Chapter 3

Water risk hotspots and the impact on production, markets and food security

This chapter analyses the impact of future water risk hotspots on agriculture. It reviews agriculture production impacts, considers the market and trade effects of such risks, and looks at the broader effects of these risks on food security. The discussion combines insights from the literature on water risks in agriculture, from case studies on Northeast China, Northwest India, and the Southwest United States, as well as results from a simulation of the global impact of projected agriculture water risks in these three regions.

Key messages

Agriculture water risks at hotspot locations can cause three layers of impacts. First, water risks will directly affect agriculture production. Second, these production effects may have broader market implications both domestically and potentially internationally. Third, broader food security and associated indirect effects may also occur.

Agriculture production effects at hotspot locations will vary in scope and duration according to the type and combination of water risks. In the absence of policy action, Northeast China’s agriculture is expected to face water shortage due to competition for water use with other sectors, possible continued groundwater depletion in parts of the region, and the uncertain effects of climate change, leading to possible pressure on field crops such as maize and wheat. In Northwest India, groundwater depletion and quality impacts will combine with more variable monsoons to exert pressure on wheat and rice. In the Southwest United States, continued surface water volatility, higher temperature, increased water demand and groundwater pressure would reduce irrigation acreage and may result in a shift of activities away from feed and forage crops towards activities with higher revenue per amount of water used.

Agricultural impacts in highly productive regions can spillover to domestic and international markets. A simulation of simultaneous gradual irrigation stresses in the three hotspot regions, results in price rises of 5% to 8% of selected commodities globally, reductions in production in the three countries, and significant shifts in trade of field crops, such as maize, wheat, rice and cotton. A drought in the US Southwest alone in 2021 would not significantly affect global markets, but a combined drought in Northwest India and Northeast China in 2030 would result in price increases of similar amplitude and shifts in trade. Simulated global climate change projections alter these impacts, in some cases aggravating those for key crops in the three countries.

Recent developments show that agriculture water risks can also have impacts beyond the sector, affecting food security and indirectly resulting in impacts to other countries. Agriculture water risks partially explain the multiplication of foreign land purchases often by water scarce countries in relatively better water endowed countries. Agriculture water risks can also result in social tensions, fuelling conflicts that can become regional, and they can drive migration both domestically and internationally.

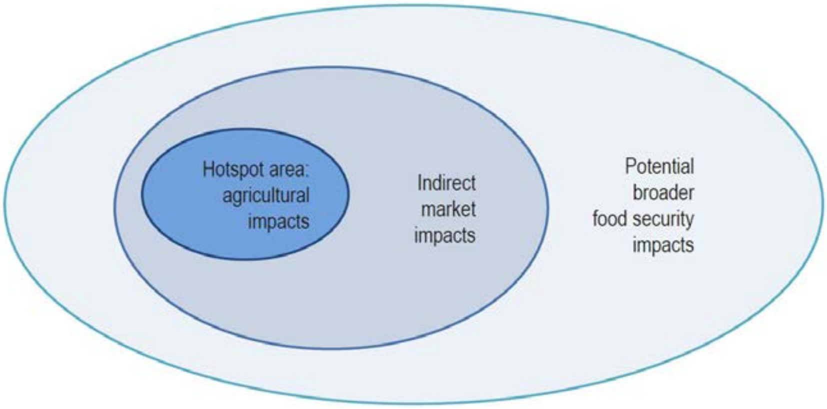
The previous chapters identified specific countries and regions as future water risk hotspots for global agriculture production. This chapter analyses more specifically the impacts such risks may have on agriculture locally, nationally and globally on market partners, and broader food security. The chapter addresses impacts at any water risk hotspot location at the regional, national or subnational levels, even if much of the analysis focuses on the three identified regions of Northeast China, the Southwest United States and Northwest India.

3.1. Ripples and risks: Three layers of impacts from agriculture water risk hotspots

Water risk hotspots for agriculture concentrate risks, but can generate different layers of impact. In relatively well-integrated food markets, high agriculture production risks may impact food chains locally, regionally and internationally. Agriculture production risks may also have different types of economic effects on producers, market chain actors, consumers of the concerned products, and even other consumers if they impact the price of other commodities. These impacts will often be less extreme the further from the maximum risk location (hotspot) and the longer after a shock (if there is a shock), but different types of impacts may also disturb this ripple-like effect.

To capture these gradual and differentiated effects synthetically, three levels of impacts arising from agriculture water risk hotspots (Figure 3.1) are evaluated. A first tier of impacts, mainly agriculture production-related, encompasses direct effects in the targeted (hotspot) regions. A second tier includes market-related indirect impacts, affecting market actors, possibly trade partners, and competitors.[1] The third tier comprises food security and broader consequences, which may concern a larger range of countries. Any country may be affected by one or more of the three types of impacts, or not be affected at all by specific agriculture water risk hotspots.

Figure 3.1. Three layers of impacts from water risk hotspots



Source: Author's own work.

The following three subsections will use this impact differentiation as a benchmark. For each of the three levels of impact, some of the key expected effects of agriculture water risks hotspots will be reviewed, drawing in particular from analyses touching on the three case studies.

3.2. Local water risks at the hotspot locations: Productivity losses and changes in agriculture activities

Main types of agriculture impacts from water risks

The nature and amplitude of production impacts depend largely on agriculture water risks. Table 3.1 gives an illustration of the type of agriculture impacts one might envisage for specific regions under different time and risk horizons. Expected impacts range from losses of productivity and increased costs of production to observed shifts of production. The type of impact will vary for different water risks; in Brazil water shortages and excess affect depress agriculture income, but shortages have a much stronger effect than floods (Hidalgo et al., 2010). The impacts will also vary by agriculture activity due to the differences in water demand elasticities in the short and longer run, the vulnerability of farm systems, market integration and substitution. Livestock operations will not face the same risks as perennials or annual crops. Implications on land allocation and use will therefore be variable.

Table 3.1. The impact of water risks on agriculture

Type of water risk	Short-term temporary shocks	Medium-term prolonged	Long-term irreversible impacts
Quantity: "too little"	Droughts affecting rainfed agriculture in particular, and putting pressure on surface water irrigation.	Prolonged dry conditions with diminution of surface water and groundwater recharge leading to rainfed agriculture loss, limits on irrigated agriculture, affecting grass-fed livestock affected and putting pressure on groundwater systems.	Loss of rainfed and irrigated land, eliminating extensive livestock systems with limited seasonal surface water and possible severe groundwater depletion and quality issues.
Quantity: "too much"	Severe floods affecting seasonal crops	Progressive augmentation of surface water requiring drainage systems and changes in crop and livestock agriculture activities.	Excess water preventing agriculture activities, surface and groundwater flooding.
Quality: "too polluted"	Eutrophication Salinisation Other contaminations	Increased concentration and costs of treatment, new risks with uncertain treatments.	Unusable water systems-irreversible groundwater or soil contamination.

Source: Author's own work.

Impacts may also vary when considering long-term changes versus increased variability of water availability. For instance, a gradual but continuous decline in water availability, due to the reallocation of water demand or slow changes in the water cycle, will result in a similarly gradual reduction of soil moisture, leading to crop yield losses, reduced irrigated land and ultimately prevent agriculture crop cultivation. In Australia, it was estimated that water-limited potential wheat yields reduced by 27% (or 1.1%/year) between 1990 and 2015, due primarily to reduced rainfalls in the same period (Hochman et al., 2017). This evolution contributed to the observed stalled yields of wheat nationally during the same period. In contrast, a few repeated dry extreme events can also shock the soil system but be followed either by a (partial) recovery of soil moisture, or on the contrary by irreversible changes.

These differences and the large uncertainty associated with climate change make future agriculture impact assessments highly difficult especially for weather related events. Still, reviewing ex post studies provides evidence that these events can have significant effects.

Damages are especially important in developing countries. FAO (2015) evaluated the damages and losses[2] from 140 weather-related disasters affecting more than 250 000 people between 2003 and 2013 in developing countries. It found not only important damages to agriculture (84% of the economic impact of drought), but also strong declines in agriculture outputs. Moreover, economic losses to farmers tended to be transferred on to further losses in the food value chains and the rest of the economy in countries highly dependent on agriculture. Table 3.2 provides an overview of results from FAO studies on the damages and losses of selected weather extreme events to the agriculture sector of mainly developing economies. Of the 78 disasters with available sub-sector damage data, the crop subsector absorbed over 42% of total damages and losses caused by disasters. Livestock activities were slightly less affected, accounting for 34% of the total economic impact of weather-related disasters to agriculture.[3] Furthermore, the losses to agriculture vary by type of disaster. Floods and storms explain up to 93% of the damages from extreme weather events to the crop subsector. Droughts tend to impact more on livestock: 86% of the economic losses from weather-related disasters to livestock are caused by droughts.

Table 3.2. Agriculture damages and losses due to storms, floods and droughts

Type of event	Country affected	Estimated damages	Estimates losses
All extreme weather-related disasters (2003-13)	Developing economies		Losses worth USD 80 billion in crops and livestock production (333 million tonnes of cereals, pulses, meat, milk, etc.) (worth USD 80 billion) Average 2.6 percentage-point loss of agricultural value-added growth
All extreme droughts (1991-2013)	Sub-Saharan Africa		Losses worth USD 31 billion lost in crop and livestock production Food imports increased by USD 6 billion Average 3.5 percentage-point loss of agricultural value-added growth
El Niño southern oscillation event (2015-2016)	Philippines	144 083 ha of farms affected	Losses worth USD 70.8 million in crops (218 379 tonnes of crops lost (worth USD 70.8 million)
***El Niño* southern oscillation event (2015-2016)**	El Salvador	60% of maize crop destroyed	85 858 ha of maize lost or damaged
Typhoon Haiyan (8 November 2013)	Central Provinces, Philippines	USD 700 million damages to the agriculture sector 600 000 ha of farmland (crops, orchards, plantations) affected 44 million coconut trees damaged or destroyed	1.1 million tonnes of crops lost
Typhoon Koppu (18 October 2015)	Central Provinces, Philippines	USD 180 million in agriculture damage	
Heavy rainfall (October 2015)	Ono Island, Fiji		Drop in sugar cane production by 25%
Flood (2010)	Pakistan	USD 5 billion estimated in damages and losses	Agriculture sector growth dropped by 3.3 percentage points between 2009 and 2010 National GDP dropped by 1.2 percentage points
Drought and extreme cold winter (2014-2015)	Mongolia	Area available for grazing pasture reduced to cover only 60% of national herd's needs	Wheat harvest down by 40%
Drought (2008-2011)	Kenya	USD 11 billion estimated in damages and losses	Agriculture sector growth dropped by 5 percentage points in 2008 and by a further 2.3 percentage points in 2009

Source: FAO (2015).

Weather-related events can also generate important damages in developed economies (OECD, 2016). Box 3.1 reports the results of empirical studies on drought agriculture damages. They show that droughts can result in significant crop yield reductions in Europe and North America, but that the specific amplitude of damages is highly dependent on regional differences. Similar estimations did not find significant average effects of floods on crop yields in these regions. This may be partially explained by the fact that agriculture damages from floods are generally not well reported (OECD, 2016).

Box 3.1. Estimating the effects of droughts on cropland

Lesk et al. (2016) estimated the impact of droughts and floods on crop production, area harvested and yields. Droughts tend to reduce national cereal production significantly by 10.1% on average, equivalent to roughly six years of production growth. In particular, drought was linked to significant decreases in both yield and area harvested. However, no significant lasting effect was noted in the years after the disasters as production resumed normal levels immediately after the drought.

When disaggregating the data by region, Lesk et al. (2016) found that droughts had a greater impact on cereal yields, and consequently on total production, in Australia and New Zealand as well as developed economies in Europe and North America, than it did in Asia, Africa and Latin America. Indeed, cereals production was reduced by 19 percentage points in the more developed economies compared with 12.1 and 9.2 percentage points in Asia and Africa, respectively. The data did not show any significant impact of droughts on cereal production in Latin America and the Caribbean. The authors explain this difference by the fact that agriculture in developed economies is more technically developed, with seed varieties selected to make the best of normal optimal weather conditions. When the weather varies from this optimal, the yield potential is not reached. The relatively lesser yield gap from drought in developing economies is due to the larger prevalence of traditional indigenous seed varieties that still have some tolerance to naturally more frequent drought occurrences.

Even within Europe, the agriculture impact of droughts varies highly between countries. Naumann et al. (2015) estimated the relationship between drought and crop production in European countries that have not changed their border in the past 50 years. Using meteorological data to calculate several drought indices and FAO data to track grains production between 1950 and 2012, the authors posit that the relationship between drought intensity s and the average damage to crop production D can be modelled as: $D(s) = \alpha.s^{\beta}$. Declining this formula to different countries, the results show that the expected damage to crop production in Spain and Italy follows the severity of droughts according to a power law. In Germany and Portugal, the relationship between drought severity and damage to crop production is linear. In France, the United Kingdom, Ireland, Denmark, Austria, Hungary and Romania, damages to crop increase at a decelerating pace as drought severity increases. Interestingly, historical data show that crop production in Finland and Norway actually increases with drought severity.

Source: Lesk et al. (2016) and Naumann et al. (2016).

A key question relates to the long-term effects of water risks on agriculture systems: When do water risks become irreversible (see Table 3.1)? The dynamic of water risks determines the potential irreversibility of their impacts and the possible responses from the sector. One could anticipate that agriculture continues to recover under gradually worsening water conditions up to a certain threshold. This could happen, for example, with the continuing depletion of aquifers worsening to the point where it is no longer economically viable to use them for irrigation. However, it is difficult to anticipate such a threshold when crises are observed at different time intervals. For instance, three significant climatic events (droughts or floods) may happen over a few years and the next events may not happen for ten years or more, making it difficult to evaluate whether conditions have irreversibly changed.

Even if their effects may not be irreversible in the long run, extreme weather events that follow each other frequently can have lasting high impacts on agriculture production, threatening local and national food security (FAO, 2015). For example, the agriculture sector of the Philippines was affected by 75 consecutive disasters between 2006 and 2013 for a cumulated damage of USD 3.8 billion; Pakistan’s agriculture sector was also struck by recurrent disasters between 2005 and 2011 for cumulated damages of USD 8 billion; and Tabasco State of Mexico witnessed five consecutive floods in the years up to 2011 with damages reaching USD 1.2 billion. When droughts extend over several years, they impose a longer level of stress on agriculture production. Several studies have identified a significant negative impact of long drought episodes on the overall growth of the agriculture and food sector in the countries affected (FAO, 2015; UNISDR and CRED, 2015).[4]

The overall vulnerability of production systems will determine whether repeated crises lead to long-term effects. Because of their overall greater vulnerability to disasters, farmers in developing economies are more challenged than those in developed economies to find the seeds, fertilisers, machinery and technical assistance needed to start a new production season and recover from weather events.

Expected impacts for agriculture production in the three hotspot regions

Water scarcity is likely to remain an important constraint for agriculture production in Northeast China. First, rising competition for water resources is likely to negatively impact agriculture production. Urbanisation and a growing population with higher incomes will not only increase the direct demand for water but also for water-intensive industrial goods and food products. Rising incomes are expected to change food consumption patterns towards meat and highly processed goods. This may motivate farmers to increase production of livestock, which is usually more water-intensive per unit of output than crops and lead to the expansion of local agro-industries, which will contribute to raising demand for clean water. Though it is difficult to draw general conclusions from projections,[5] literature suggests that climate change may benefit certain crops in Northeast China through rising precipitation but hurt others through rising temperatures. On the other hand, higher temperatures may increase irrigation water demand (Wada et al. 2013)[6] and the projected reduction in long-term water storage in glaciers will negatively impact future agriculture production in the long run.

Several studies suggest that the effects associated with increasing future water demand will dominate the effects of climate change on the Chinese agriculture sector., including in the Northeast Combining water demand and diverse climate projections, Rosenzweig et al. (2004) find that "Northeastern China suffers from the greatest lack of water availability for agriculture" among 11 major international agriculture regions. Hezaji et al. (2014), also combining socio-economic scenarios with climate change, show that the increase in water stress in the region is very large in the future, regardless of the implementation of any greenhouse gas mitigation scenario. Tao et al. (2003), modelling both factors, find that the soil-moisture deficit would increase generally with consequent impacts on yields. Xiong et al. (2010) model climate change, water and agriculture land and find that economic drivers supplant climate effects, concluding that "there will be insufficient water for agriculture in China in the coming decades, due primarily to increases in water demand for non-agriculture uses". In part of Northeast China, rice, wheat and maize areas could reduce by up to 60% by 2040 according to their projections. Combining crop and water simulation models with climate change to capture change in climate, water availability and land constraints, Xiong et al. (2009) project a drop of cereal production by 9% (scenario B2) to 18% (Scenario A2) in 2040. None of these projections account for water quality degradation and the continued depletion of the North China Plain aquifer.

In the North China Plain sub-region, the status and use of groundwater reserves will be determinant for the future of cereal production. Irrigated activities will be threatened if the water table continues to fall (as projected in the literature). Grogan et al. (2015) estimates that without the mined groundwater[7] agriculture irrigation currently uses, crop production in the region would fall 101 million tonnes, or 10% of the national production. Additional recharge could increase groundwater if precipitation effectively increases in the future, but the lag for water to reach the aquifer may mean that it comes after much of the stock has been depleted.

Losses in productivity may also have broader consequences on rural development. Future projections suggest that income levels for rice and corn producers are particularly vulnerable. As rural incomes decline, rural to urban migration may also increase as farmers seek alternative income opportunities. The lack of sufficient drinking water and the impacts of extreme events may be additional drivers of migration.[8] By 2020, it is estimated that 30 million environmental refugees will flee water stress in China (World Bank, in China Water Risk, 2016).

The combination of climate change and groundwater depletion is also expected to affect the viability of agriculture in Northwest India. First, climate change projections consider that India's agriculture will be significantly impacted (e.g. OECD, 2015). Due to higher temperatures, rainfall variability and decreasing access to freshwater for irrigation, productivity of most of the crops in India is projected to decline by 10% to 40% by the end of the century (Shrivastava, 2016). In the Northwest region, rising mean temperature and higher frequency of extremely hot days are expected to reduce yield in future decades (Jalota et al., 2014). Considering both factors of moisture deficit and heat, CRIDA (2013) projected that irrigated rice yields would fall by about 16% in Haryana and Punjab by 2050. Wheat could be even more affected, since it is grown during the Rabi (winter-spring) cropping season, which is more exposed to drought, and because it is a winter crop particularly sensible to heat stresses (Krishan et al., 2015). Livestock will also be concerned: the Government of Haryana (2011) forecasts a 10% to 25% loss in milk production due to rising temperature and moisture deficit. Finally, the increase of mean temperatures and the intensification of monsoon rains will favour the development of pests and parasites (Hundal and Kaur, 2006).

At the same time, continued groundwater depletion may decrease farmers' resilience to droughts. Thanks to tube well irrigation, crops in Northwest India are less vulnerable to drought than other regions, ensuring them the lowest inter-annual production variability (Kawashima, 2012). However, the actual pace of groundwater depletion threatens the sustainability of this system. Seckler et al. (1999) estimate that if pumping costs become out of reach for farmers using tube well irrigation, India could lose 25% or more of its total crop production. If Punjab had no access to irrigation, the maximum attainable yield for wheat would fall by half compared to the current local yield, and by more than two thirds for rice (Bruinsma, 2003). A collapse of the groundwater irrigation system would be all the more dramatic in Northwest India since rainfed crops are particularly exposed to climate change in this region. Soora et al. (2013) found that the Northwest will suffer from the highest yield deviation in the country for rainfed rice by 2080, with a decline ranging from 7% to 22% according to various scenarios.

