results do not account for specific extreme events such as flash flooding or individual heat waves. All crop modeling has been done under the assumption that historic increases in CO_2 fertilization continue to increase with atmospheric CO_2 content. Uncertainty related to this assumption would lead to overestimating yields and underestimating the likelihood of breadbasket failures. See technical appendix of the full report for further details.

[12] For wheat: China, EU, India, Russia, and the United States. For corn: Argentina, Brazil, China, EU, and the United States. For soy: Argentina, Brazil, China, India, and the United States. For rice: Bangladesh, China, India, Indonesia, and Vietnam.

[13] Chunwu Zhu et al., "Carbon dioxide (CO_2) levels this century will alter the protein, micronutrients, and vitamin content of rice grains with potential health consequences for the poorest rice-dependent countries," *Science Advances*, May 23, 2018, Volume 4, Number 5.

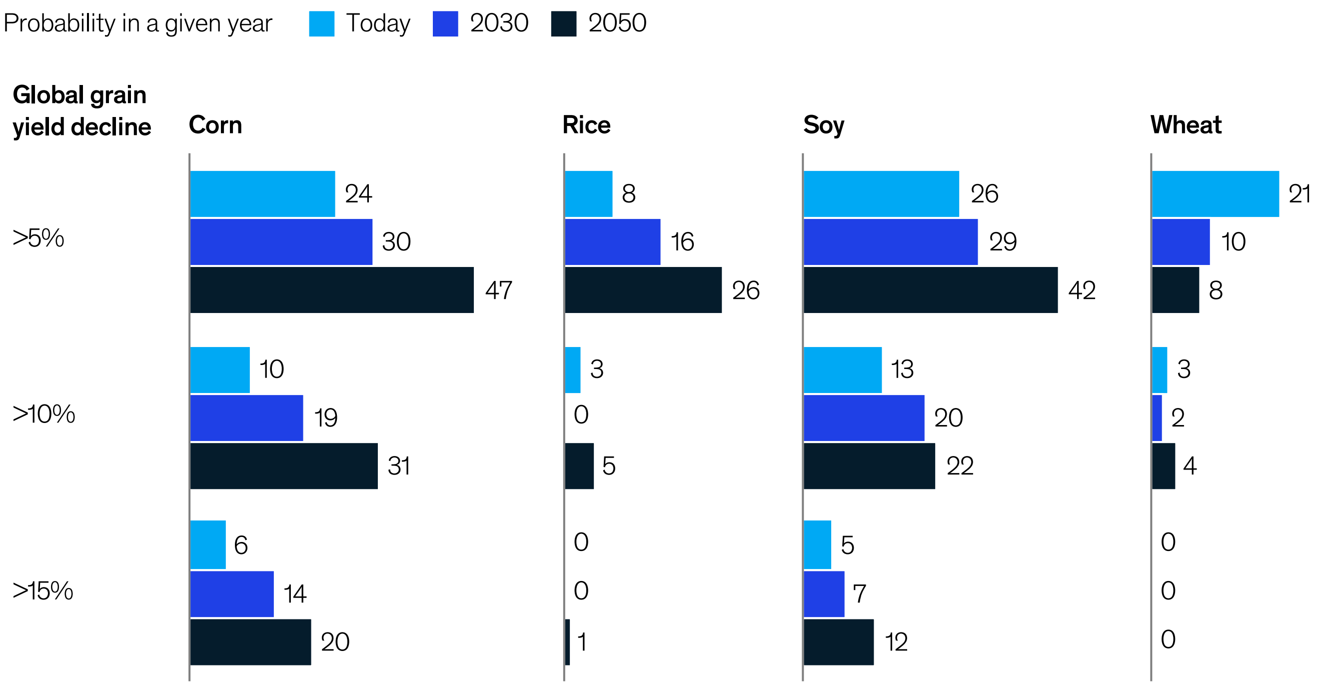
The analysis suggests that a "true" multiple-breadbasket failure—simultaneous shocks to grain production through acute climate events in a sufficient number of breadbaskets to affect global production—becomes increasingly likely in the decades ahead, driven by an increase in both the likelihood and the severity of climate events. For example, a greater than 15 percent shock to grain production was a 1-in-100 event between 1998 and 2017. This likelihood doubles by 2030 to 1 in 50, suggesting that there is an 18 percent likelihood of such a failure at least once in the decade centered on 2030. A greater than 10 percent yield shock has an 11 percent annual probability or a 69 percent cumulative probability of occurring at least once in the decade centered on 2030. This is up from 6 percent and 46 percent, respectively today.[14]