Possible increases in the cost to pump deeper groundwater may exacerbate farmer's losses resulting from lower average yields and production levels. In the coming decades, ICAR (2015) forecasts a 1.78% annual growth rate of energy used by irrigation pumps in the country. Although electricity subsidies reduce the cost impact on farmers—while inducing further depletion (Box 2.4 in Chapter 2)—they will face increased capital expenditures. Low-cost wells equipped with surface-mounted centrifugal pumps are not powerful enough to lift water beyond eight meters (Sekhri, 2014). Therefore, farmers have to invest in deep tube wells equipped with electric submersible pumps, costing around USD 2 500. A survey conducted in Punjab reveals that from 2006 to 2014, 54% of farmers had purchased submersible pumps and 45% invested in higher capacity motors (Walia and Sharma, 2015). From 1997 to 2007, total annual expenses on tube well infrastructures by farmers of Punjab reached about INR 15 billion (e.g. USD 362 million in 2007). At the same time, the aggregated debt of farms rose four-fold (Hira, 2009). Indebtedness and water access restrictions caused by depleting groundwater have dramatic consequences for rural development: in average, villages where aquifers have fallen below eight meters suffer from a 10% increase in poverty rate (Sekhri, 2014).[9]

Changes in water availability in the Southwest United States will affect agriculture because water is an important input for crop production and agriculture is the largest water user in the region. There is a large and growing body of literature on the impact of water scarcity on Southwestern agriculture (Frisvold and Konyar, 2012; Frisvold et al., 2013). These studies show that urban encroachment and the growing demand for water to accommodate continued population growth and restore degraded ecosystems are projected to reduce water availability for agriculture.

The combination of increased water demand, higher temperature and more volatile precipitations is expected to reduce irrigated land and agriculture water use in the region. For instance, the total amount of land irrigated at least in part with Colorado River water could decline from current levels by between 4% and 16% by 2060, primarily due to reductions in irrigated area and land conversion in Arizona (USBR, 2012). Similar reductions are expected in the case of California, where urban growth on agriculture land, with lower water requirements per area, could offset the increased water demand due to increased evaporation (CDWR, 2013 and 2014). Agriculture in the southern portion of the California Central Valley, in particular, could experience the greatest shortages, with reliability (or water supply being able to meet demand) consistently below 95% and below 50% in the hottest and driest climate scenarios (CDWR, 2013). These projections also do not account for expected reductions with the implementation of the 2014 groundwater legislation, which shall reduce groundwater use in the short run, but increase reliability of groundwater resources once implemented.

These effects will have significant impacts on agriculture production. Table 3.3 shows the results of varied projections. Overall, crop production in the Southwest United States will cover less land due to limits on water supplies and urban encroachment. Lower value, water-intensive crops, such as feed and forage crops, are likely to experience the greatest losses. Feed prices are likely to rise, thereby increasing costs for livestock and dairy producers. Additionally, climate change is likely to alter the location and productivity of pasture and rangeland, the distribution of livestock parasites and pathogens, and the thermal environment of animals.

Table 3.3. Examples of projected impacts from climate change and future water stresses in the Southwest United States

Agriculture activity	Region or states	Expected impacts	Reference
All	Southwest	Effects of 25% water reduction: Irrigation area reduced by 1.5%, increased in dryland production area. Land fallowing reduces net income by USD 65m.	Frisvold and Konyar (2012)
All	California	Irrigated land and water use decline by 20% and 21%, respectively, with revenue decline by 11% due to partial offset from higher crop prices and crop shifting. The largest reductions in crop area were for pasture, field crops, grains, and rice.	Howitt et al. (2009)
Field crops	Entire country with specific regions	By 2050, climate change (1) reduces crop yield for all field crops, except wheat and hay; (2) reduces irrigated crop area due, in part, to reductions in surface water availability in the US West; and (3) reduces the production of all crops. Higher commodity prices are insufficient to offset declining crop yields and returns, thereby reducing producer welfare.	Marshall et al. (2015)
Specialty crops	California	Changes in winter chill by 2050 "will no longer support some of the main tree crops currently grown in California", but it will have little effect on almonds and pomegranates because these crops have low chilling requirements.	Luedeling et al. (2009)
		No specialty crop really gains from warming, cherries are at the greatest risk; almonds may suffer from winter warming.	Lobell and Field (2011)
Livestock	Southwest	Warmer temperatures will likely lengthen the growing season and improve pasture productivity at higher elevations and in the North of the region, offsetting increased feeding cost rises.	Frisvold et al. (2013)
		In the South, such as Arizona, and Central and Southeastern California, higher temperatures will shorten the growing season and reduce yields.	Brown et al. (2015)
Dairy	Entire country with specific regions	Diminished dairy productivity due to heat stress: Maricopa County, Arizona, would experience a diminished dairy productivity of 18% by mid-century, compared to a loss of 4% in Tulare County, California, and 2% in Weld County, Colorado.	Mauger et al. (2015)

Source: Authors' own work based on cited studies.

The impacts of these changes on farmer livelihood, rural communities will depend on the magnitude and rate of change, as well as the ability to adapt to these changes. In an economic assessment, Frisvold and Konyar (2012) estimated that a 25% reduction in water availability in the Southwest United States would reduce regional employment by only 3%, with the largest impacts in Arizona. Howitt et al. (2014) projected that the direct, indirect, and induced job losses from the California drought would total 17 100 seasonal and part-time jobs. Actual employment data, however, found that agriculture employment reached a record-high 417 000 people in 2014 (California Employment Development Department, 2015). While agriculture employment would likely have been even higher if there had been less land fallowing in 2014, these losses were offset by a shift away from field crops that employ relatively few people per hectare of land, toward tree crops and tomatoes that employ more people per hectare (Cooley et al., 2015).

3.3. The market and trade effects of water risks in the agro-food sector

From production risks to market and trade impacts

Market responses to agriculture production shocks depend on multiple market variables. Prices do not always respond to changes in yields. They respond when production shocks are large enough. For instance, the yields of corn and soybeans in the Midwest have been found to be negatively correlated with US market prices (Dismukes and Coble, 2006), because, in this case, "most farm-level yields are closely related to area-wide production" and the area's production accounts for a significant share of world production (Ibid.). An important production shock in a non-integrated small market may lead to large price changes in that market. In contrast, large yield shocks in a limited area of a relatively open country or in a country with a small global market share will not impact prices.

Market impacts also depend on supply and demand. By impacting local food production, water risks can cause different types of market and trade effects depending on the type of product, the amplitude of the shock and the market conditions. Assuming a significant shock in a larger market for a product with relative inelastic demand (and no immediate substitute), the relative prices will rise. The unabsorbed demand may be balanced by imports from non-affected producing regions. But even a significant shock in a smaller (price taker) market may result in relative entry of competing regions products that have acquired a cost advantage.

Market effects can be either short lived or result in long-term shifts. When extreme weather events hit regions that are significant exporters of agriculture commodities, international food prices can soar on spot and future markets. For example, the international price of wheat and maize rose by 25% in June and July 2012 after summer droughts in North America and Eastern Europe, which worried international markets and affected the global outlook for cereals and soya production (World Bank, 2012). On the other hand, gradual shifts in water risks that lead to production changes can result in long term market changes.

Market effects can also propagate internationally. Liu et al (2014) explored the impacts of irrigation risks on agriculture production and the role of international trade. Their simulations focus on regions that are expected to face irrigation failures, including China, South Asian countries, and the Middle East-North Africa region. The results show that a water decline would lead to significant production declines, shift irrigated land to other areas, and result in a significant reshuffling of international trade (Box 3.2). In particular, countries of Europe, North America, South America, and Oceania, as well as non-affected Asian countries are found to increase significantly their exports towards countries at risk of shortages.

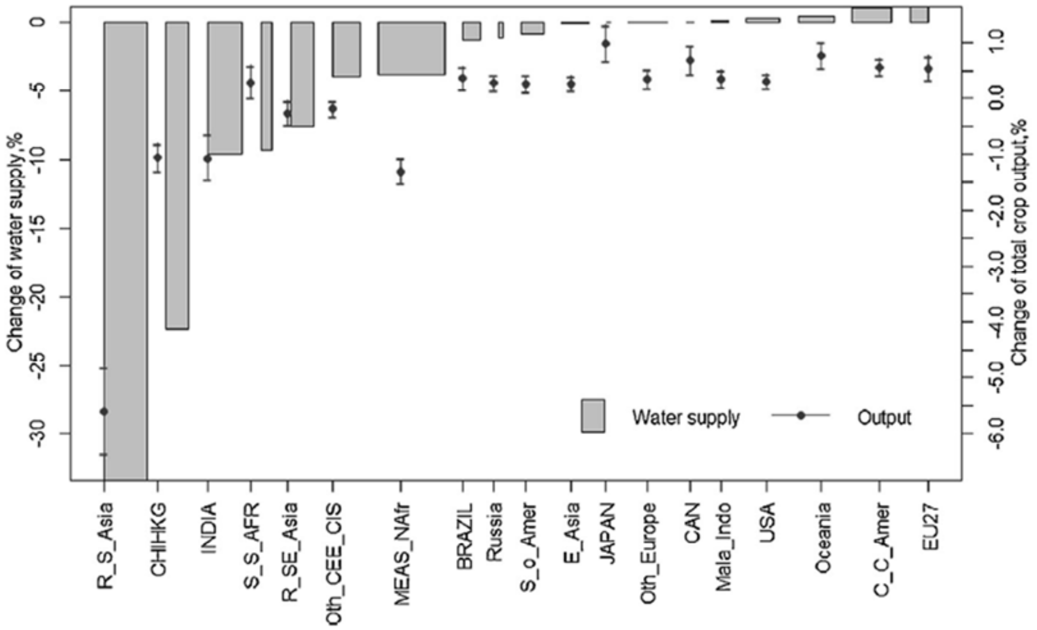
Both market and trade effects can be amplified when water risks are prevalent in multiple regions at once. Links in the global water cycles can result in multiple impacts with wider effects. For instance, the 2002-03 drought impacted wheat production in Europe, the Russian Federation, Indian and China (Bailey et al., 2015). Bailey et al. (2015) argue that multiple shocks on wheat and rice production in Asia, Europe and the United States could lead to even greater response due to policy reactions (e.g. export restrictions), with large effects on global market, short-term and long-term food security.

Box 3.2. Simulating the effects of irrigation shortfall on cereal production and international trade

Liu et al. (2014) simulated the production and trade implications of a shortfall of irrigation by 2030 due to shift in demand in the absence of policy action. The projections on irrigation water availability from the IMPACT model are used to simulate production and bilateral trade effects using a current representation of the economy with the global computable general equilibrium model GTAP-BIO-W.

Figure 3.2 shows that the simulated reduction in water supply, which focused largely on China, South Asia and Eastern Mediterranean river basins, results in reduction of total crop output production ranging from 1% to 6%.The model also finds significant changes in land use. Regions under high stress reduce their irrigated land, and given productivity differences, extend their overall cropland, while regions not subject to these stress increase irrigated cropland. The overall pressure on land (+7.6 million ha) leads to reduced pastureland and forestry in many regions.

Figure 3.2. Effects of limited irrigation on water supply and total crop production



Note: R_S_Asia: Rest of South Asia, CHIHKG: China mainland and Hong Kong, China, S_S_AFR: Sub-Saharan Africa, R_SE_Asia: Rest of Southeast, Oth_CEE_CIS: Other CIS countries, MEAS_NAfr: Middle East and North Africa, S_o_ Amer: South America, E_ Asia: East Asia, Oth_Europe: Other Europe, CAN: Canada, C_C_ Amer: Central America. Bar width is proportional to the share of output value that is from irrigated crops in the region. Error bars associated with output indicate the 95% confidence interval of the mean for a normal distribution.
Source : Liu et al. (2014).

The study shows that these shifts in production translate into some redistribution of international trade flows. Price rises associated with higher costs of production in stressed regions alter the overall balance of net comparative advantages. As shown in Figure 3.3, affected regions (China, South Asia, and Middle-East North Africa)- significantly increase their imports from agriculture regions without these stresses, such as Europe, North America, the Rest of Asia, Latin America and Oceania. If China and India still export a little more they import much more from these regions. Overall trade increase in all commodities except sugar crops, dairy cattle, processed ruminant meats, processed rice, and processed food (where water-stressed countries tend to dominate the market).

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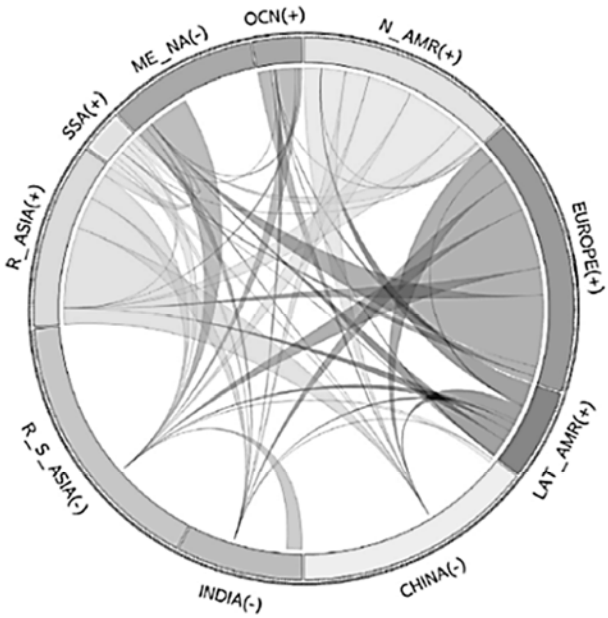
Figure 3.3. International trade shifts in maize, wheat and rice due to irrigation shortfalls



Notes: Wide sides of the arrow indicate the source of additional exports, narrow side indicates the importer; the size of the arrow represents the importance of trade shifts. The signs indicate net trade effect (+: export, - import). LAT_AMR: Latin America, N_AMR: North America, OCN: Oceania, ME_NA: Middle East and North Africa, SSA: Sub-Saharan Africa, R_S_Asia: Rest of South Asia, R_Asia: Rest of Asia.

Source : Liu et al. (2014).

These market and trade effects of water risks can impact food security in countries with large population of relatively low-income farmers or consumers. Local water driven agriculture shocks can affect poor and relatively market-isolated farmers, reducing their own staple food and revenue. At the same time, urban or market-connected consumers will suffer losses in income due to the increasing price of food. Willenbockel (2012) simulates the impact of extreme weather events on agriculture productivity market and food security in 2030 under a climate change scenario. A yield shock is implemented for the impacted country or region and the results are then measured for all regions. The results show for instance that a yield shock on cereals in North America, mimicking that in 1988, would result in world export price increases of 32% and 140% for wheat and maize respectively, impacting import and consumer prices in Sub-Saharan Africa. Similar effects are found for shocks on India and other East Asia, South America or Oceania, with different crops and amplitudes.

Sector impacts from water risks in the hotspot regions

In Northeast China, any impact on water shall have significant economic impacts in agriculture and beyond. Droughts, floods, storms and sea-level rise already generate large economic impacts in China, including in agriculture (Sadoff et al., 2015). The total loss due to water stress projected in 2030 in Northeast China could range from USD 1.1 to 1.7 billion (ECA, 2009).

Shifts in food demand due to a growing population and changing consumption patterns will likely increase water stress for agriculture. Though China’s population may peak in 2030, the gap between food demand and supply was estimated to be around 68 million tons in 2040 (Yao, 2007). Shifts in consumption patterns may increase demand for water-intensive products, such as meat and dairy. Estimates for East Asia suggest that per capita consumption of meat will increase 38% by 2030 and 60% by 2050 (FAO, 2012). The projected increase in milk and dairy demand is even higher–48% by 2030 and 68% by 2050. Of course, the impact on water and trade depends on whether future demand is met by domestic production or imports. As livestock is very water intensive due to feed the decision to rely on domestic production would heavily intensify water stress if located in the Northeast. However, recent increases in meat and milk imports suggest trade may be at least part of the solution.

Collectively, changes in supply and demand may impact China's international trade positions. If agriculture productivity growth in the Northeast declines due to water scarcity, China may become less self-sufficient and increase imports. Although China has managed to deal with production shortages in the last years, increasing demand for food and feed will make it harder to rely on domestic production. In particular, further imports of water-sensitive grains, such as rice and corn, will be needed. Large stocks will only be able to buffer production gaps for a limited time. Assuming stable world food prices, this would increase China's already-rising import demand on global markets in the long run. Moreover, the rising trends in meat imports hint towards further reliance on global markets for meat and dairy products. At the same time, improving conditions for wheat and potato production could shift consumption patterns and exports of these crops.

Northwest India's agriculture sector impact may be significant because of the importance of the region in national supplies and exports of grains. A production drop in this region could significantly affect production and food security in India, since Punjab and Haryana supply 50% of the federal rice stock, and 85% of the federal wheat stock (Shiao et al., 2015). This food grain contributes to the national public distribution system through "fair price shops", providing subsidised food to poor households in the whole country, as required by the 2013 National Food Security Act. In 2013 approximately 800 Million people benefited from this policy, which represents 67% of Indian population (The Times of India, 2013). A cut in the main domestic rice provision source, or increased uncertainty in agriculture outputs of the Northwest, could also lead India to reduce its net exportations in order to support governmental stocks. India is currently the second top rice exporting country and will stay a major rice exporter, even if its world share is expected to decrease by 2024 (OECD-FAO, 2015). In the recent past, the volume and composition variations in India's rice stocks had enough significance to affect commodity prices at a global scale, as during the 2008 global food crisis (Mohanti, 2016; Childs and Kiawu, 2009).

In the Southwest United States, increased competition for more variable and uncertain water supplies will undoubtedly affect the agriculture sector. In addition to California's leading role in agriculture productivity and consumption, agriculture exports from the state have exceeded USD 18 billion annually since 2012 (CDFA, 2015). Water shortages and reallocation will affect production and exports, magnifying local impacts across the global stage (MacDonald, 2010). Field crops, livestock and dairy products, the most affected activities—due in part to a reallocation of water to high value specialty crops—represent a significant share of exports. In 2014, California's exports of dairy products, beef and related products, rice, cotton and hay amounted to USD 4.2 billion or 19.5% of the state's total agriculture export value (CDFA, 2015). Still, given the large number of variables affecting future agriculture productivity, including irrigation efficiency, crop shifting, improvements in crop yields, variability in global markets, and demand generally, it is extremely difficult to project the possible economic impacts of long-term drought and water reallocations beyond the region.

Local agriculture water risks can impact prices and trade: Illustration from a simulation of the international effects of water risk in the three hotspot regions

To complement the assessment of agriculture water risks impacts, a series of simulations of water risks is conducted in the three hotspot regions, using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) version 3.1 (Robinson et al., 2015). The objective of the simulations is to assess the possible national and international market effects such risks might have in the future. Due to the difficulty of modelling a large range of water risks in each region, and the uncertainties they face, the exercise is designed as "water stress test" of the agriculture system rather than a set of accurate projections.[10]

The four main scenarios include a baseline with no water or climatic shocks (noted S0); the introduction of two types of gradual irrigation stresses in the three regions, aiming to capture (a) a reduction in usable surface water (mimicked by lowering basin efficiency, noted SB) and groundwater for agriculture (noted SG); and (b) exogenous yield shocks in particular years on key agriculture activities in the hotspot regions to reflect cyclical extreme weather events, and more specifically droughts (noted SD). These four scenarios (S0, SB, SG, SD) are then combined with the introduction of two global climate change simulations using regional climate projections RCP 8.5 IPSL S1 and Hadley S1. The full specification of scenarios is described in Annex 3.A1.2 and a background on extreme events used to design the scenario SD is provided in Annex 3.A1.3. Results are presented below as relative differences in production, international trade and prices between the different simulations and the baseline with no shock.

There are several caveats to the simulations. First, the selected hotspot regions are defined based on selected river basins, so they may not be exactly fit the previously defined hotspots. Second, the shocks are proxy water stresses rather than realistic water shocks, as per IMPACT 3.1 version, which does not include a full integration of hydrogeological systems with agriculture (see Annex 3.A1.2).[11] Third, each of the exogenous shock parameter was set up to stress the system in, but it may not reflect actual shocks. Fourth, because hydro climatic shocks are generally not independent, the scenario proposed do not account for water-related events that could happen in other regions of the world. Fifth, the two climate scenarios present two possible projections among other possible. The results of these projections should be subject to cautious interpretation, because of the lack of reliance of regional precipitation projections (Liu et al., 2014). Lastly, because IMPACT is a partial equilibrium model, price and trade effects are based on excess supply and demand equilibria at the global scale; they do not capture changes in bilateral trade relationships and they do not take into account of other sectors' feedback loops.

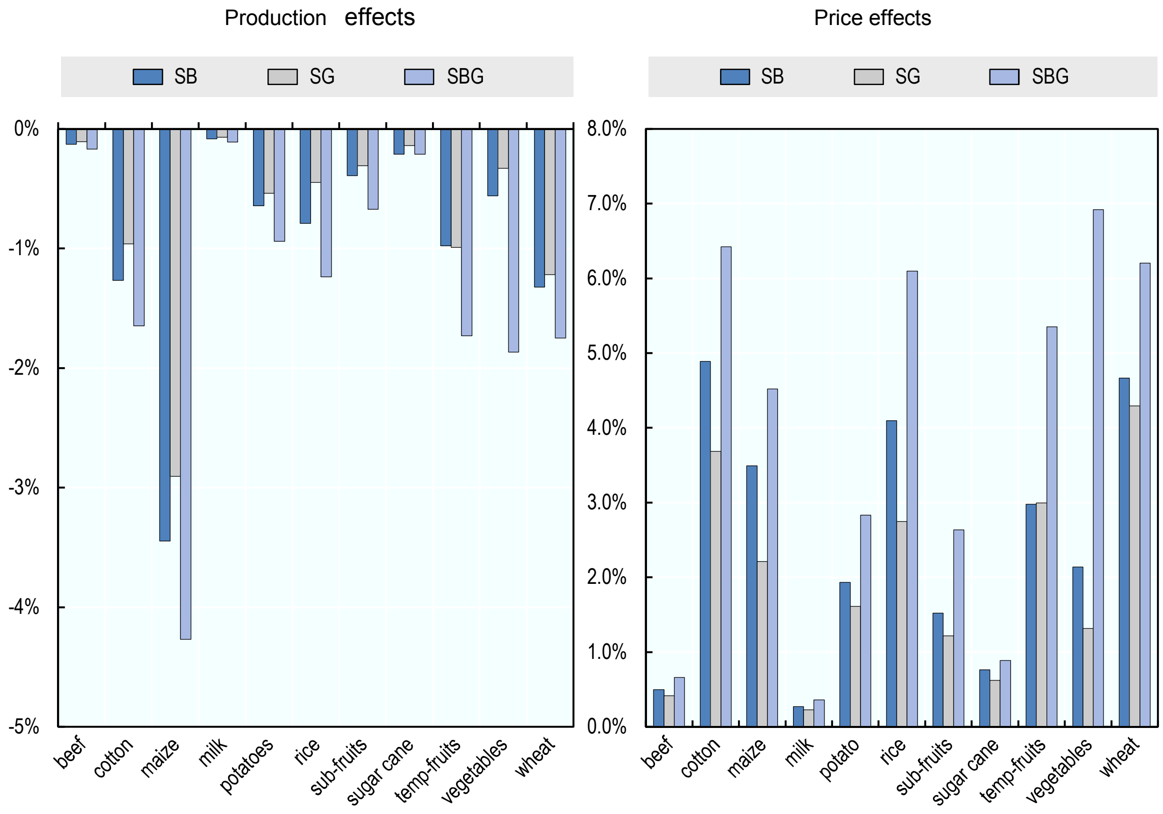
The main results are presented at the global scale, for hotspot countries and for trade partners for the two categories of risks: gradual water stresses and drought. Further results, including those combining some of the shocks with climate change projections, are shown in Annex 3.A2.

Gradual irrigation stresses in the three hotspot regions reduces field crop fruit and vegetable production in China, India, and in the US, increasing prices and affecting international trade in these products

The basin water deficiency (SB) and groundwater (SG) scenarios are run separately and in combination (SBG) simultaneously in the three hotspot regions and gradually implemented until 2050 without and with climate change. The results reported here pertain to the year 2050 and are outlined for key agriculture activities identified as possibly affected. Unless specified otherwise, the results are presented compared to the baseline S0 with no water or climate change shock.

Globally, irrigation stresses in the three regions decline global production in selected commodities compared to the baseline. Maize production is the first impacted with reductions of 3% to 4% (Figure 3.4, left). Cotton, wheat and temperate fruit production are also affected with declines over 1% of global production. Vegetables and rice are mostly affected under the combined scenario SBG. These losses are significantly amplified when adding the two climate change projections (Annex 3.A2). Maize production then decreases by close to 25% and 20% globally under the IPSL and Hadley projections, respectively. Cotton is the second activity affected with impact between 8% and 10%. Potato, rice and fruit follow with effects around 5-7%. Irrigation shocks only marginally affect these climatic losses; the SG scenario leads to lower effects than the SB scenario, and losses under the combined SBG scenario are greater than those with the individual scenarios.

Figure 3.4. Global production and price impacts with irrigation stresses

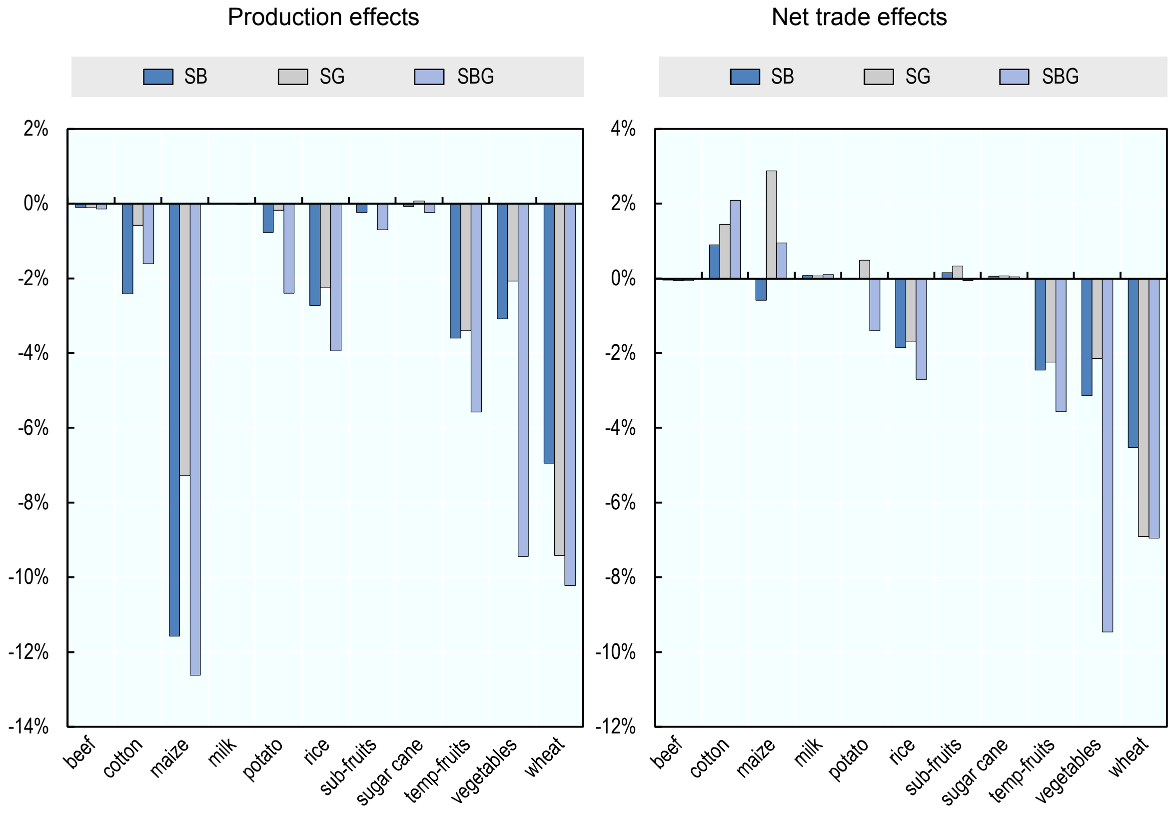


Note: Sub-fruits are subtropical fruits, temp-fruits: temperate fruits.
Source: Results from IMPACT simulations.

Consequently, global prices increase for directly concerned commodities (Figure 3.4, right), to a different degree. Heterogeneous price elasticities of excess demand for different products translated into a stronger price impact on wheat, cotton, rice and fruits than on maize. Overall, the price increases for these five activities range from 3% to 4.5% for the scenario SB, 2% to 4% for SG, and 4% to 7% for the combined shocks SGB compared to the baseline S0. As shown in the Annex 3.A2, climate change projections amplify absolute price effects significantly (over 10% increase for most activities). Maize, cotton and rice are the most affected with over 30% price increase under any scenario and projection. If these increases do not match the price impacts of recent food crises (1974, 2008, see Headey and Fan, 2011), they still would bear significance on the three countries and associated markets.

In China, the gradual deterioration of basin water efficiency and groundwater reserves in the Northeast and the two other hotspot regions affects the production and trade of cotton, maize, potato, rice, wheat, fruits and vegetables in 2050 (Figure 3.5). The largest negative impact is seen on maize and wheat, whose production drops by more than 10% under the scenario SG and the combined SBG scenarios. These effects result largely from yield losses of 8% to 10% depending on the scenario. The production of vegetables, fruits and rice also decline to a lower degree. These gradual stresses also result in a decline in the net trade in rice, fruits, and wheat (less than a 1%), and vegetables (up to 3% for the SBG scenario).

Figure 3.5. Relative changes in production and net trade in China by 2050 with gradual irrigation stresses



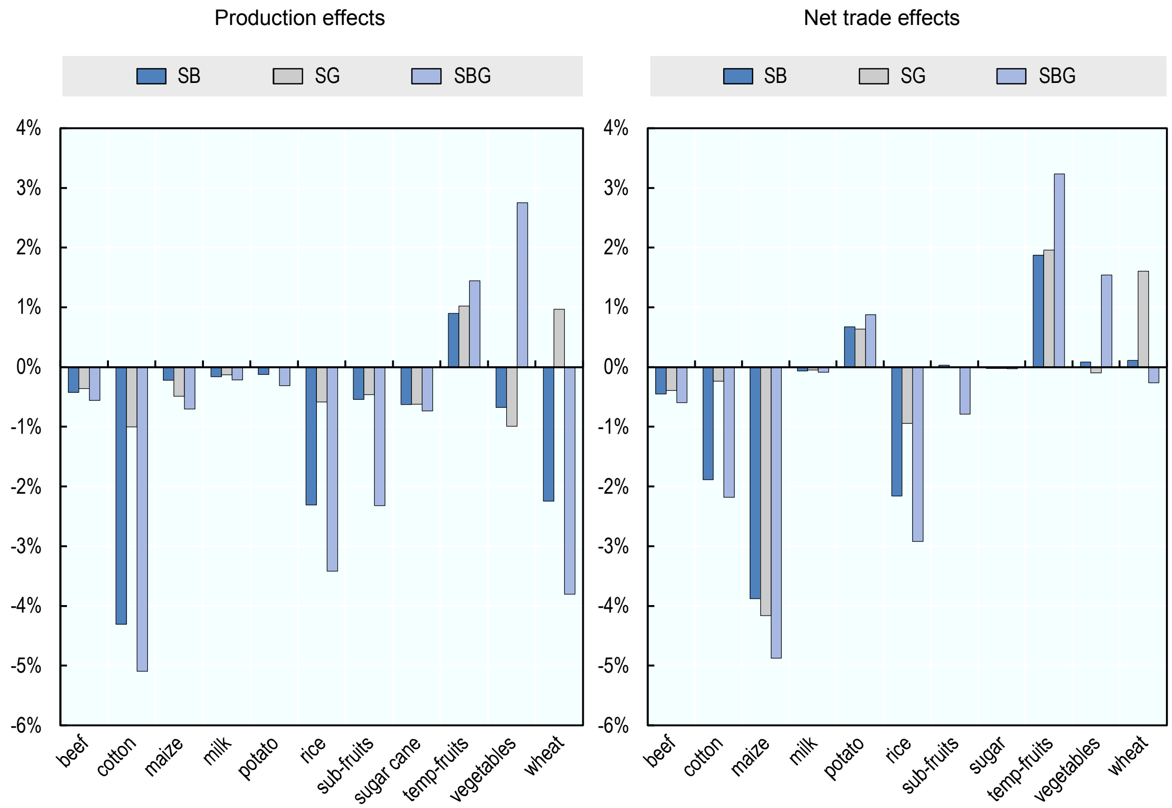
Note: Sub-fruits are subtropical fruits, temp-fruits: temperate fruits. Net trade changes may imply shifts in the direction of trade flows.
Source: Result from the IMPACT simulations.

Adding the two global climate change projections, however, alters the national production effects for most agriculture activities. Under the Hadley projection, the production of milk, potato, cotton and fruits in particular increases significantly—potentially due to temperature and precipitation changes in China and a change in relative competitiveness—but these effects do not prevent relatively large losses in the production of maize (by 16% to 22%, see Annex 3.A2). Under the IPSL scenario, maize production drops by 23% to 30%, while other changes remain small. Climate projections are generally more positive under the SG scenario than the SB one, with the SBG still being the most negative.

In India, gradual irrigation stresses in the Northwest region impact cotton, wheat and rice production, but these effects are lower than those observed in China and there is significant variation across the types of imposed irrigation stresses (Figure 3.6). This difference may be partly due to the fact that the Northwest (for rice or wheat) may not represent as large a national share of agriculture production as the Northeast China (for maize and wheat). Scenario SB reduces the production of cotton, rice and wheat by 2 to 4%, when the groundwater scenario reduces these productions much less (1% and even positive effect for wheat). These differences are due to the modelling differences -groundwater stresses lead to expanded areas for wheat and cotton at the national level and the respective competitiveness of the different crops in the three regions in this scenario. The three crops are most affected, however, under the combined scenario SBG. Under the same scenario, there is an increase in the production of vegetables responding to the significant production decline in China.

The effects on international trade only partially reflect these changes. Cotton and rice exports are reduced, but the maize trade balance is the most negatively affected. Following a small production increase, India also increases its trade balance for temperate fruits.

Figure 3.6. Changes in production and net trade in India by 2050 with gradual irrigation stresses



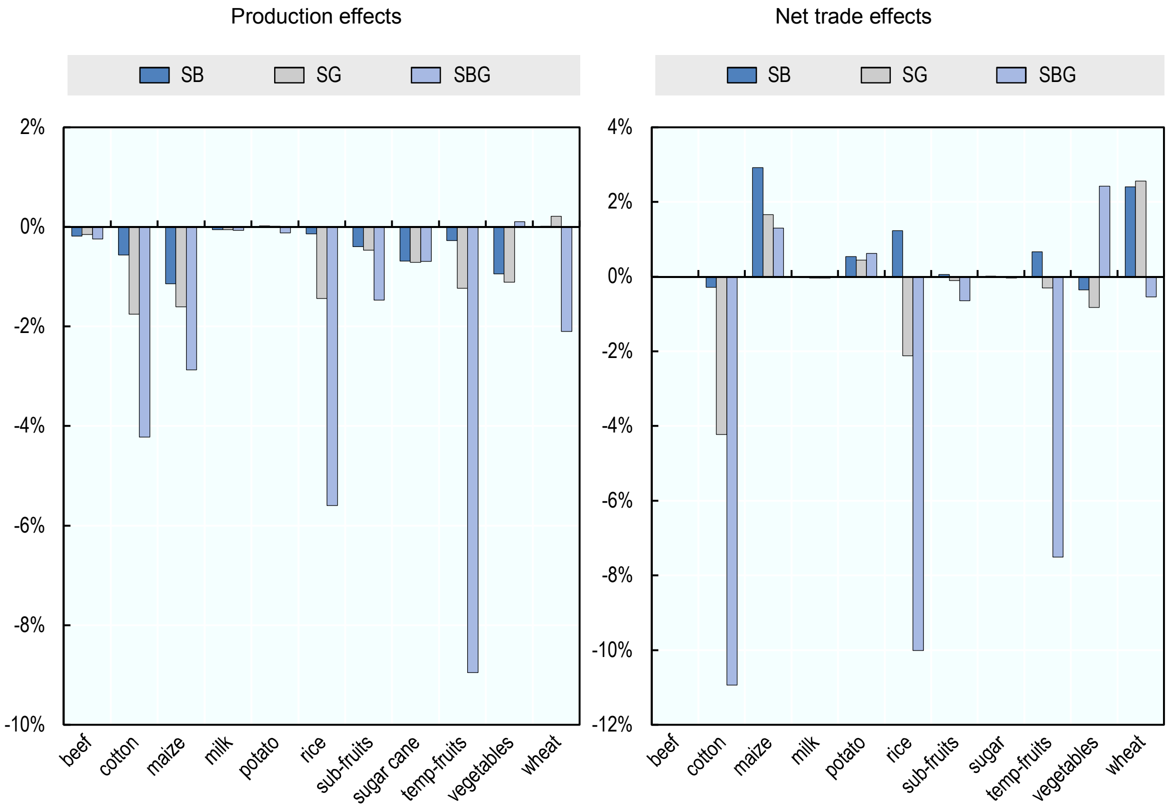
Note: Sub-fruits are subtropical fruits, temp-fruits: temperate fruits. Net trade changes may imply shifts in the direction of trade flows.
Source*:* derived from IMPACT simulations.

The results of the two climate change projections differ widely across projections (Annex 3.A2). The Hadley projection highlights losses of cereal production by over 20%. Wheat and vegetables production decline by over 25%, maize, rice and sugar cane by 20% or more, and cotton by 15%.These impacts marginalise the role of irrigation stresses. The IPSL projection, on the other hand, projects very small losses in the production of rice, wheat and vegetables, with a 10% production gain in maize production.

In the United States, irrigation stresses in the Southwest impact the production and trade of fruits, cotton, maize and rice. Production effects, however, only exceed 2% with the combined scenario SBG (Figure 3.7). In contrast with the other two countries, the groundwater scenario SG leads to relatively higher damages than SB, probably because the basin efficiency parameter starts at a much higher level than in China and India. Under SBG, fruit production, which is prevalently produced under irrigation in the Southwest (Cooley et al., 2016), declines by almost 9%. Exports drop by almost 11% for cotton, by 10% for rice and by 7.5% for fruits. Net trade for maize and wheat on the other hand increases slightly due to a relative gain in competitiveness compared to the other two shocked countries.

Climate change projections consistently lead to further production losses in maize, rice and cotton production under the three irrigation stress scenarios (Annex 3.A2). The amplitude of these effects is larger under the Hadley projection than the IPSL one. Under the IPSL projection there is an increase in potato production. The US net trade balance is reduced significantly in multiple activities, with significant losses especially for rice (-35%) and cotton (-20%).

Figure 3.7. Changes in production and net trade in the United States by 2050 with gradual irrigation stresses



Note: Sub-fruits are subtropical fruits, temp-fruits: temperate fruits. Net trade changes may imply shifts in the direction of trade flows.
Source: Derived from IMPACT simulation results.

The price impacts also trigger responses in international markets, leading to changes in net trade balances across countries, particularly for cotton, maize, rice, and wheat. The main impacts of the different scenarios, i.e. irrigation stresses with and without the two climate projects, are reported in Table 3.4 for the most significant relative trade effects for the different commodities. The complete table of effects is presented in Annex 3.A2. Major changes are foreseen in particular in the cotton, maize, rice and wheat markets, consistent with the most significant production losses observed in the three hotspot countries. Major agriculture exporters, such as Australia, Brazil, Chile, or European nations, gain in global market shares. In contrast, beef and dairy markets remain largely unaffected.