These increases are driven mainly by risks to corn, soy, and rice production, as climate change leads more frequently to weather patterns that adversely affect their growing conditions. Corn, for example, has a plant physiological threshold of about 20 degrees Celsius, beyond which yields decline dramatically.[15] Similarly, both drought and extreme precipitation (beyond roughly 0.5 meter of seasonal precipitation) lead to suboptimal yields.[16] In the US Midwest, one of the key corn production regions globally, hotter summer temperatures and higher likelihood of excessive spring rain (as seen in 2019) drive higher likelihood of harvest failures.[17] Wheat is the one crop that seems to benefit from the higher temperatures that climate change causes in some of the main production regions (Breadbasket failure-6).

Case study Breadbasket failure-6

Climate change will affect yields of each grain differently.

Based on RCP 8.5



Note: See the Technical Appendix of the full report for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multimodel ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.
Source: Woods Hole Research Center

[14] In the historical data of the past 20 years, we already see several shocks to supply in the main breadbaskets. For example, in 2003, detrended grain production went down approximately 10 percent compared with the detrended three-year average (2000–02). The reason this did not create a food price shock was that other regions that are not breadbaskets were less affected, and the overall trend of increasing yields as well as healthy stock-to-use ratios provided an additional buffer. In the future, however, when shocks become more frequent and severe, those mitigating circumstances may disappear.

[15] Solomon Hsiang et al., "Estimating economic damage from climate change in the United States," *Science*, June 30, 2017, Volume 356, Number 6345.

[16] Ibid.

[17] *Heat in the heartland: Climate change and economic risk in the Midwest*, Risky Business Project, January 2015.

There could be episodes where grain prices could rise over 100 percent, affecting about 750 million people and increasing the risk of social unrest

A key indicator of grain price increases is the amount of storage in the global food system. Historically, every episode of low storage of grains has led to price hikes. Although storage is hard to measure, the Agricultural Market Information System of the Food and Agriculture Organization of the United Nations (FAO) tries to calculate it using a stock-to-use ratio.[18] It estimates that the proportion of current stocks to annual use is about 30 percent for rice, wheat, and corn and 10 percent for soy. This amounts to about 110 days' worth of consumption for cereals and 36 days for soy. These levels are relatively high historically, and explain the current low prices. For example, cereal stock-to-use ratios reached about 20 percent in the more severe price crisis of 2008–09 and between 20 and 25 percent in the 2010–12 price crisis, while severe price shocks in the 1970s and 1990s (for example, wheat price spikes in 1973–76 and 1996) occurred with stock-to-use ratios of about 15 percent. As Bobenrieth et al. point out, "severe supply shortages [and consequent reduction in stock-to-use ratios] always coincide with price spikes."[19]

Since current stock-to-use ratios are historically high at 30 percent of consumption, it is virtually impossible that the world will run out of grain within any one year. However, even limited reductions in stock-to-use ratios have triggered past episodes of spiking food prices, and we have no reason to expect that this would not be the case in the event of a multiple-breadbasket failure.[20]

In our analysis, we explore the impacts of a 15 percent drop in global supply in a given year, which would cause stock-to-use rations to drop to about 20 percent. In that case, historical precedent suggests that prices could easily spike by 100 percent or more in the short term. We acknowledge that food commodity prices are difficult to predict. While a supply shock will typically raise prices, other factors can come into play to either amplify or counteract. These include, among other things, unpredictable consumer demand adjustments, unpredictable adjustments in the demand for biofuels, the use of protectionist measures, and, controversially, market responses such as hedging activity.