Table 3.4. Largest relative net trade effects of the irrigation stresses and climate change scenarios by commodity[1]

Commodity	Scenarios	Most important net trade effects	Countries
Cotton	All except Hadley projections	+49% to +194%	Australia-NZ
	All scenarios	+1% to +21%	China
	All scenarios except SB	-11% to -43%	United States
Maize	All scenarios	+1% to +33%	Australia-NZ
	All scenarios	+1% to+ 25%	Brazil and Chile
	All scenarios	+1% to +22%	EG4
	All scenarios	-4% to -7%	India
	All scenarios	-8% to -23%	Japan
	All scenarios	-9% to -81%	Russia
Rice	All scenarios	+9% to +15%	Brazil
	All scenarios	+3% to +37%	E17
	All scenarios	+1% to +34%	Chile
	All scenarios	-1% to -15%	India
	SBG scenarios	-10% to -66%	United States
Wheat	All scenarios	+3% to+ 39%	Russia
	SB, SG, SBG scenarios	+4 to +5%	EG4
	All scenarios	-3% to -18%	Australia-NZ
	All scenarios	-5% to -22%	EU-7
	SG scenarios	+2 to +6%	India
	SB, SG, SBG scenarios	-5% to -7%	China
	All scenarios	-7% to -97%	Brazil
	SB, SG, and SBG (no climate projection)	+12%	EU-7
	All scenarios	-30% to -43%	E-17
Vegetables	SGB scenario	+4% to +31%	Chile
	SGB scenario	+3% to +16%	Japan
	All scenarios	-2% to -12%	Russia
	SB, SG, and SGB (no climate projection)	-13% to -17%	Canada
	All scenarios	+4% to +58%	Chile
Temperate fruits	All scenarios	+2% to +7%	India
	SGB scenarios	-7.5 to -11%	United States
Sugarcane	All scenarios	+1 to +11%	Brazil and Chile

Note: 1. The absolute size of trade change depends on the initial volume of trade flows, net trade changes can result in shift in the direction of trade flows, which should be accounted for when interpreting these results. EG4: France, Germany, Italy, United Kingdom, E17: Austria, Belgium, Luxemburg, Netherlands, Ireland, Spain, Portugal, Greece, Czech Republic, Slovakia, Poland, Hungary, Estonia, Finland, Denmark, Sweden Slovenia; EU7 : Bulgaria, Lithuania, Latvia, Croatia, Malta, Cyprus, Romania.

Note by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

Source: Derived from IMPACT simulations.

These simulations show that irrigation stresses are bound to affect field crop activity first and foremost; furthermore, maize and wheat are projected to be more impacted than rice in the three regions. At the same time, cotton and temperate fruit, water-dependent crops that are largely produced in the three countries, also face significant production losses. Basin deficiency scenarios lead to greater impact than those representing groundwater depletion, except in the United States. Climate change projections alter the impacts especially in China and India, although both still face losses in field crops. International prices increase by 2% to 6% for cereals, and trade is reshuffled, especially for field crop commodities–cotton, maize, rice and wheat- that are largely produced in the three hotspot regions.

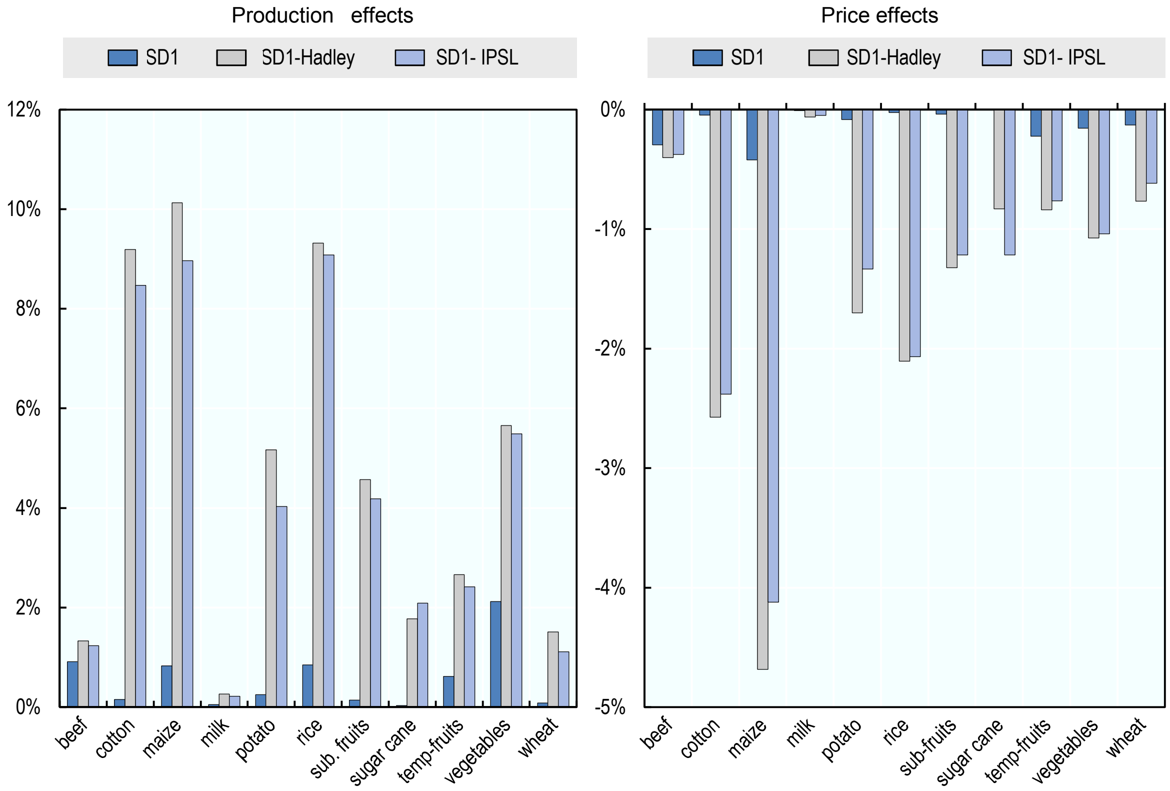
Drought scenarios: Limited impacts of a drought in the US Southwest, measurable field crop production and trade implications of a combined drought in Northeastern China and Northwestern India

This scenario investigates the impact of extreme events, in particular due to changes in precipitation cycles. A rapid assessment of the frequency, duration and impacts of El Nino Oscillations (ENSO), Pacific Decodal Oscillations (PDO) and Indian Ocean Dipole (IOD) in the three hotspot regions was conducted, based on past and recent trends (see Annex 3.A1.3). This assessment was used to provide plausible types of events affecting the hotspot regions in the future. Two sub-scenarios are run: scenario SD1, modelling a drought in the US Southwest around 2021, and scenario SD2 whereby China and especially India are subject to drought around 2030.

Given the lack of adequate modelling tools to assess the full impact of droughts, exogenous yield shocks are modelled in each of the concerned region for key agriculture activities (as explained in Annex 3.A1). It thereby replicates the exercise conducted by Willenbockel (2012). The main results are shown below, with some complements in Annex 3.A2.

Under scenario SD1, a drought in the Southwest United States in 2021 induces significant reduction of yields mostly of field crops (Annex 3.A1.2). The drought is insufficient to induce significant impacts on global markets (Figure 3.8 right). Global production impacts are significant only when combining the drought with climate projection, resulting in production declines for maize, cotton and rice (Figure 3.8 left). World prices for vegetables increase by 2% under the drought, and much more for maize, cotton and rice under climate projections (over 8%).

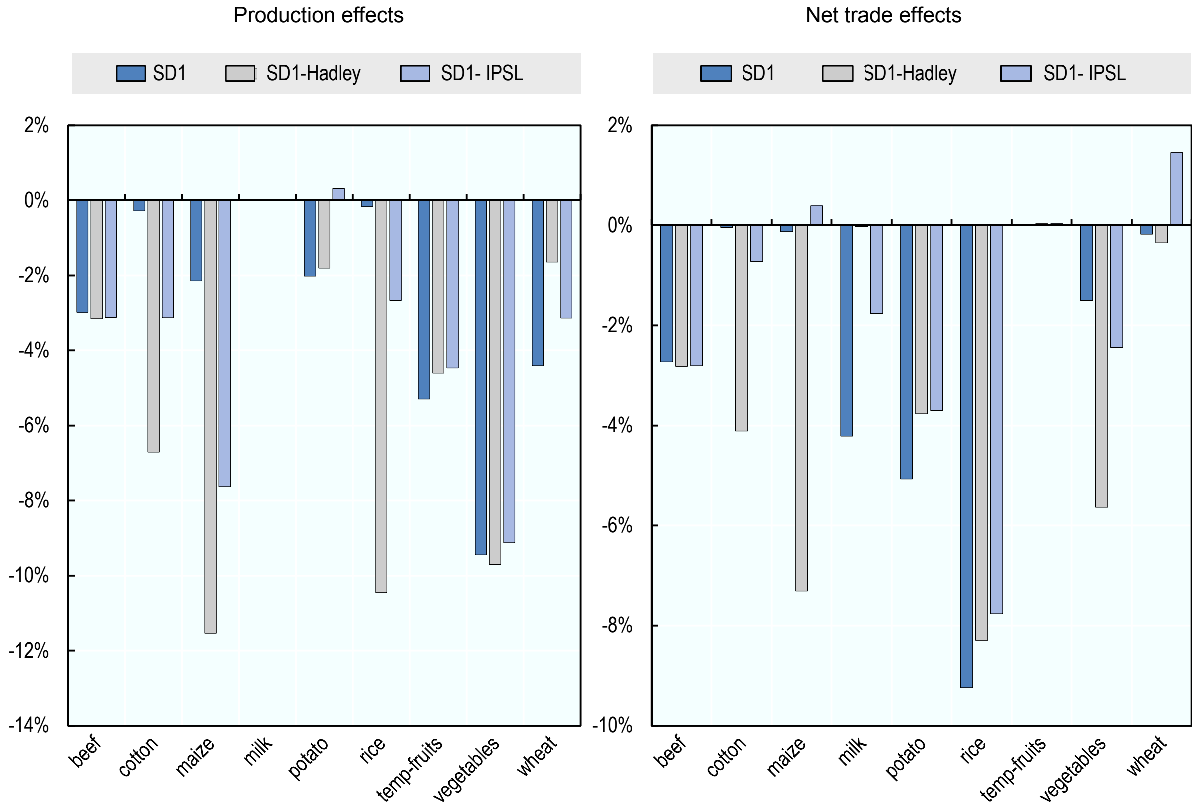
Figure 3.8. Changes in global production and world prices with a drought in 2021 in the US Southwest



Note: Sub-fruits are subtropical fruits, temp-fruits: temperate fruits. Net trade changes may imply shifts in the direction of trade flows.
Source: Derived from IMPACT results.

The imposed yield shock in the Southwest United States leads to a reduction of production of the relevant activities in the United States, particularly vegetables and fruits (-8% and -6%, respectively), given the importance of the region to their national production (Figure 3.9).[12] Beef production is also reduced by 3%. Similarly, this leads to significant reduction of trade in fruits and vegetables, and to a lesser extent beef. The trade balance of wheat is also reduced by 4%. The drought production effects are stronger than that of climate change for the main affected crops.

Figure 3.9. Changes in production and trade in the United States with a drought in 2021

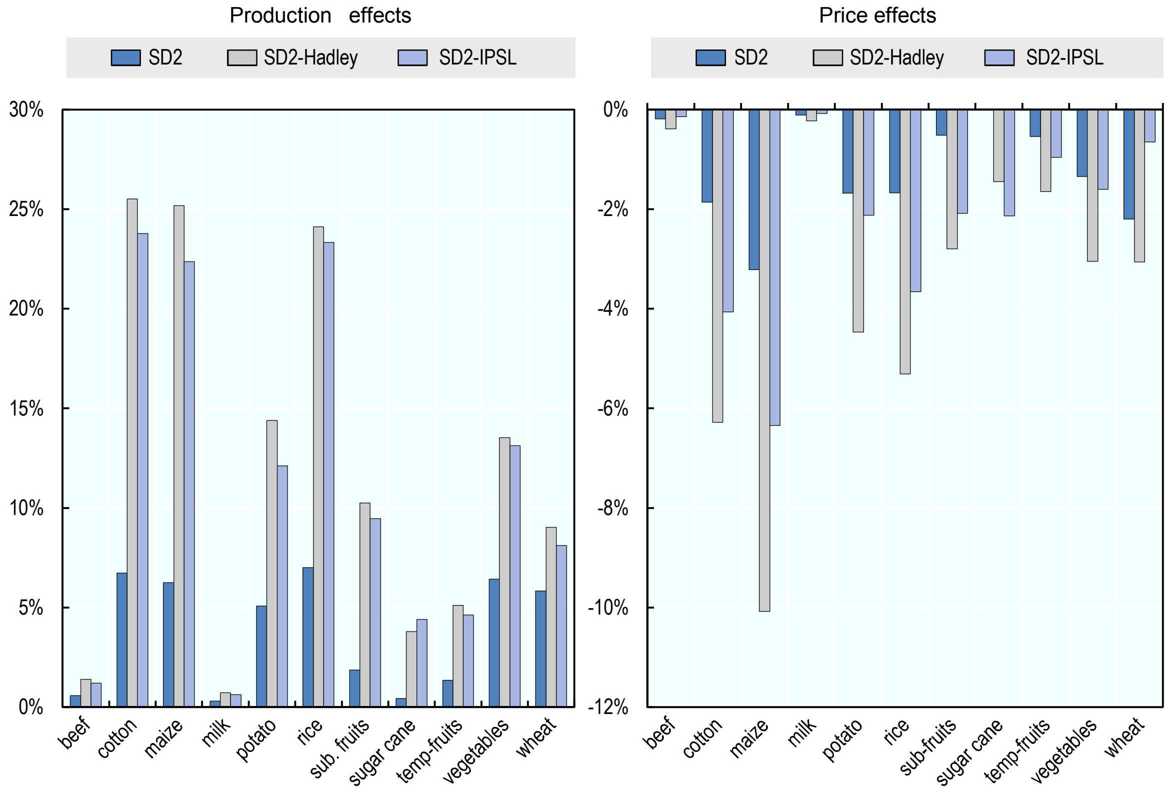


Note: Temp-fruits are temperate fruits. Net trade changes may imply shifts in the direction of trade flows.
Source: Derived from IMPACT results.

International effects from the SD1 scenario are limited. In particular, the 2021 Southwest United States drought affects agriculture production in China and India marginally relative to the baseline or climate projections (Annex 3.A2). Other countries gain small increments in market shares and limited reshuffling derived from price increases. Naturally, adding global climate change projections induces much larger changes in trade.

A drought in China and India in 2030, designed to reduce yields of several crops (Annex 3.A1.2) also translates into production losses of field crops. Losses of 2% to 3% of world production for wheat, cotton and maize (Figure 3.10) trigger price increases by over 5% for these crops as well as rice, vegetables and potatoes. These impacts are amplified with climate projections; e.g. price increases over 20% for cotton, rice and maize.

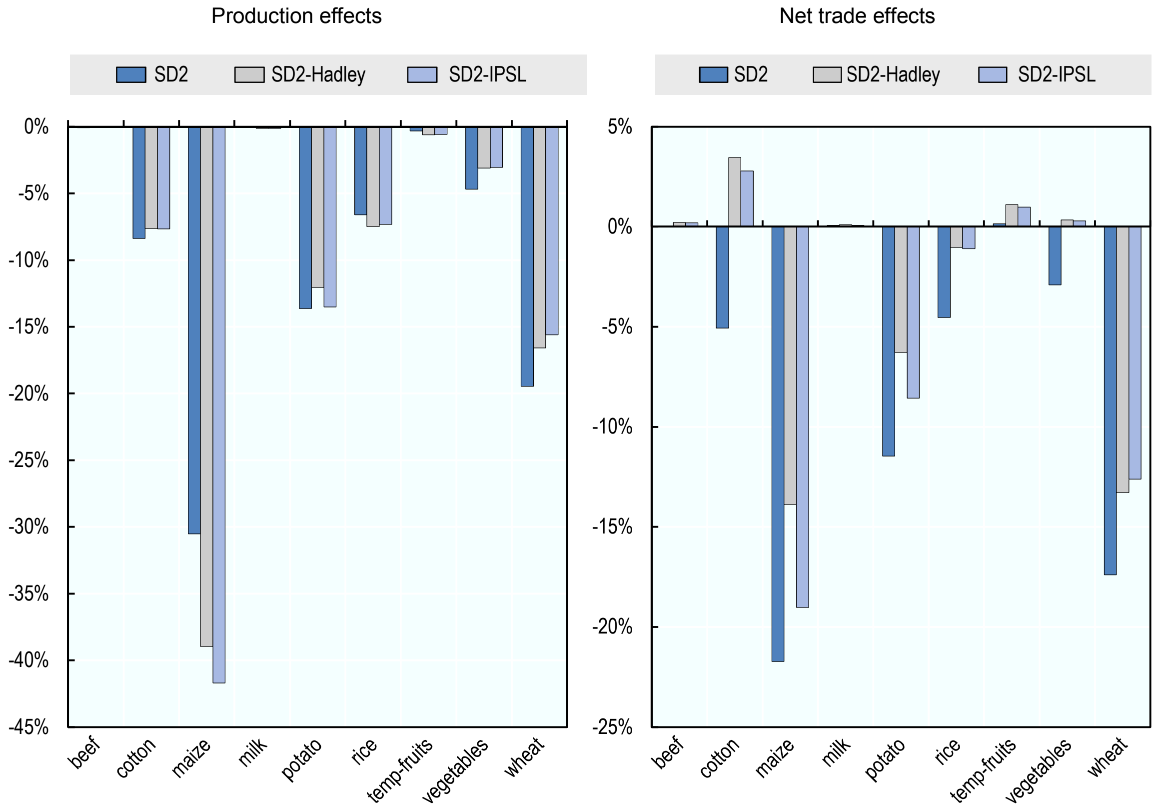
Figure 3.10. Changes in world production and prices with a drought in NE China and NW India in 2030



Note: Sub-fruits are subtropical fruits, temp-fruits: temperate fruits. Net trade changes may imply shifts in the direction of trade flows.
Source: Derived from IMPACT results.

As modelled, the drought in Northeast China does result in significant losses in production of maize and wheat, cotton and potato (exceeding for instance the 2.5% grain production reduction of the 2002-03 drought in China see Annex 3.A1.3) (Figure 3.11). These impacts induce a reduced trade balance in maize, potatoes and wheat. In both cases, the drought impacts are similar to that of climate change projections.

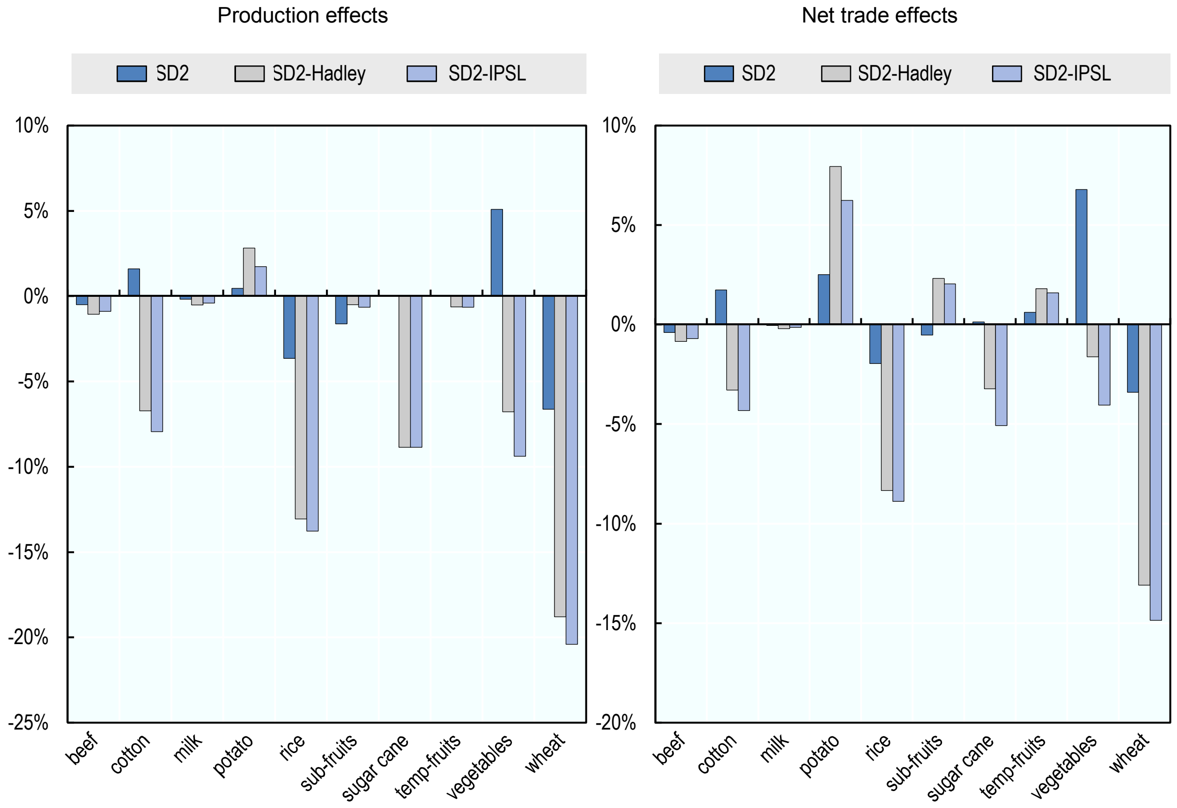
Figure 3.11. Changes in production and trade in China with a drought in Northeast China and Northwest India in 2030



Note: Temp-fruits are temperate fruits. Net trade changes may imply shifts in the direction of trade flows.
Source: Derived from IMPACT results.

In contrast, India is still more impacted by climate change than by the drought (Figure 3.12). Wheat and rice are the most affected by drought and climate change. The impact on wheat is similar to that reached in the 2015 drought (Annex 3.A1.3). Cotton and vegetable production increase under the drought and decline significantly under the climate change projections. These results are directly translated into net trade effects.

Figure 3.12. Changes in production and trade in India with a drought in NE China and NW India in 2030



Note: Sub-fruits are subtropical fruits, temp-fruits: temperate fruits. Net trade changes may imply shifts in the direction of trade flows.
Source: Derived from IMPACT results.

The drought in China and India in 2030 affects other countries' trade balance more than the 2021 drought in the Southwest United States (Annex 3.A2). Significant trade effects are found in large countries especially for the most impacted commodities. The reduction of the trade balance for cotton in China results in increased of cotton exports by other countries, including Brazil (+6%), and Australia (+143%). Significant changes are also found in the maize market with increase in exports from Brazil and from the United States (+7%). Net trade increases are spread out across countries for rice, potatoes and vegetables. The lowering of the trade balance of wheat in China and India also creates room for competitors, with an increase in net trade by 6% to 7% in Europe, the Russian Federation, Canada and the United States.

The results of this exercise demonstrate that weather shocks in key agriculture regions can lead to significant temporary shocks on the market of water dependent crops, but that the amplitude and distribution of impacts will clearly depend on the region affected. The shock in the Southwest United States is largely absorbed internally, while shocks in Northwest India and Northeast China can trigger market and trade implications. Market volatility will clearly increase faster with shocks in large production areas for crops that are subject to water risks. At the same time, these simulations indicate that production shocks may be foreshadowed by the impact of climate change in vulnerable areas. Unlike the simulated shocks, which were implemented in three regions, climate change affects all countries and regions, so the effects on competitiveness are likely to be different. Furthermore, because climate change affects not only water but also temperature it is projected to have stronger effects at least in some countries.

Nevertheless, the literature remains undecided as to whether gradual changes versus extreme shocks will be most significant. Empirical studies using past data have shown that gradual warming could have less impact than inter-seasonal variation and weather events, at least in some locations (Carleton and Hsiang, 2016). For instance, Fishman (2016) showed that precipitation variation offsets the heat effect of models in India. Projections remain unable to capture both phenomena, so the validity of their projected impacts, particularly in agriculture, is still questionable (Carleton and Hsiang, 2016).

3.4. Broader food security and socio-economic concerns

A third type of impact regroups food security and socio-economic concerns, which can affect non-hotspot countries or trading partners thereof. This section succinctly reviews two increasingly observed pathways from agriculture water risks to broader international consequences. First, long-term water risks threatening local food security is manifested by foreign land purchases by relatively poorly water endowed but well capital endowed countries. Second, countries with a large agriculturally dependent population can be subject to social unrest and important migratory movements of population with regional, continental or global implications. These effects do not concern all three hotspot regions, but they apply to multiple other agricultural regions that are increasingly subject to water risks.

Agriculture water risks and foreign land purchases

Water resource has progressively become an important driving factor in international land investment strategies (Pearce, 2013). Rising demand for agriculture production, following the 2008 food crisis, and long term rising water risks have contributed to fuel the observed multiplication of land purchases or long-term leasing contracts (United Nations, 2010; von Braun and Meinzen-Dick, 2009). Interest in such transaction stems from unequal land and water endowment, originating especially from water-poor countries,[13] such as Gulf States, but also from countries with large population such as China or India concerned with broader food security concerns by (Ibid.), and from private companies in Europe, North America, South Korea or Japan (Smaller and Mann, 2009). These investments take place on a wide range of countries; most transactions focus on developing countries especially in Africa, but some are also taking place in developed countries (Smaller and Mann, 2009).

Foreign land purchase is mostly undertaken by private companies, such as agribusiness, and investment banks that anticipate a growing value for access to fertile land linked with freshwater, with the purpose of local consumption or exports. At the same time, governments are often involved either directly or through state-owned entities, taking an active part in negotiations, with the objective of responding to their own internal food demand (von Braun and Meinzen-Dick, 2009). For instance, in 2008, Saudi Arabia shifted its strategy from mining its groundwater for agriculture irrigation to investing into water-endowed foreign land for food and feed procurement by establishing the “King Abdullah initiative for Saudi agriculture investment abroad” (Smaller and Mann, 2009).

If some of these transactions may provide opportunities and can be considered as a specific type of foreign direct investment, many others raise issues about property and water rights, leading to tensions or even conflicts within local populations (Zetland and Möller-Gulland, 2012). Some perfectly legal transactions may potentially worsen long-term water risks in hotspot areas (see Box 3.3). In other cases, they may threaten long-term food security by giving land and water rights away, often without assessing the current and future consequences for agriculture or water users (Skinner and Cotula, 2011; United Nations, 2010; Woodhouse, 2012). These deals also can generate broader political conflicts, as observed in Madagascar (von Braun and Meinzen-Dick, 2009).

Box 3.3. Investing in irrigated land in a productive hotspot region: Producing hay in the Southwest United States

Several recent land investments were made by large Gulf State companies in the Southwest United States. In particular, Almarai, the largest dairy company in Saudi Arabia, bought 5666 hectares (14 000 acres) in California's Palo Verde Valley and in Arizona to grow and export back alfalfa for cattle feed.

Both acquisitions were explicitly pursued to alleviate agriculture water shortage risks. Alfalfa is a water intensive crop whose cultivation has been banned temporarily in Saudi Arabia because of water shortage, prompting Almarai to look for foreign land with more secure water. Despite the Southwest facing its own water challenges, the company ensured that it could benefit from its productivity while keeping a steady flow of water. To do so it purchased land in with senior water rights in California, with priority over the Colorado River Basin. And in Vicksburg, Arizona, it purchased quasi deserted land that could be irrigated with groundwater given the lack of clear regulatory oversight.

If these perfectly legal transactions have resulted in farmer engagements and approvals, creating business opportunities, it also created concerns from local water users in Arizona, whereby aquifer levels are rapidly dropping. In the longer term, it does raise the question of the sustainability of the system, and possible raising conflicts in the future, especially when considering the growing water risk shortages in the region.

Source: NPR (2015); Spagat and Batrawy (2016).

Since the land contracts are signed under international law, they are often more binding to the states than the ownership of local communities under domestic law, whose rights may be unclear outside of the traditional context (Smaller and Mann, 2009). Therefore, in case of dispute, the local owners or users may have difficulties to claim their rights against expropriation, notably regarding access to water resources. As a consequence, foreign agriculture investment is often associated with decreased standards of living and loss of subsistence means for local communities and long term consequences with water users. On the other hand, international law guarantees to foreign investors the access to the necessary means of production, including access to local freshwater.

The number of such land purchase is substantial but remains difficult to monitor and assess; still observers believe that it could increase in the future along with water and climate risks. Overall, it was estimated that appropriation of water rights associated with land purchases represent 140 billion m3 of surface and groundwater each year (Rulli et al., 2013). In Africa, large-scale land acquisition covered 22 million ha (the size of the United Kingdom); of these only 3% were found to be used for production in 2015, but the production mostly focused on relatively high water requirement crops (sugarcane, jatropha, eucalyptus) (Johansson et al., 2016). Hundreds of examples are discussed in the literature, even if they are not always well documented (von Braun and Meinzen-Dick, 2009; Zetland and Möller-Gulland, 2012). It is likely that the trend will continue to increase with climate change and growing water scarcity and food security tensions (Smaller and Mann, 2009; United Nations, 2010).

Agriculture water risks, conflicts and migration

There is a growing concern that water risks impacts on food security have fuelled conflicts and migration. In January 2017, agriculture ministers of the G20 countries signed a declaration in which they note that "Water scarcity and excess water threaten agriculture and food security and nutrition. This can contribute to political and social instability and to large –scale migration" (G20, 2017). As noted in Chapter 1, the World Economic Forum has ranked water crises as a major risk factor (WEF, 2015, 2016 and 2017). The importance of security risks has also been identified by intelligence agencies (Office of the Director of National Intelligence, 2012, cited in Siegel, 2015).

A growing body of research has assessed the potential links between climate change, water availability and conflict. If there is mixed empirical evidence on the impact of droughts and temperature shocks and conflicts globally (Gleditsh, 2012; Nillesen and Bulte, 2014), such link has been substantiated in a number of specific cases, especially in the African context. Civil wars in Somalia, Sudan, and South Sudan were largely fuelled by drought (Breisinger et al., 2015). Other conflicts have been partially attributed to drought and climate change (Gleick, 2014; Kelley et al., 201; Jägerskog et al., 2016).

In most of these cases, a climatic event was associated with ongoing water stress, creating production shortages and income disruption, deepening inequalities and exacerbating existing social grievances (Breisinger et al., 2015). Conflicts arose in rural areas, often moving to urban areas then lifted into tensions with governmental authorities, due to insufficient responses. The implications range from temporary political crises to outright civil or international wars.

An indirect implication of tensions growing importance of water risks relates to migration. If climate events have long been a driver of migration (Jägerskog et al., 2016), the relationship between climatic events and migration is also empirically ambiguous, due to its relationship with multiple socio-economic variables (Black et al., 2012). Still, a migration-climate risk link was established more convincingly in some regions and circumstances. Sea level rise, storms, floods, cyclones, or droughts have encouraged people to migrate in many countries, although they also were fuelled by other socio-economic and political factors, including an inadequate management of water and land (Black et al., 2012; Weiss, 2015).

Recent studies have focused on the possible link of worsening climatic conditions associated with climate change in certain areas and migration, which could then induce conflict. Given the large uncertainties, estimates of climate- induced migrants vary widely, from 25 million to 1 billion by 2050 (Weiss, 2015). Werz and Conley (2012) identified four regions most likely to be subject to intense migration in the future, due to climate change and water insecurity: Northwest Africa (international migration due to climate change, food and water insecurity), Bangladesh (floods and increased sea-level) and India (population growth), the Andean region (melting glaciers), and China (continued internal migration due to climate change).

If the reported links between water risks, especially affecting agriculture, conflict and migration remain complex and would warrant further research (Post, et al., 2016), the evidence on increasing water risks suggest that these links may strengthen in the future in the absence of policy response.

Notes

1. These indirect market effects also include possible trade policy responses derived from market shocks induced by water risks in hotspot countries.

2. Damages of droughts and floods (FAO, 2015) refers to agriculture losses as “the changes in the economic flows arising from the disaster”: decline in crop, livestock, aquaculture output; increased costs of farm inputs and services; changes to food market prices

3. The remaining share of damages were incurred by forests, fisheries and irrigation, acknowledging that the forest and fisheries impacts were likely to be under-reported (FAO, 2015)

4. Not all extreme event result in long-term effects. With a large pool of events viewed from on a global scale, Lesk et al. (2016) found no significant impact of extreme weather disasters on crop production in the long term: production resumed its pre-disaster level the following year.

5. Cross-study comparability is limited as the results are largely dependent on assumptions, such whether or not farms have access to sufficient irrigation and the effects of CO2 fertilization (Piao et al., 2010; Wang et al., 2014).

6. The amplitude of the effects of climate change on irrigation could however be limited; Döll (2002) suggests that net irrigation requirements would increase less than the regular inter-annual variability.

7. Groundwater used beyond recharge.

8. Bad water quality – compounded by rising water scarcity - may also trigger negative health impacts. Water pollution in the Yellow River watershed has already created excessive levels of chromium and lead in rice and cadmium in cabbage. High rates of mental and physical development challenges have also been attributed to arsenic and lead contamination of food and water along the Yellow river. In rural areas the mortality rate for diseases related to water pollution is the highest, especially for stomach cancer and liver cancer and is far above world average. Given the projections of increasing pollution, these effects are likely to worsen in the future.

9. Shallow groundwater depletion creates incentives to drill deeper tubewells, up to 200m depth, which induce vertical leakages, compromising the recharge of shallow aquifers and thereby rising pumping costs even faster (BGS, 2015).

10. More countries or regions could have been subject to shocks, to reflect the determination of future water risks (chapter 2), but it would not serve the purpose of evaluating the impact of water risks in a few selected regions.

11. Irrigation water demand and supply are not formally defined in the IMPACT model, as they are exogenous variables coming from the Impact Water Model Simulation Model (IWSM).

12. It may be that a drought-induced water-supply shortfall would be reflected primarily in a reduction in acreage and less in terms of a reduction in yield. But perhaps it is more likely to see yield reductions for perennial fruit/nut tree crops where farms are more dependent on surface water supplies. The IMPACT model version used for this report does not allow running simulations for

perennial fruits and vegetables specifically as they are aggregated into the "fruit and vegetables" category.

13. At a global scale, water gaps are considerable: countries of the Gulf Cooperation Council use 80% of their water for irrigation, while it is only the case for 2% of the water supply in Africa, revealing largely untapped resources.

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Annex 3.A1

Modelling scenarios and assumptions

The model used for this study is the multi-market partial equilibrium model IMPACT 3.1, which enables projecting both climate change and water stress at a subnational level on specific commodities (Robinson et al., 2015). The projection of irrigation water demand depends on changes in irrigated area and cropping patterns, water use efficiency, and rainfall harvest technology. Global climate change can also affect future irrigation water demand through changes in temperature and precipitation.

More precisely, irrigation water demand and supply are not formally defined in this model, as they are exogenous variables coming from the Impact Water Model Simulation Model (IWSM). The variation in water availability for agriculture year by year in different climate scenarios has an impact on yields. This mechanism is modelled through the use of the IMPACT water models. These include (1) a global hydrology model that determines runoff to the river basins included in the IMPACT model; (2) water basin management models for each food production unit (FPU, the unit of modelling, combining watersheds with agriculture production areas) that optimally allocate available water to competing non-agricultural and agricultural uses, including irrigation; and (3) a water allocation and stress model that allocates available irrigation water to crops and, when the water supply is less than demand by crop, computes the impact of the water shortage on crop yields, accounting for differences among crops and varieties. These yield shocks are then passed to the IMPACT model, affecting year-to-year crop yields (Robinson et al., 2015).

The following sections summarise the scenarios and assumptions of the proposed simulations. A subsequent section then reviews the evidence of impact and occurrence of extreme precipitation patterns in the three regions.

3.A1.1. Geographical and agriculture scope

The three regions are defined as follow in the simulations:

- Northeast China covers four main river basins. The Huang He, also known as the Yellow River watershed, contains the country's second largest river. The Huang He rises in the southern Qinghai province on the Plateau of Tibet. Another river basin, the Huai He is located about halfway between the Yellow River and Yangtze, the latter being the two largest rivers in China. The Huai He is considered the geographical dividing line between Northern and Southern China. The last two watersheds modelled are the Hai He basin and the Songhua basin, which are drained by the Liao River. Maize, vegetables, wheat, potatoes and cotton are the main crops produced in Northeast China.

- Three major water river basins can be delimited in Northwest India: the Indus, the Luni, and the Ganges. The Indus river basin spreads over states of Jammu & Kashmir, Himachal Pradesh, Punjab, Rajasthan, Haryana and Union Territory of Chandigarh with an area of 321 289 km^2, nearly 9.8% of the total geographical area of India. The Luni watershed includes the western part of Rajasthan and the northern part of Gujarat. The Ganges River is the third river basin concerned, covering a very large share of Northern India, but is left aside from the simulation as much of this region lies outside of Northwest India. Sugar cane, wheat, rice, potatoes, subtropical fruits are the main crops produced in Northwest India.

- Three main watersheds delimit the Southwest United States: the California River Basin, the Colorado River Basin, and the Great Basin. The Colorado River Basin, houses the largest river in the Southwest, and includes parts of California, Utah, Arizona, New Mexico, Colorado, and Wyoming. The Great Basin watershed includes parts of Southern California, most of Utah, the northwest half of Nevada, and parts of both Oregon and Idaho. Dairy, cattle (beef), maize, fruits, vegetables, wheat and potatoes are the main commodities produced in United States Southwest.

3.A1.2. Modelling water stress on irrigation in IMPACT

The baseline scenario is defined by assuming no climate change (no RCP) and no adaptation policies. This scenario is referred to as BAU (Business as usual) and is noted S0. For water stress simulations, we implement three scenario variations–basin efficiency deficit (SB) and groundwater depletion (SG) and drought (SD). Two regional climate scenarios (RCP 8.5 IPSL and RCP 8.5 Hadley) are added. This equates to a possible twelve scenario runs (three climate options * four combinations of water stress).

The two reference climate scenarios, which are defined by no water stress simulations, are referred to as Hadley S1 and IPSL S1. Thus, the specific effects of the two water stress simulations on agriculture are readily analysed by comparing each additional water stress scenario (SD, SB, SG) to the reference scenario (S0). Table 3.A1.1 describes the scenarios implemented in the study.