People in poorer countries will feel the effects of rising food prices the most, given that a higher share of their expenditure goes toward food. Substitution strategies such as buying cheaper food and reducing meat consumption are effective only to the extent that households were previously able to afford them, which does not pertain to the very poor, including the 750 million people (about 10 percent of the world's population) living below the international poverty line of $1.90 per day.[21] In addition, urban populations will be affected more because rural populations typically derive a larger share of their income from sales of agricultural commodities, which increase as commodity prices rise.[22] However, overall, research suggests that most poor households are net buyers of food and hence will suffer from higher food prices. Some researchers estimate that a 100 percent price rise would increase extreme poverty by 13 percentage points in the short run (that is, more than doubling the extreme poverty rate).[23] Extreme poverty and undernourishment are closely linked, so such a shock would likely lead to reversals in the long-term decline in stunted and wasting children and to an increase in child mortality.

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18 Calculated as stock-to-use ratio times 365 days. In this case, with ratios at 30 percent, stocks will last 30 percent of 365 days, or 110 days.

19 Eugenio Bobenrieth et al., "Stocks-to-use ratios and prices as indicators of vulnerability to spikes in global cereal markets," *Agricultural Economics*, February 2013, Volume 44, supplement 43–52.

20 Matthias Kalkuhl, Joachim von Braun, and Maximo Torero, eds., *Food Price Volatility and Its Implications for Food Security and Policy,* Cham, Switzerland: Springer, 2016; Brian Wright, "Global biofuels: Key to the puzzle of grain market behavior," *Journal of Economic Perspectives*, Winter 2014, Volume 28, Number 1, pp. 73–98.

21 PovcalNet, World Bank, iresearch.worldbank.org/PovcalNet/povDuplicateWB.aspx.

22 Kym Anderson, Maros Ivanic, and William J. Martin, *Food price spikes, price insulation, and poverty*, National Bureau of Economic Research working paper number 19530, October 2013.

23 Maros Ivanic and Will Martin, *Short- and long-run impacts of food price changes on poverty*, World Bank policy research working paper WPS7011, August 1, 2014.

In economic terms, the United Nations calculated the effect of a doubling of food commodity prices on real GDP for a sample of countries and found that it would hurt poor, import-dependent countries most.[24] Higher import prices, which divert household income away from domestic spending, drive the change. For example, Nigeria could experience a reduction in real GDP growth of 7.2 percent, Senegal 6.6 percent, and Mozambique 6.1 percent. In Nigeria, such a macroeconomic shock could push the country into a recession, similar in magnitude to the country's situation in the early 1980s, which contributed to ethnic conflict and political pressure to expel two million illegal workers.[25] In addition, lower household spending reduces government tax revenue. If governments are also forced to increase spending on food subsidies, there could be impacts on budget deficits, and potentially credit ratings. Last, higher spending on imports would have impacts on the trade balance.[26]

More broadly, negative economic shocks of this size could lead to widespread social and political unrest, global conflict, and increased terrorism, though the likelihood of such events are hard to predict. For example, researchers link the unrest in Egypt in 2011, which marked the real beginning of the Arab Spring following initial unrest in Tunisia, to reduced imports of wheat driven by high world market prices.[27] Piazza finds that high and volatile food prices are a strong predictor of terrorism, because hardship caused by the higher cost of living decreases the legitimacy of governments.[28]

Policy makers have begun to build a more resilient food system, but more can be done

Following the food price shortages of the past decade, the G-20 developed an action plan to reduce price volatility.[29] The main steps included: the creation of better market information and transparency to avoid uncertainty, which led to the establishment of the FAO Agricultural Market Information System; policy measures to strengthen long-term productivity, for example by supporting agricultural research and innovation; policy coordination to prevent and mitigate price crises, including reducing food export restrictions; and improving and developing risk management tools for governments, firms, and farmers as well as improvements to the commodity derivative markets. While we believe this is a good start, more can be done that does not require the same degree of coordination. We offer a set of actions can be undertaken by individual governments, agricultural trading companies, and multilateral organizations.

For governments, a relatively straightforward way to manage domestic grain prices is by keeping large amounts of stocks that are built up in times of low prices and released when prices increase, essentially creating a price ceiling. While such a policy does not require coordination with other countries, governments should be aware of a number of challenges when designing their policies.