Table 3. A1.1. Specification of the key water stress scenarios

Scenario	Measure specification	Regional scope / river basins	Timing	Activities affected
Deficit in basin efficiency Scenario (SB)	50% decreased basin water use efficiency by 2050 compared with 2005 levels, until all regional basins reach a maximum efficiency of 46%.	*Southwest United States* California basin; Colorado river basin; Great basin	2005-50	All
	50% decreased basin water use efficiency by 2050 compared with 2005 levels, until all regional basins reach a maximum efficiency of 33%.	*Northwest India* Indus basin; Luni basin	2005-50	All
	50% decreased basin water use efficiency by 2050 compared with 2005 levels, until all regional basins reach a maximum efficiency of 40%	*Northeast China* Hail He basin; Huai He basin; Huang He basin Songhua basin	2005-50	All
Groundwater depletion scenario (SG)	50% increased groundwater depletion by 2050 compared with 2005 levels.	*Southwest United States* California basin; Colorado river basin; Great basin	2005-50	All
	50% increased groundwater depletion by 2050 compared with 2005 levels.	*Northwest India* Indus basin; Luni basin	2005-50	All
	50% increased groundwater depletion by 2050 compared with 2005 levels.	*Northeast China* Hail He basin; Huai He basin; Huang He basin Songhua basin	2005-50	All
Drought scenario (SD)	Simulation of a drought that decreases the average yields of field crops by 30%, cattle and dairy by 20% vegetable by 15%, and fruits by 10%	*Southwest United States* California basin; Colorado river basin Great Basin	2021	Beef, dairy, maize, fruits and vegetables, wheat, potatoes
	Simulation of a drought that decreases field crop average yields by 30% and subtropical fruit average yield by 10%.	*Northwest India* Indus basin; Luni basin	2030	Sugar cane, wheat, rice, potatoes, subtropical fruits
	Simulation of a drought that decreases decrease average yields of field crop by 30%, vegetables by 15%	*Northeast China* Hail He basin; Huai He Basin; Huang He basin Songhua basin	2030	Maize, vegetable, wheat, rice, potatoes, cotton.

Source: Authors' own assumptions.

Technical specification of the basin deficiency scenario (SB)

The scenario on decreased basin efficiency is designed to mimic a deterioration of future water supplies usable for irrigation. Based on various definitions provided by Keller et al. (1996), the IMPACT model defines basin efficiency as the ratio of beneficial water depletion (crop evapotranspiration and salt leaching) to total irrigation water depletion at the basin scale. Basin efficiency in the base year (2005) is calculated as the ratio of the net irrigation water demand to the total irrigation water depletion estimated from records (Shiklomanov, 1999). The projection of irrigation water demand depends on the changes in irrigated area and cropping patterns, basin efficiency, and effective rainfall. Global climate change affects future irrigation water demand through changes in precipitation and temperature along with other meteorological variables that affect crop evapotranspiration. Irrigation demand in the FPU is calculated for a given cropping pattern after taking into account the basin efficiency of the irrigation system.

As simulated, reduced basin efficiency has a negative impact on surface water availability for irrigation. The assumed parameters do not aim to provide accurate or realistic projections, especially in the United States Southwest, but they are meant to implement water supply constraint shocks that could affect irrigated agriculture in the three regions. In other words, the scenarios provide a means to gauge the resistance of the irrigation sector to water stress (providing a "water stress test" like the other scenarios).

As shown in Table 3.A1.1, surface water constraint is simulated by assuming a 50% decrease in the baseline basin efficiency by 2050. This translates into simulating the gradual transition to a maximum of 46%, 40% and 33%, basin efficiency by 2050 in the Southwest United States, Northeast China and Northwest India, respectively. The shocks are intended to provide a pessimistic illustration of the possible impacts of agriculture water risks in the three regions, rather than an accurate projection of observed trends. This efficiency loss by 2050 is assumed to follow a linear decrease over the 45-year projection period, representing slow but steady decreases in basin efficiency. The basin efficiency trend for each FPU is assumed to be linear over the period and can be calculated as follows: $\frac{ee_{fpu,yrs}-ee_{fpu,2005}}{n}$ with $ee_{fpu,2005} > ee_{fpu,yrs}$ s with ee = Effective Basin Efficiency defined on *fpu* and *yrs* and *n* = number of periods (n=2050-2005=45).

There is no direct relationship between the yield parameter and basin efficiency (ee). Basin efficiency is used in the water allocation part of the IMPACT water models. Decreasing efficiency, all things equal, will decrease water supply in the basin by affecting water reliability and by increasing the risks associated with water scarcity. When water is a limiting factor, the impacts of basin efficiency variations are spread across all crops, and as such it is usually difficult to see major yield changes unless the change in efficiency is large or the water stress is severe. As the water allocation is optimised at the full basin (not the FPU) it is possible to see limited effects in yields in a basin where the efficiency decreases, as it may limit water to be used in other FPUs within the basin.

Technical specification of the groundwater depletion scenario (SG)

The second irrigation policy to be explored is groundwater overuse, where withdrawal of water is assumed to exceed recharge, leading to underground aquifers depletion. A 50% increase in groundwater depletion by 2050 compared with 2005 levels is modelled in all water basins. Similar to the irrigation efficiency trend, groundwater depletion is assumed to increase linearly over the 45-year projection period. It should be noted that both decreased basin efficiency and increased groundwater depletion could lead to lower yields, but will mostly affect water reliability and increase the risks associated with water scarcity.

Groundwater depletion is defined as the case when groundwater abstraction is greater than groundwater recharge, including return flows. For the desired 2050 groundwater reduction level to be reached, a groundwater withdrawal trend has to be estimated. The groundwater trend for each FPU is assumed to be linear over the period and can be calculated as follows: $\frac{gwd_{fpu,yrs}-gwd_{fpu,2005}}{n}$ $gwd_{fpu,2005}$ > Max $gwd_{fpu,yrs}$

with *gwd* = groundwater depletion defined on *fpu* and *yrs* and *n* is the number of periods (n=2050-2005=45).

Similar to basin efficiency, there is no direct relationship between yield and groundwater depletion (gwd). Groundwater is used in the water allocation part of the IMPACT water models. Increasing groundwater depletion, all other things equal, will decrease water supply in the basin. As the water allocation is optimised at the full basin (not the FPU) it is possible to see limited effects in yields in a basin where the groundwater depletion is higher, as it may limit water to be used in other FPUs within the basin. In practice, groundwater depletion may not impact groundwater withdrawal; in the Southwest United States, producers tend to update pumps to maintain their groundwater pumping (but in such case, it would affect their production costs).

Technical specification of the drought scenario (SD)

To evaluate the impact of water stress on irrigation in the three regions, a drought scenario can be elaborated. In that effect, an exogenous shock is applied on crop yields that will decrease to reflect the consequences of a drought, as seen in Table 3.A1.1. In IMPACT model, yields are estimated from initial yields, exogenous assumptions on yield growth (from technology, water, and climate shocks working through DSSAT and the water models), and current net price of the outputs, which takes into account the cost of inputs. The first three effects on yield are essentially exogenous to IMPACT, while the last one is endogenous and part of the IMPACT model equations.

$$Yield_{j,fpu,lnd} = YieldInt_{j,fpu,lnd} \times YieldInt2_{j,fpu,lnd} \times WatShk_{j,fpu,lnd} \times CliShk_{j,fpu,lnd} \times YieldShk_{j,fpu,lnd} \times \left(\frac{PNET_{j,cty}}{PNET0_{j,cty}}\right)^{Y\varepsilon}$$

With the following parameters:

Yield	Final Crop Yield
YieldInt	Crop yield intercept (base year crop yield)
YieldInt2	Exogenous Crop yield growth multiplier due to technology
YieldShk	Exogenous yield shock
WatShk	Water stress shock (from water models) – continuous parameter
CliShk	Climate change shock (from water and crop models) – continuous parameter
PNET	Current Net Price
PNET0	Base Year Net Price (used to index prices in equation)
Yε	Yield supply elasticity with respect to net price

To model a drought in all basins, a yield decrease is simulated for various commodities by shocking the parameter *yieldshk*. In United States Southwest, yields decrease by 30% for crops (maize, wheat and potatoes), 20% for cattle and dairy, 15% for vegetables and 10% for fruits for the year 2021. In Northeast China, drought simulations decrease average yields of field crop (maize, wheat, rice, potatoes, cotton) by 30% and vegetables by 15% in 2030. In Northwest India, a 30% crop yield (sugar cane, wheat, rice, potatoes) decrease, and a 10% subtropical fruit yield decrease are simulated in 2030 to reflect a drought. These figures are based on yield decreases observed in the IMPACT model simulations under various climate change assumptions (Ignaciuk and Mason-D'Croz, 2014).

3.A1.3. Extreme precipitation patterns and agriculture production in the three regions

This section reviews past evidence on the damages of extreme precipitation patterns in the three regions, and provides a rapid assessment of possible future events.

Frequency of extreme precipitations in relation with El Niño Southern Oscillation (ENSO) : Pacific Decadal Oscillation (PDO) and Indian Ocean Dipole (IOD) in the three countries

In Northeast China, the drought frequency increased to 6.88% during 1977-2010 from the 2.80% observed during 1951-76 (Yu et al., 2014). The relationship between rainfalls and ENSO events are more complex. The influence in the North of the country is not clear. A study estimates that 30% of the annual rainfalls anomalies are related to ENSO in China, but more clearly in the South (Lau and Weng, 2001). It might depend of different types of *El Niño* (Central Pacific vs East Pacific) (Yuan and Yang, 2012). However, *El Niño* is associated with drought and La Nina with above normal precipitations in North China (Yu et al., 2014). At the same time, a negative Pacific Decadal Oscillation (PDO) strengthens the monsoon in the North (Browning, 2013).

In Northwest India, relatively strong trends have been associated with ENSO events but there have been exceptions. From 1950-2012, 80% of La Nina events (ENSO-) were associated with above normal precipitations during the monsoon (*kharif*) (Di Liberto, 2014). 71% of El Nino events (ENSO+) were associated with below normal precipitations during the monsoon (Di Liberto, 2014). El Nino is also associated with abnormal heavy rains and hails from February to April in Northwest India (Mukherjee, 2015), which is normally the dry season (*Rabi*). However, there have been significant anomalies: in 1997-98, the strongest *El Niño* of the century was associated with above normal precipitations, and one of the driest monsoons recorded, in 2002, was associated with a weak *El Niño*. At the same time a positive PDO is associated with drought and a negative PDO with above normal rainfalls when negative (Krishnan et al., 2003). A negative IOD (Indian Ocean Dipole) index is correlated with dry monsoon (Rao, 2015).

In the Southwest United States, and specifically California, strong ENSO+ events seem to be statistically associated with increased precipitations. The influence is more significant in Southern California. Trends in ENSO indices from 1950-2010 show that there was an even distribution in sub/normal/over precipitations in the North during the 23 *El Niño* events. But three of the five "strong" indices came with above normal precipitations (+120%)–the fifth below normal. In the central part of California, there was also an even distribution in sub/normal/over precipitations during the 23 *El Niño* events; but four of the five "strong" came with more than 140% above normal precipitations–the fifth below normal. In the South, there was also an even distribution in sub/normal/over precipitations during the 23 *El Niño* events; but four of the five "strong" came with more than 140% above normal precipitations–the fifth normal. (Null, 2015).[1] ENSO- is statistically associated with decreased precipitations, at least in Southern California. Observing the La Nina events from 1950-2000 in California, the following observations were made. In the North, over the 12 *La Niñas*, four were below normal (-20% and more), six normal, two above (+20% and more) (Ref Station San Francisco); in the South: Over the 12 *La Niñas*, seven were below normal (-20% and more, including 4 of -40% and more), five normal, zero above (+20% and more) (Null, 2004). PDO positive events were associated with drought, and PDO negative events with above normal rainfalls (Browning, 2013; Totten, 2015).

Impact of recent extreme events on agriculture in the three regions

A review of recent extreme weather events in the three regions provides a benchmark to the possible impact of future extreme events. Tables 3.A1.2 to 3.A1.6 offer a rapid characterisation of the main climatic phenomena in the three regions since 1988 and their reported impact on agriculture.

Table 3.A1.2. Impacts of climatic events in the three hotspot regions: 1988-1989.

1988-1989: **Strong negative Oceanic *Niño* Index –PDO hot- IOD 0**		
India (NW)	**United States (California)**	**China (NE)**
- Very severe floods in September 1988: 1 463 villages inundated in Punjab, 381 in Haryana (Dartmouth Flood Observatory, 2003a). - 80% of standing crops destroyed in Punjab (Shiva, 1991).	- Drought t begun in 1987 and lasted over 1988 and 89. Extremely severe US-wide. - In California, 15 to 40 recurrence interval depending on areas (Paulson et al., 1990). - USD 500M loss in farm sales (USACE, 1993).	- Persistent rains attributed to *La Nina;* USD 150 million farm loss country-wide (FAO, 1998). - Including, in August 1998 : Eastern Shandong Province, Yellow River flooded 33 villages (16810 ha); Shanxi (36880 ha flooded); Henan (153100 ha) (Dartmouth Flood Observatory, 2006).

Source: Authors' own work based on cited references.

Table 3.A1.3. Impacts of climatic events in the three hotspot regions: 1997-1998

1997-1998: Very strong Oceanic Niño Index- PDO hot – Very high IOD		
India (NW)	**United States (California)**	**China (NE)**
-1998: India's deadliest heat wave. The monsoon precipitations were normal. This could be explained by the high IOD (Indian Ocean Dipole) index, correlated with a good monsoon. There was no significant drop in agriculture production (World Bank, 2014). -The year is an example of ambiguity: even if ENSO+ is statistically associated with droughts in India, this is not systematic. (Levrault, 2016).	-Floods in California in February 1998, associated with El Nino (New York Times, 1998). The exceedance probability of the February 23 flood peak reached 4%, equivalent to a one in 25-year flood (Bowers, 2001). -February 1998 brought several record-breaking rainfalls (Greatest rainfall since 1877), with 50-year storm event intensities (Dartmouth Flood Observatory, 2006). -March: Flood in Monterey, San Luis Obispo, San Benito, Napa: estimated 342M$ crop loss; May: Heavy rain in central California, estimated USD 310 M crop loss; June: flood in Southern San Joaquin Valley, estimated crop loss USD 100M (Lobell et al., 2009). -The floods in January 1997, not under El Nino conditions, were worse (1.8B$ total costs vs 0.55B$) (City of Newport Beach, 2014). -There is a large difference in Californian losses between similar El Niño; USD 2 billion in 1982–83 versus USD 1.1 billion in 1997–98 (Changnon, 1999).	-Beginning of a five years drought in NE China. -1997: catastrophic drought in the Yellow river basin (226 days zero flow) (Yu et al., 2014); up to 60 million metric tons grain loss. -2.5% yield loss (grain) because of drought (OECD, 1999).

Source: Authors' own work based on cited references.

Table 3.A1.4. Impact of climatic events in the three hotspot regions: 2002-2003

2002-2003 : Moderately strong Oceanic Niño Index – PDO cold-IOD 0		
India (NW)	**United States (California)**	**China (NE)**
Very severe drought: 22% aggregate rainfall anomaly and -25% trend deviation in agriculture production (World Bank, 2014). -All Punjabi districts affected, reported as the most severe (Government of Punjab, 2016).	Storms and heavy rains end of December 2002, partly due to Nino conditions in the Pacific. Affected 65 000 km2, including the long-term inundation of San Joaquin and Sacramento Valley (Dartmouth Flood Observatory, 2003b; State of California, 2012).	-No particular drought. -Amelioration of the hydric conditions after several years of drought in Northern China (500-600. 10*5 tonnes crop loss /year in 2000 and 2001 due to drought (Xurong and Xiaohui, 2012). -Could be explained by shift to cold PDO, which increases monsoon in the north and decreases it in the South (Browning, 2013).

Source: Authors' own work based on cited references.

Table 3.A1.5. Impact of climatic events in the three hotspot regions: 2007-2008

2007-2008 : Strong Negative Oceanic Niño Index (La Nina) – PDO cold- IOD 0		
India (NW)	**United States (California)**	**China (NE)**
-Severe floods, including in the NW, in August 2007 and 2008. Floods in Punjab 2007: INR 582995000 (= USD 8.6M) crop damages. 2008: INR 645084000 (=9.6M$) (2nd and 3rd most expensive since at least 1960. The worst flood occurred in 1995) (Government of Punjab, 2016).	- Drought in California : USD 20 M USDA drought-related crop insurance payments in California during the 2007-2009 drought (Christian-Smith et al., 2011). - While 2007 and 2008 were dry years, they are among the decade's highest in terms of yield of irrigated crops state-wide. - Still, USD 368 M was lost due to drought and pumping restrictions across the entire San Joaquin Valley. This represents a 2.5% decline in revenue across the Valley. USD 328 M (89%) is in Kern and the west-side regions. (Michael et al., 2010).	-Severe floods from June to August 2007. The 2007 flood volume of Huai River is the second largest since1949, next to that of 1954 basin. It represented three times the normal average (Chen, 2008). -In the summer 2007, there was a severe drought in Southern China (Dartmouth Flood Observatory, 2003) (inversely, El Nino bring floods in South, like in 1997-8 and 2015-16) (CCTV, 2016a). -In 2008, 10 typhoons or tropical storms hit China (vs 7 in average) (Chen, 2009).

Source: Authors' own work based on cited references.

Table 3.A1.6. Impact of climatic events in the three hotspot regions: 2015-16

2015-2016: Very strong Oceanic Niño Index – PDO hot- IOD+		
India (NW)	**United States (California)**	**China (NE)**
-Heat records in 2015 – 2016 -dry kharif season in 2015: 40% rain deficit in Punjab, 38% in Haryana (Dhaliwal, 2016). -Unseasonal rains and hails during rabi 2015 (biggest losses: Haryana and Rajasthan, which led to a 7% drop in wheat production in India 2015 (to 86.53mt) (Srinhidi, et al., 2015); the standing crop worth Rs717 crore was damaged over an area of 294,177 hectares in Punjab) (Bhatnagar, 2015). The same phenomenon occurred in 2016.	-Expected increase in rainfalls because *El Niño* after four years of drought (Howitt et al., 2015) did not occur (Downey, 2016). -USD 900M$ crop loss, USD 350M livestock loss, USD 590M in additional pumping in California (Howitt et al., 2015).	-Droughts in central and Northern China 2015-2016 (CCTV, 2016b). -Drought summer 2015 affected 1.15 million hectares of crops in NE (China Daily, 2015). -Drought in the summer 2016 affected over 1 million hectare of crops (Hebei, Henan and Shaanxi provinces) (CCTV, 2016b). Countrywide, estimated loss of USD 1.2B for farmers (Agweb, 2016).

Source: Authors' own work based on cited references.

Future precipitation events in the three regions

Table 3.A1.7 provides a review of the influence of ENSO, PDO and IOD indexes on precipitations anomalies, and Table 3.A1.8 matches PDO and ENSO influences on precipitation.

Table 3.A1.7. Influence of positive and negative ENSO, PDO and IOD events on precipitation in the three regions

		India (NW)	United States (California)	China (NE)
ENSO	+	↘	↗	(↘)
	-	↗	↘	(↗)
PDO	+	↘	↘	↘
	-	↗	↗	↗
IOD	+	↗		
	-	↘		

Note: ↘ Favours reduced precipitations; ↗ Favours increased precipitations; ( ) Unclear effect.
Source: Authors, derived from the reviewed literature.

Table 3.A1.8. Combining ENSO and PDO influences on precipitation in the three regions

	Positive ENSO			**Negative ENSO**		
	NW India	SW United States	NE China	NW India	SW United States	NE China
Positive PDO	↘↘*	↗↘	(↘)↘	↗↘*	↘↘	(↗)↘
	Ex: 1997-1998; 2015-2016			Ex: 1988-1989		
Negative PDO	↘↗*	↗↗	(↘)↗	↗↗*	↘↗	(↗)↗
	Ex: 2002-2003			Ex: 2007-2008		

Note: the first arrow indicate the ENSO influence, the second the influence of the PDO.
Source: Authors, derived from the reviewed literature.

Timeline for ENSO, PDO and IOD events

Frequency and duration

- ENSO events last 6-18 months. In the latest 50 years, very strong *El Niño* occur every 15 years approximately (Levrault, 2016), La Nina can occur every 4 to 5 years with very strong La Nina every 23 years (Cai et al., 2015).
- PDO events last 20-30 years, and fluctuate between positive and negative phases.
- IOD fluctuates every 3 to 8 years between positive, negative and neutral phases (IRD, 2013).

According to some studies, if the current global heating trend is maintained, the frequency of ENSO+ events (El Niño) is likely to accelerate, and even double at the end of the century (every 7-8 years) (Levrault, 2016).

Long-range forecasts

The IRI (Columbia University) publishes monthly probabilistic ENSO forecasts up to 10 months ahead. This forecast is the reference used by the NOAA (Climate Prediction Center, 2016). As of 2016, it was considered that there were neutral ENSO conditions. During the fall-winter 2016-2017, La Nina conditions were expected with 75% probability (IRI, 2016).

For the PDO, the predictability relies on the strong inter-seasonal and even inter-annual persistence probability. Models analysing SST-anomalies can predict evolutions of the PDO index three to four seasons in advance (Alexander et al., 2008). PDO shifted in a warm mode in January 2014, so PDO+ conditions are expected to last in the coming years (Browning 2013). IOD long-range forecasts published by the Indian Ministry of Earth Sciences go up to nine months ahead. The latest release (June 2016) anticipates a negative IOD during the 6 next months (Ministry of Earth Sciences, 2016).

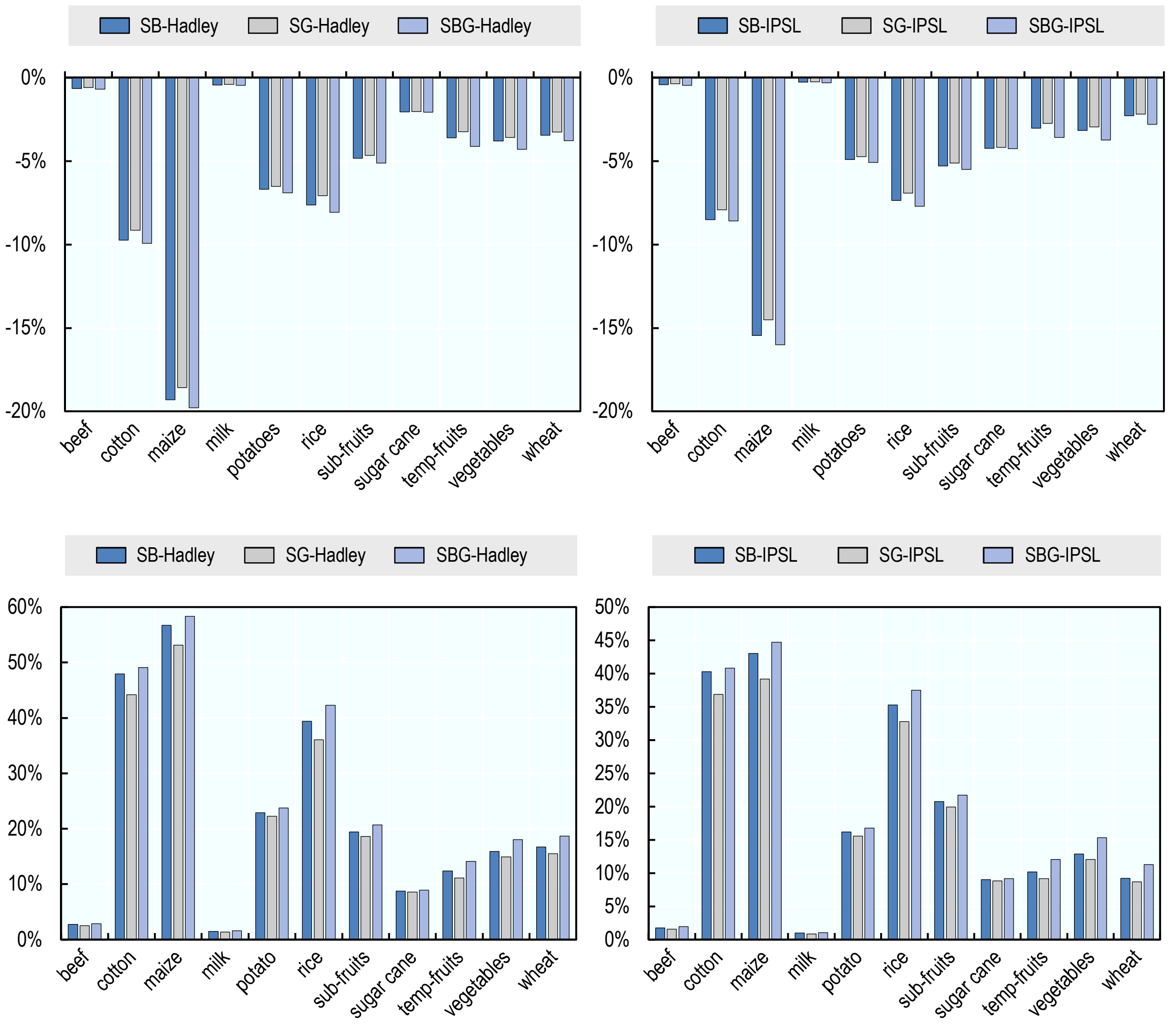
Annex 3.A2.

Additional results from the simulations

3.A2.1. Additional results of the simulation for the irrigation stress scenarios

Figure 3.A2.1. Global production and price impact of irrigation stresses under the Hadley and ISPL climate projections by 2050 compared to the baseline

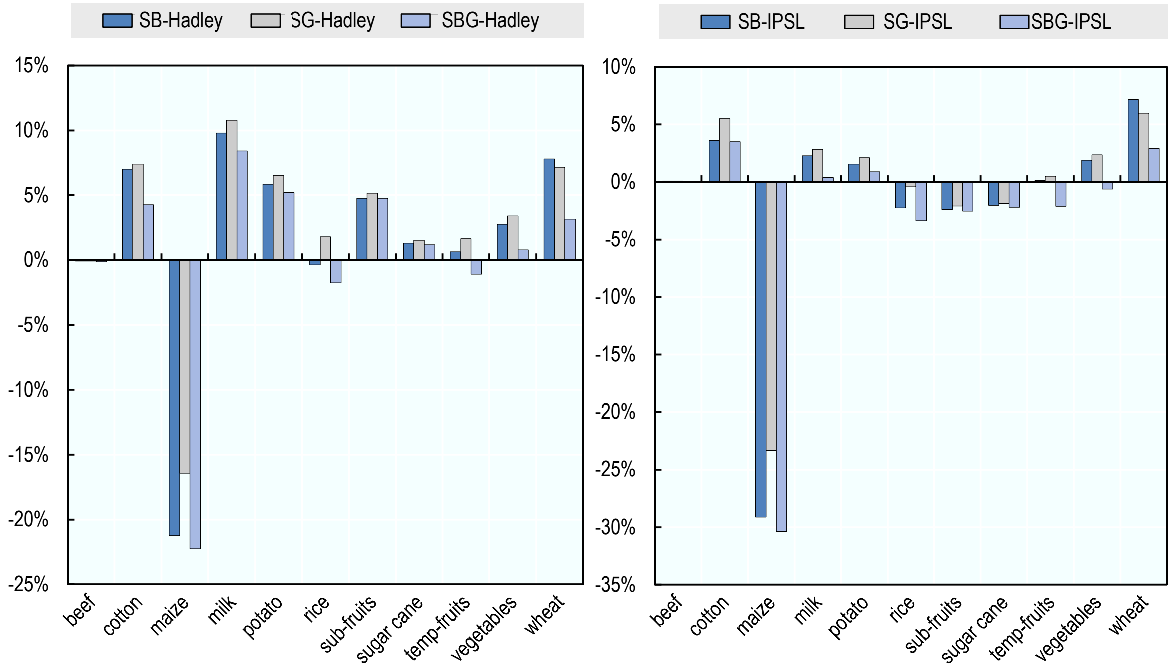
Top: Production, Bottom: World prices, Left: Hadley, Right: ISPL



Note: Sub-fruits are subtropical fruits, temp-fruits are temperate fruits.

Source: Derived from IMPACT results.

Figure 3.A2.2. Impact of irrigation stresses and climate change on production in China

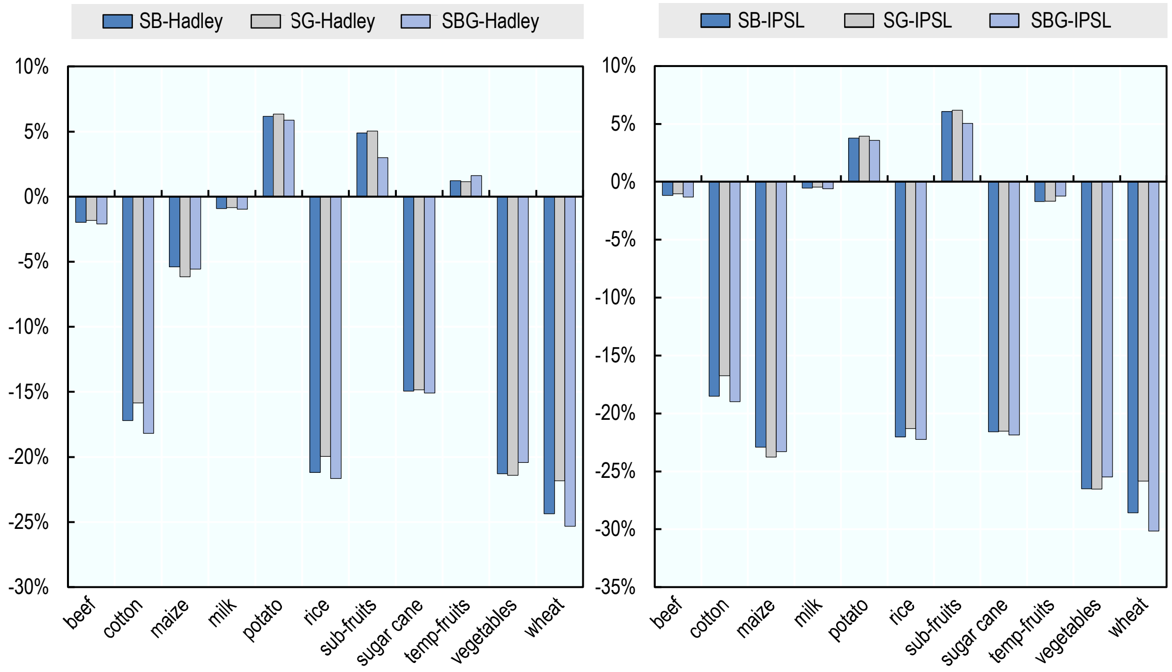


Hadley projections

ISPL projections

Note: Sub-fruits are subtropical fruits, temp-fruits are temperate fruits.
Source: Derived from IMPACT results.

Figure 3.A2.3. Production impact of irrigation stresses and climate change in India



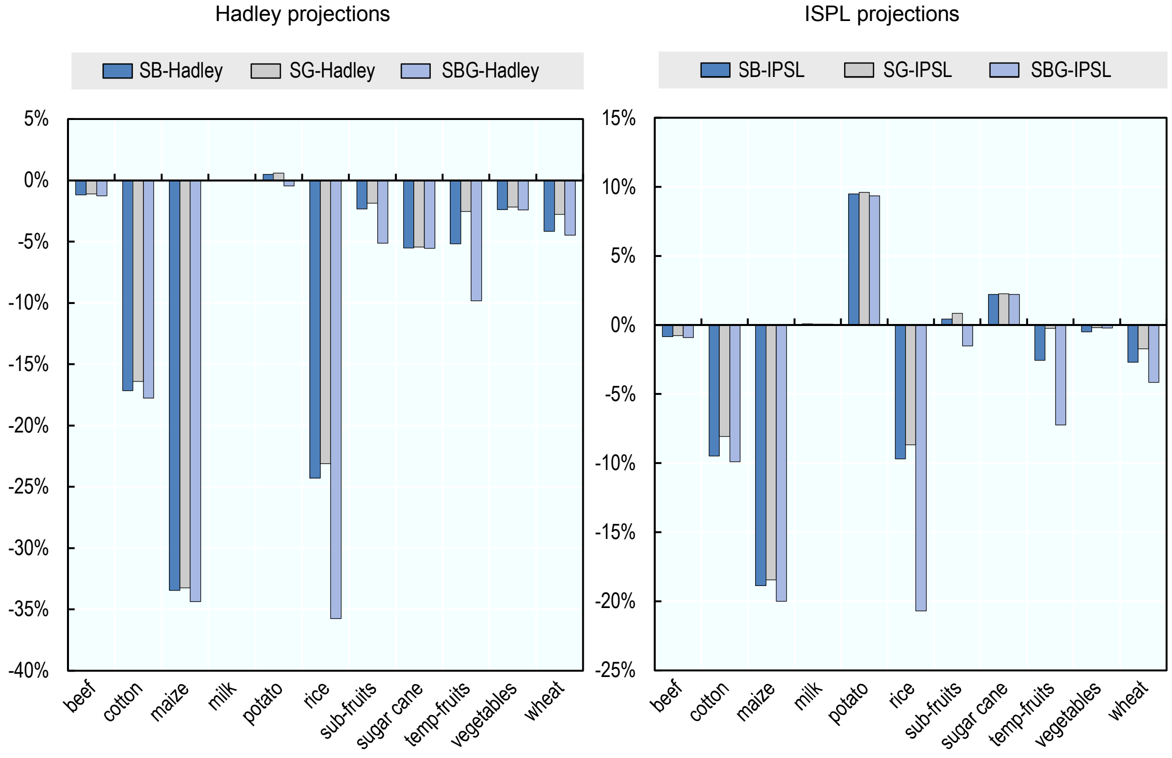
Hadley projections

ISPL projections

Note: Sub-fruits are subtropical fruits, temp-fruits are temperate fruits.

Source: Derived from IMPACT results.

Figure 3.A2.4. Production impacts of irrigation stresses and climate change in the United States



Note: Sub-fruits are subtropical fruits, temp-fruits are temperate fruits.
Source: Derived from IMPACT results.

Trade impacts

Table 3.A2.1. Relative impact of irrigation stresses on the net trade balance of selected countries

Commodity	Country	SB	SG	SBG	Hadley	Hadley	Hadley	ISPL	ISPL	ISPL
					SB	SG	SBG	SB	SG	SBG
Beef	Brazil	-0.1%	0.0%	-0.1%	-1.2%	-1.2%	-1.2%	-0.9%	-0.8%	-0.9%
Beef	Canada	-0.1%	-0.1%	-0.1%	-0.3%	-0.3%	-0.4%	-0.1%	-0.1%	-0.2%
Beef	Chili	0.3%	0.2%	0.3%	1.4%	1.3%	1.5%	0.9%	0.8%	1.0%
Beef	Japan	0.0%	0.0%	0.0%	-0.5%	-0.5%	-0.5%	-0.4%	-0.4%	-0.4%
Beef	Korea	-0.1%	-0.1%	-0.1%	-0.6%	-0.6%	-0.6%	-0.4%	-0.4%	-0.4%
Beef	Mexico	0.0%	0.0%	-0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%
Beef	Russia	0.0%	0.0%	0.0%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
Beef	United States	0.0%	0.0%	0.0%	-0.3%	-0.3%	-0.3%	-0.3%	-0.2%	-0.3%
Beef	Australia-NZ	-0.4%	-0.4%	-0.5%	-1.4%	-1.3%	-1.5%	-0.7%	-0.6%	-0.9%
Beef	E17	0.0%	0.0%	0.0%	0.8%	0.8%	0.8%	0.7%	0.6%	0.7%
Beef	EG4	0.1%	0.1%	0.1%	1.0%	0.9%	1.0%	0.8%	0.7%	0.8%
Beef	EU7	-0.1%	-0.1%	-0.1%	-0.3%	-0.3%	-0.3%	-0.2%	-0.2%	-0.3%
Milk	Brazil	-0.2%	-0.2%	-0.2%	-1.3%	-1.2%	-1.3%	-0.9%	-0.9%	-1.0%
Milk	Canada	0.1%	0.1%	0.1%	0.4%	0.4%	0.5%	0.2%	0.2%	0.3%
Milk	Chili	0.0%	0.0%	0.0%	-0.6%	-0.5%	-0.6%	-0.5%	-0.5%	-0.5%
Milk	Japan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%	-0.1%
Milk	Korea	0.0%	0.0%	0.0%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Milk	Mexico	0.0%	0.0%	0.1%	0.6%	0.6%	0.6%	0.5%	0.4%	0.5%

Milk	Russia	0.0%	0.0%	0.1%	0.5%	0.4%	0.5%	0.4%	0.3%	0.4%
Milk	United States	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Milk	Australia-NZ	0.2%	0.2%	0.3%	0.7%	0.6%	0.7%	0.2%	0.1%	0.3%
Milk	E17	0.1%	0.1%	0.2%	1.1%	1.1%	1.2%	0.8%	0.7%	0.8%
Milk	EG4	0.1%	0.1%	0.2%	1.1%	1.0%	1.1%	0.8%	0.7%	0.8%
Milk	EU7	0.1%	0.0%	0.1%	0.5%	0.5%	0.5%	0.4%	0.3%	0.4%
Maize	Brazil	2.3%	1.3%	2.8%	23.5%	21.8%	24.2%	14.4%	12.2%	15.2%
Maize	Canada	0.3%	-0.4%	0.8%	8.1%	6.9%	8.6%	15.6%	14.1%	16.2%
Maize	Chili	1.5%	1.0%	1.9%	25.1%	24.1%	25.5%	22.7%	21.5%	23.1%
Maize	Japan	-8.7%	-8.5%	-10.5%	-21.5%	-21.1%	-23.2%	-11.8%	-11.5%	-12.7%
Maize	Korea	-3.3%	-3.9%	-3.4%	14.1%	13.3%	14.1%	13.4%	12.4%	13.6%
Maize	Mexico	2.2%	1.5%	2.8%	3.8%	2.5%	4.4%	1.1%	-0.5%	1.8%
Maize	Russia	-9.4%	-10.6%	-11.2%	-78.2%	-79.1%	-79.6%	-28.4%	-30.3%	-28.8%
Maize	United States	2.9%	1.7%	1.3%	-29.9%	-30.3%	-30.6%	-12.4%	-12.6%	-13.4%
Maize	Australia-NZ	2.1%	1.1%	2.5%	31.9%	30.2%	32.5%	21.5%	19.5%	22.2%
Maize	E17	1.1%	0.2%	1.4%	-0.2%	-1.4%	0.1%	9.9%	8.2%	10.4%
Maize	EG4	3%	1%	4%	10.0%	7.8%	11.0%	21.4%	18.5%	22.7%
Maize	EU7	0.8%	0.0%	0.0%	-26.8%	-27.7%	-27.3%	-3.8%	-5.2%	-3.9%
Rice	Brazil	9.6%	8.8%	10.7%	8.7%	7.4%	9.8%	14.5%	13.6%	15.4%
Rice	Canada	1.4%	1.0%	2.1%	11.2%	10.5%	11.9%	10.3%	9.7%	10.8%
Rice	Chili	1.6%	1.0%	2.3%	33.5%	32.4%	34.5%	32.7%	31.9%	33.4%
Rice	Japan	1.1%	0.7%	1.6%	15.4%	14.7%	16.0%	15.5%	14.9%	15.9%
Rice	Korea	1.5%	1.0%	2.1%	8.2%	7.3%	9.0%	6.9%	6.2%	7.5%
Rice	Mexico	1.5%	1.0%	2.3%	6.4%	5.5%	7.1%	4.6%	3.9%	5.2%
Rice	Russia	-0.1%	-1.3%	1.1%	11.7%	10.0%	12.9%	16.8%	15.7%	17.9%
Rice	United States	1.2%	-2.1%	-10.0%	-41.2%	-39.5%	-65.7%	-10.2%	-8.7%	-33.8%
Rice	Australia-NZ	1.9%	1.2%	2.9%	-3.6%	-4.7%	-2.6%	7.8%	6.9%	8.6%
Rice	E17	3.8%	2.6%	5.3%	37.4%	35.3%	39.0%	33.8%	32.3%	35.1%
Rice	EG4	3.3%	2.0%	4.7%	17.5%	15.5%	19.0%	16.5%	15.2%	17.7%
Rice	EU7	1.3%	0.7%	2.1%	14.4%	13.4%	15.2%	17.1%	16.5%	17.8%
Wheat	Brazil	-7.9%	-7.0%	-9.5%	-90.8%	-85.3%	-97.1%	-45.8%	-42.3%	-48.1%
Wheat	Canada	-1.0%	-0.6%	-0.3%	-19.5%	-19.4%	-18.5%	-10.5%	-10.3%	-9.5%
Wheat	Chili	2.5%	2.4%	3.2%	-5.7%	-6.1%	-4.8%	-4.4%	-4.7%	-3.6%
Wheat	Japan	1.4%	1.3%	1.8%	6.5%	6.2%	7.0%	4.9%	4.7%	5.4%
Wheat	Korea	1.4%	1.3%	1.8%	5.3%	5.0%	5.8%	3.3%	3.1%	3.8%
Wheat	Mexico	0.7%	0.7%	0.9%	-3.6%	-3.6%	-3.4%	-2.3%	-2.1%	-1.9%
Wheat	Russia	2.6%	2.3%	4.2%	17.7%	16.7%	19.6%	37.0%	36.0%	38.7%
Wheat	United States	2.4%	2.6%	-0.5%	1.2%	3.1%	1.2%	1.0%	2.3%	-0.9%
Wheat	Australia-NZ	-2.9%	-2.6%	-3.0%	-18.6%	-18.4%	-18.4%	-12.2%	-11.9%	-11.8%
Wheat	E17	3.8%	3.6%	4.7%	4.8%	4.3%	5.7%	4.4%	3.9%	5.3%
Wheat	EG4	5.1%	4.8%	6.4%	0.6%	-0.1%	1.8%	-2.0%	-2.7%	-0.8%
Wheat	EU7	-5.0%	-4.8%	-4.6%	-19.3%	-19.2%	-18.6%	-22.6%	-22.4%	-22.0%
Potatoes	Brazil	1.0%	0.9%	1.4%	1.8%	1.7%	2.1%	7.5%	7.5%	7.7%
Potatoes	Canada	-0.4%	-0.5%	-0.1%	-8.1%	-8.1%	-7.9%	4.5%	4.5%	4.6%
Potatoes	Chili	0.6%	0.4%	0.8%	62.5%	62.5%	62.5%	59.4%	59.5%	59.4%
Potatoes	Japan	0.6%	0.5%	0.7%	2.2%	2.1%	2.3%	-3.5%	-3.6%	-3.4%
Potatoes	Korea	0.8%	0.7%	1.0%	-5.2%	-5.4%	-5.1%	-6.1%	-6.3%	-6.0%
Potatoes	Mexico	0.9%	0.8%	1.4%	11.4%	11.2%	11.7%	-12.7%	-12.9%	-12.5%
Potatoes	Russia	-3.3%	-3.5%	-3.1%	-3.6%	-3.7%	-3.5%	0.4%	0.4%	0.5%
Potatoes	United States	0.5%	0.4%	0.6%	5.9%	5.9%	5.1%	13.8%	13.8%	13.8%
Potatoes	Australia-NZ	0.4%	0.3%	0.7%	4.1%	4.0%	4.2%	3.4%	3.3%	3.6%
Potatoes	E17	-0.3%	-0.4%	-0.1%	-43.1%	-43.2%	-42.9%	-29.6%	-29.6%	-29.5%