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24 *ERISC phase II: How food prices link environmental constraints to sovereign credit risk*, United Nations Environment Programme, May 2016.
25 Associated Press, "Expelled foreigners pouring out of Nigeria," *New York Times*, May 5, 1985; World Bank.
26 *ERISC phase II: How food prices link environmental constraints to sovereign credit risk*, United Nations Environment Programme, May 2016.
27 Willeke Veninga and Rico Ihle, "Import vulnerability in the Middle East: Effects of the Arab spring on Egyptian wheat trade," *Food Security*, February 2018, Volume 10, Number 1, pp. 183–94; Caitlin E. Werrell, Francesco Femia, and Anne-Marie Slaughter, *The Arab Spring and Climate Change*, Center for American Progress, February 28, 2013.
28 James A. Piazza, "The cost of living and terror: Does consumer price volatility fuel terrorism?," *Southern Economic Journal*, April 2013, Volume 79, Number 4.
29 *Ministerial declaration: Action plan on food price volatility and agriculture*, G20 Agriculture Ministers, June 22–23, 2011.

First, high food stocks drain resources during times of low prices and do not provide any immediate benefit. The benefit is realized only in crises, which are often unpredictable in both extent and timing.[30] This may introduce political difficulties in providing the necessary resources. Second, acquiring large amounts of grains on world markets can prove hard, and countries run the risk of paying premiums. The costs of storage and storage losses must also be managed, which have been estimated to be $32 to $40 per year and ton in Africa.[31] Third, in some countries, "leakages" from storage have been reported, caused by ineffective control and accountability systems. In India, for example, researchers found that 47 percent of stored grain was diverted to the open market.[32] Additionally, the existence of large stocks can introduce uncertainty into the market regarding when and how reserves will be released, which may further increase volatility.[33] Finally, keeping prices artificially low during times of crisis can also discourage behavior that would help to lower consumption, such as reducing food waste, switching to more efficient diets (away from meat and toward plant-based nutrition), and minimizing nonfood use, for example for biofuels. Despite all these challenges, increased storage is likely to be the most straightforward and reliable tool to prevent large domestic price spikes. By introducing near-term redundancy, increased storage increases long-term resilience.

In addition, governments could consider increasing the flexibility of the nonfood use of grains. For example, regulators could explicitly introduce mechanisms controlling demand for biofuels. In this case, the mandate could be automatically relaxed as certain price thresholds are crossed. To the extent that those rules are provided to the market for guidance, they could reduce uncertainty and volatility. Wright suggests that governments enter into contingent contracts with grain producers, paying an annual fee that allows governments to divert grains to food aid programs in times of high prices.[34]

Given the large amounts of grain calories fed to animals and converted to meat, dairy, and eggs at a very inefficient conversion rate (producing one calorie of beef takes about eight calories of feed, pork about four, chicken two), reduced meat consumption would provide an additional lever to reduce demand for grains.[35] However, to the extent that this demand reduction is permanent and prices do not remain, on average, at current levels (for example, via increased grain storage in good years), the resulting drop in grain commodity prices may drive farmers out of business and further reduce the available amount of grain during breadbasket failures.

Agricultural trading companies may want to review their long-term strategies regarding storage capacity investment and utilization as well as their trading strategies in light of the revised probabilities of multiple-breadbasket failures. To the extent that governments deem food storage and the ability to ship grains quickly and reliably to consumers a positive externality, they may choose to subsidize private-sector storage, encouraging the private sector to increase storage facilities, or to invest in improved transportation infrastructure (rail lines and ports, for example).

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30 Maximo Torero, "Alternative mechanisms to reduce food price volatility and price spikes: Policy responses at the global level," in Matthias Kalkuhl, Joachim von Braun, and Maximo Torero, eds., *Food Price Volatility and Its Implications for Food Security and Policy*, Cham, Switzerland: Springer, 2016.

31 Shahidur Rashid and Solomon Lemma, *Strategic grain reserves in Ethiopia: Institutional design and operational performance*, IFPRI discussion paper number 01054, IFPRI, 2011.

32 Ashok Gulati and Shweta Saini, *Leakages from Public Distribution System (PDS) and the way forward*, working paper number 294, Indian Council for Research on International Economic Relations, 2015.

33 Maximo Torero, "Alternative mechanisms to reduce food price volatility and price spikes: Policy responses at the global level," in Matthias Kalkuhl, Joachim von Braun, and Maximo Torero, eds., *Food Price Volatility and Its Implications for Food Security and Policy*, Cham, Switzerland: Springer, 2016

34 Brian Wright, "Addressing the biofuels problem: Food security options for agricultural feedstocks," in *Safeguarding food security in volatile global markets*, Adam Prakash, ed., FAO, 2011.

35 Jillian P. Fry et al., "Feed conversion efficiency in aquaculture: Do we measure it correctly?", *Environmental Research Letters*, 2018, Volume 13, Number 2.

Based on annual production of 3.5 billion tons, we estimate the cost of increasing global stocks to be $5 billion to $11 billion a year, assuming the cost of stocks to be $32 a ton.[36] Such an investment would increase the current global stock-to-use ratio to 35 to 40 percent, which could offset harvest failures of the magnitude of 15 percent. To put this into context, the estimated costs would be approximately 0.5 to 1.5 percent of the annual average gross production value.[37] However, despite sufficient global stocks, a multiple-breadbasket failure might still result in regional imbalances and thus price impacts, albeit likely on a smaller scale.

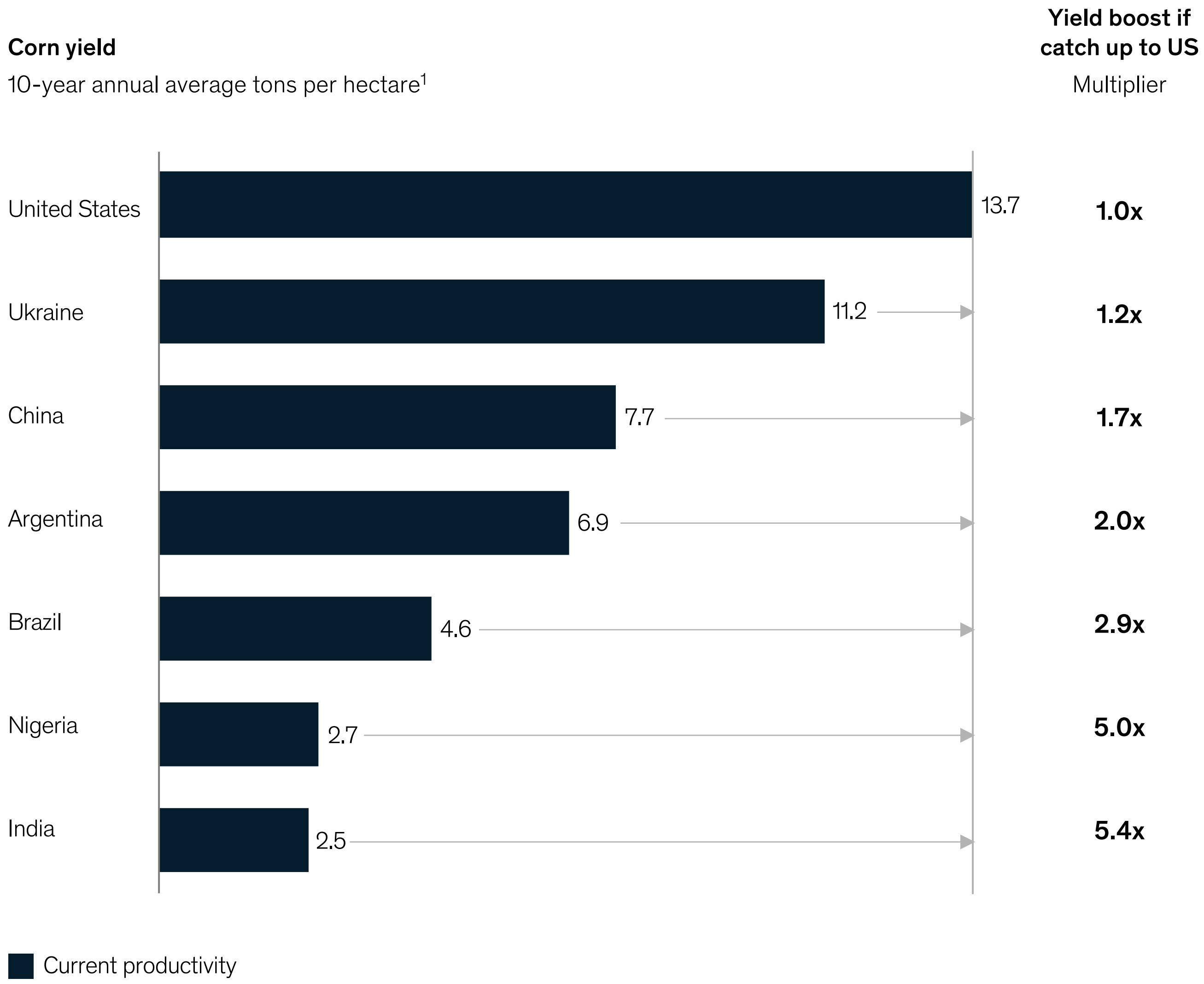
Multilateral organizations such as the World Bank and FAO could consider the creation of virtual reserves. This would involve increasing short sales in the spot market during times of high food prices, which could help to reduce prices. However, this would work only to the extent that markets "overreact" (for instance, by introducing export bans) and when there are no actual food shortages, because it does not alter supply, demand, or physical reserve levels.[38] Organizations could also explore the design of innovative mechanisms that would lead to higher private-sector storage rates.

All actors in the space could continue to improve productivity and resilience in food production, which are critical for significant improvements in global food security. In terms of improving resilience, research on genetically modified traits could be expanded. Such resilience research on genetically modified traits needs to be different from the more productivity-focused research in the past, given the different aims (for example, heat resistance instead of growth rates).

Improving productivity could be achieved in three ways: first, actors could consider how to integrate production regions into the global food system that will see yields increase as a result of climate change. For example, regions in more northern areas such as Canada, Scandinavia and Siberia could benefit from increased yields. However, the greater frequency of drought events and storms may to some extent counteract those effects.[39] The second possible approach is the continued rollout of established technology to areas with yields well below their potential (Breadbasket failure-7). Most main corn producers have similarly beneficial conditions for corn production, but much lower yields. If they were to catch up to the United States, global production would on average increase by 36 percent. The key lever to increase average yields and reduce yield volatility in many regions is irrigation. To the extent that there is sufficient regional water supply from rivers and aquifers, irrigation can essentially eliminate the risk of droughts. Modern irrigation technologies can accomplish this goal while minimizing water use, a critical feature as climate change can lead to stressed water supply. For example, drip irrigation tubes that are controlled by algorithms and linked to soil moisture sensors or satellite images can achieve 90 percent efficiency (i.e. 90 percent of the water applied is absorbed by the plant). This contrasts with 70 percent for sprinklers and 60 percent for flood irrigation.[40] Other key levers include more local R&D and farmer education (for example, by establishing a strong extension system in developing countries), improvements to the accessibility of high-quality inputs such as fertilizers and seeds, and better farming practices (e.g., no till agriculture leads to higher soil quality over time).[41] This has been attempted in the past but has encountered multiple barriers, including limited intellectual property protection, which has discouraged private-sector engagement. Climate change and the potential for multiple-breadbasket failures now add new urgency.

36 FAO STAT; figures based on global production quantity; 2015–17 average for rice, wheat, corn, and soy. Shahidur Rashid and Solomon Lemma, *Strategic grain reserves in Ethiopia: Institutional design and operational performance*, IFPRI discussion paper number 01054, IFPRI, 2011
37 FAO STAT; based on 2015–17 average.
38 Maximo Torero, "Alternative mechanisms to reduce food price volatility and price spikes: Policy responses at the global level," in Matthias Kalkuhl, Joachim von Braun, and Maximo Torero, eds., *Food Price Volatility and Its Implications for Food Security and Policy*, Cham, Switzerland: Springer, 2016.
39 "Impact of climate change on Canadian agriculture," Government of Canada, July 30, 2015.
40 "Annex 1: Irrigation efficiencies," FAO.
41 David S. Powlson et al., "Limited potential of no till agriculture for climate change mitigation," *Nature Climate Change*, July 2014.

Unlocking the yield potential of corn could boost production by more than five times in some countries.



1. Actual yields are 10-year FAO averages where available; if not available, shorter periods used.
Source: FAO; McKinsey Global Institute analysis

While the world today is, on average, producing more than enough food to feed the growing population, short-term price hikes from episodes of climate stress could have a significant impact on the well-being of 750 million of the world's poorest people, with the possibility of substantial broader knock-on impacts. Increasing production and storage in good years and increasing flexibility in the use of food crops to maximize calories consumed could go a long way to lessen that risk.

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