Potatoes	EG4	0.3%	0.2%	0.4%	-47.0%	-47.1%	-46.9%	-48.7%	-48.7%	-48.6%
Potatoes	EU7	12.0%	12.0%	12.3%	-23.9%	-23.8%	-23.8%	-3.7%	-3.5%	-3.7%
Vegetables	Brazil	0.7%	0.1%	5.0%	-18.3%	-18.6%	-17.0%	-11.3%	-11.4%	-9.7%
Vegetables	Canada	-16.8%	-17.4%	-13.4%	4.0%	3.5%	5.3%	6.3%	6.1%	8.0%
Vegetables	Chili	0.6%	0.1%	3.7%	29.1%	28.7%	30.2%	30.1%	29.8%	31.4%
Vegetables	Japan	0.2%	-0.2%	2.8%	14.8%	14.5%	15.5%	12.4%	12.3%	13.5%
Vegetables	Korea	0.4%	0.1%	2.7%	3.4%	3.3%	4.1%	3.5%	3.4%	4.4%
Vegetables	Mexico	0.6%	0.0%	4.2%	-8.9%	-9.2%	-7.7%	-10.7%	-10.9%	-9.3%
Vegetables	Russia	-9.1%	-9.8%	-5.7%	-13.0%	-13.4%	-12.1%	-2.2%	-2.4%	-0.8%
Vegetables	United States	-0.4%	-0.8%	2.4%	2.0%	2.0%	2.6%	3.3%	3.4%	4.4%
Vegetables	Australia-NZ	0.5%	0.0%	3.4%	-0.5%	-0.9%	0.4%	2.4%	2.1%	3.6%
Vegetables	E17	0.2%	-0.5%	4.0%	-13.7%	-14.1%	-12.7%	-0.6%	-0.8%	0.9%
Vegetables	EG4	0.3%	-0.3%	3.2%	-7.5%	-7.8%	-6.8%	-10.9%	-11.0%	-9.9%
Vegetables	EU7	-0.3%	-0.8%	3.4%	-18.2%	-18.3%	-17.4%	1.4%	1.6%	2.7%
Temp-fruits	Brazil	1.5%	1.7%	3.3%	-19.7%	-20.0%	-18.6%	-7.1%	-7.0%	-5.7%
Temp-fruits	Canada	-3.5%	-3.5%	-2.7%	7.2%	6.9%	7.8%	7.1%	7.0%	7.8%
Temp-fruits	Chili	2.5%	2.6%	4.6%	53.6%	52.7%	55.3%	56.4%	55.9%	58.3%
Temp-fruits	Japan	1.0%	1.0%	1.7%	3.1%	2.7%	3.6%	2.1%	1.9%	2.7%
Temp-fruits	Korea	1.4%	1.5%	2.4%	5.4%	5.0%	6.2%	4.6%	4.3%	5.5%
Temp-fruits	Mexico	1.8%	1.8%	3.4%	-15.8%	-16.4%	-14.7%	-16.7%	-17.0%	-15.4%
Temp-fruits	Russia	-0.4%	-0.4%	0.7%	5.4%	4.9%	6.1%	8.2%	8.0%	9.1%
Temp-fruits	United States	0.7%	-0.3%	-7.5%	-1.9%	0.4%	-6.2%	0.3%	2.4%	-4.0%
Temp-fruits	Australia-NZ	1.1%	1.1%	2.1%	-3.7%	-4.1%	-3.0%	-0.4%	-0.6%	0.5%
Temp-fruits	E17	1.8%	1.8%	3.1%	-12.3%	-12.7%	-11.5%	-1.8%	-2.0%	-0.8%
Temp-fruits	EG4	1.1%	1.0%	2.1%	-6.9%	-7.2%	-6.2%	-7.1%	-7.2%	-6.2%
Temp-fruits	EU7	0.9%	1.0%	2.3%	-11.2%	-11.5%	-10.4%	0.6%	0.8%	1.7%
Sub-fruits	Brazil	0.0%	0.1%	0.5%	-24.2%	-24.1%	-23.7%	-13.8%	-13.5%	-13.5%
Sub-fruits	Canada	0.5%	0.4%	0.8%	6.1%	5.9%	6.5%	6.7%	6.5%	6.9%
Sub-fruits	Chili	-0.6%	-0.8%	-0.3%	45.5%	45.4%	46.0%	57.1%	57.2%	57.5%
Sub-fruits	Japan	0.2%	0.2%	0.3%	5.1%	5.1%	5.3%	6.3%	6.2%	6.4%
Sub-fruits	Korea	0.6%	0.5%	0.8%	22.2%	21.9%	22.6%	19.0%	18.7%	19.2%
Sub-fruits	Mexico	-0.1%	0.0%	0.3%	-13.7%	-13.6%	-13.3%	-22.0%	-21.9%	-21.8%
Sub-fruits	Russia	-1.5%	-1.6%	-1.3%	9.1%	9.0%	9.3%	13.0%	12.9%	13.1%
Sub-fruits	United States	0.1%	-0.1%	-0.6%	3.3%	3.5%	0.9%	6.5%	6.7%	4.9%
Sub-fruits	Australia-NZ	0.0%	-0.2%	0.3%	2.4%	2.2%	2.7%	2.9%	2.7%	3.1%
Sub-fruits	E17	1.0%	0.9%	1.3%	-9.1%	-9.2%	-8.7%	-4.4%	-4.6%	-4.2%
Sub-fruits	EG4	0.4%	0.3%	0.6%	-0.4%	-0.6%	-0.1%	-1.6%	-1.7%	-1.4%
Sub-fruits	EU7	0.1%	0.1%	0.4%	-8.3%	-8.2%	-7.9%	6.1%	6.4%	6.3%
Sugarcane	Brazil	0.9%	0.8%	1.1%	8.8%	8.7%	8.9%	10.7%	10.6%	10.9%
Sugarcane	Canada	0.2%	0.1%	0.2%	1.9%	1.9%	1.9%	2.3%	2.3%	2.3%
Sugarcane	Chili	0.6%	0.5%	0.7%	9.9%	9.8%	10.0%	10.7%	10.6%	10.8%
Sugarcane	Japan	0.3%	0.2%	0.2%	5.0%	5.0%	4.9%	5.8%	5.8%	5.8%
Sugarcane	Korea	0.3%	0.2%	0.3%	3.4%	3.4%	3.5%	3.6%	3.5%	3.6%
Sugarcane	Mexico	0.7%	0.6%	0.8%	-6.9%	-6.8%	-6.8%	-9.1%	-9.1%	-9.1%
Sugarcane	Russia	-0.8%	-0.9%	-0.8%	4.0%	3.9%	4.0%	9.1%	9.0%	9.1%
Sugarcane	United States	0.1%	0.0%	-0.2%	1.6%	1.8%	1.4%	7.5%	7.5%	7.3%
Sugarcane	Australia-NZ	0.2%	0.0%	0.0%	8.7%	8.8%	8.6%	9.8%	9.9%	9.7%
Sugarcane	E17	-0.7%	-0.9%	-0.8%	-10.5%	-10.5%	-10.6%	5.5%	5.5%	5.6%
Sugarcane	EG4	0.2%	0.1%	0.0%	-16.1%	-16.0%	-16.4%	0.5%	0.7%	0.4%
Sugarcane	EU7	0.9%	0.8%	0.9%	-2.0%	-2.0%	-2.1%	6.5%	6.5%	6.5%
Cotton	Brazil	5.2%	3.9%	7.0%	-25.7%	-28.3%	-25.1%	-13.0%	-15.0%	-12.5%
Cotton	Canada	1.4%	1.1%	1.9%	11.1%	10.4%	11.3%	9.7%	9.0%	9.8%

Cotton	Chili	0.3%	0.3%	0.4%	2.7%	2.5%	2.8%	2.3%	2.2%	2.4%
Cotton	Japan	0.8%	0.6%	1.0%	6.3%	5.9%	6.4%	5.4%	5.0%	5.5%
Cotton	Korea	1.4%	1.1%	1.9%	11.1%	10.4%	11.3%	9.7%	9.0%	9.8%
Cotton	Mexico	1.0%	0.7%	1.3%	2.2%	1.5%	2.3%	1.4%	0.8%	1.5%
Cotton	Russia	1.4%	1.1%	1.9%	11.1%	10.4%	11.3%	9.7%	9.0%	9.8%
Cotton	United States	-0.3%	-4.2%	-10.9%	-40.9%	-39.3%	-42.5%	-19.1%	-15.5%	-20.3%
Cotton	Australia-NZ	83.0%	48.8%	109.9%	-778.7%	-843.5%	-769.2%	181.4%	121.7%	194.0%
Cotton	E17	17.7%	14.8%	20.0%	22.5%	16.9%	23.2%	20.6%	16.1%	21.4%
Cotton	EG4	1.4%	1.1%	1.9%	11.1%	10.4%	11.3%	9.7%	9.0%	9.8%
Cotton	EU7	1.5%	1.1%	2.0%	10.7%	9.9%	10.9%	9.3%	8.6%	9.4%

1. The absolute size of trade change depends on the initial volume of trade flows, net trade changes can result in shift in the direction of trade flows, which should be accounted for when interpreting these results.

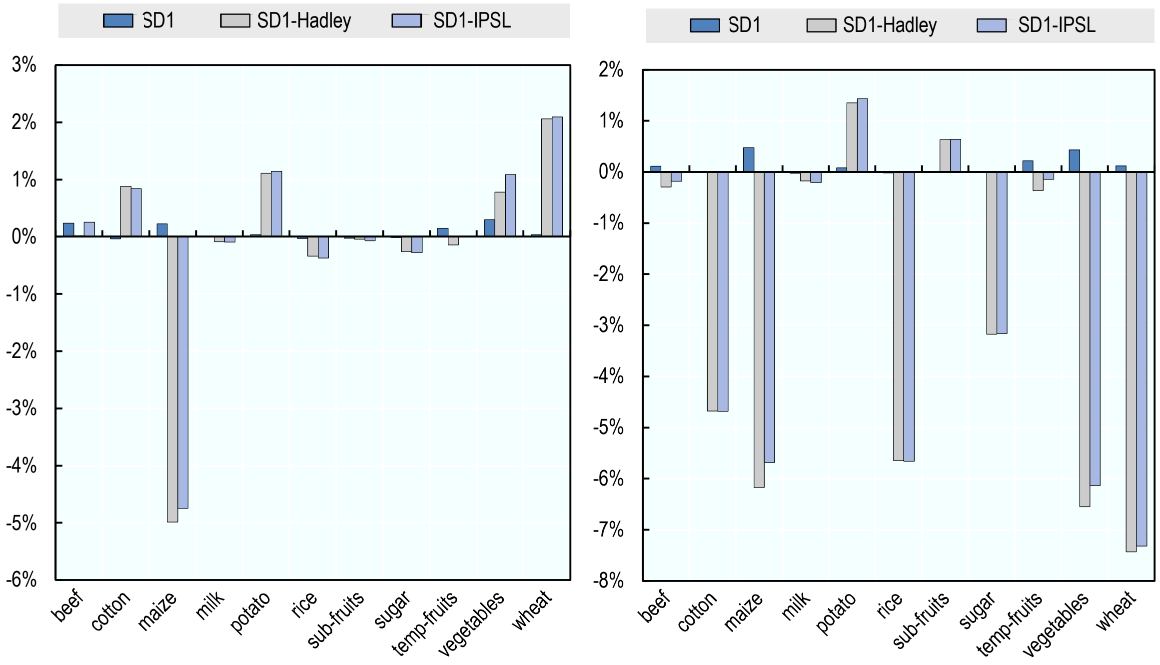
2. EG4: France, Germany, Italy, United Kingdom, E17: Austria, Belgium, Luxemburg, Netherlands, Ireland, Spain, Portugal, Greece, Czech Republic, Slovakia, Poland, Hungary, Estonia, Finland, Denmark, Sweden Slovenia; EU7: Bulgaria, Lithuania, Latvia, Croatia, Malta, Cyprus, Romania.

3. Sub-fruits are subtropical fruits, temp-fruits are temperate fruits.

Source: Derived from IMPACT simulations.

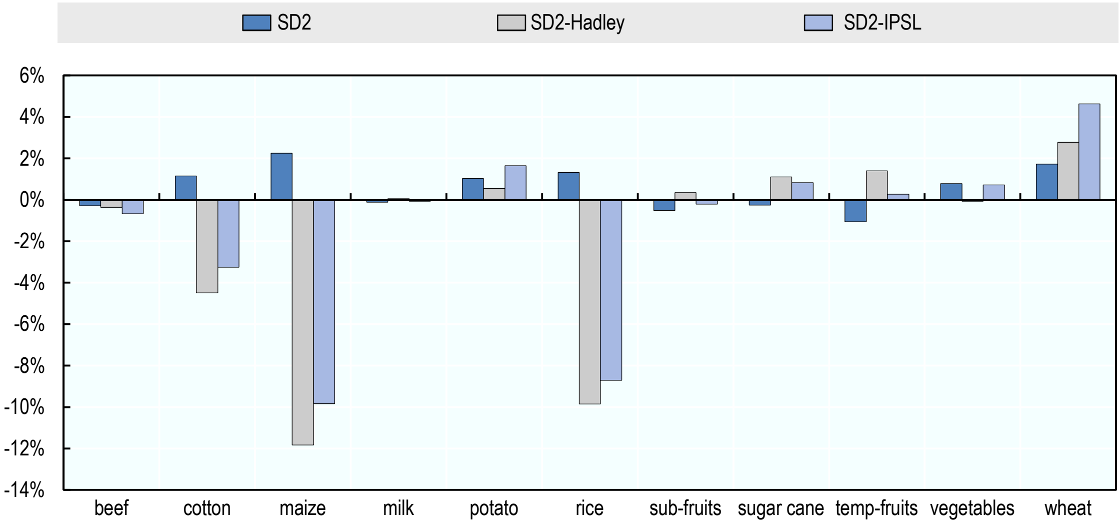
3.A2.2. Results of the simulation for the drought scenarios

Figure 3.A2.5. Changes in production compared to the baseline for China (left) and India (right) with a drought and climate change scenarios in the United States in 2021



Note: Sub-fruits are subtropical fruits, temp-fruits are temperate fruits.
Source: Derived from IMPACT results.

Figure 3.A2.6. Changes in US production compared to the baseline with a drought and climate change scenarios in China and India in 2030



Note: Sub-fruits are subtropical fruits, temp-fruits are temperate fruits.

Source: Derived from IMPACT results.

Trade effects of the two drought scenarios

Table 1. Table 3.A2.2. Effects of the drought scenarios on net trade

Crop	Country	SD1	SD1-Hadley	SD1-IPSL	SD2	SD2-Hadley	SD2-IPSL
Beef	Brazil	0.9%	0.6%	0.7%	0.0%	-0.5%	-0.4%
Beef	Canada	0.7%	0.6%	0.7%	-0.2%	-0.3%	-0.2%
Beef	Chile	0.6%	0.8%	0.7%	0.4%	0.8%	0.7%
Beef	China	0.5%	0.6%	0.6%	0.0%	0.2%	0.2%
Beef	E17	0.6%	0.8%	0.8%	0.0%	0.4%	0.3%
Beef	EG4	0.6%	0.8%	0.7%	0.1%	0.5%	0.4%
Beef	EU7	0.4%	0.4%	0.4%	-0.1%	-0.1%	-0.1%
Beef	India	0.5%	0.3%	0.4%	-0.5%	-0.9%	-0.8%
Beef	Japan	0.4%	0.3%	0.3%	0.0%	-0.1%	-0.1%
Beef	Korea	0.2%	0.1%	0.1%	-0.1%	-0.2%	-0.2%
Beef	Mexico	0.5%	0.6%	0.6%	0.0%	0.2%	0.2%
Beef	Australia-NZ	1.2%	0.9%	1.0%	-0.6%	-1.0%	-0.9%
Beef	Russia	0.4%	0.4%	0.4%	-0.1%	-0.2%	-0.2%
Beef	United States	-2.7%	-2.8%	-2.8%	-0.1%	-0.2%	-0.2%
Beef	South Africa	0.6%	0.5%	0.6%	-0.1%	-0.1%	-0.1%
Cotton	Brazil	-0.2%	-4.7%	-4.3%	6.2%	-2.8%	-2.0%
Cotton	Canada	0.0%	2.6%	2.4%	1.9%	6.6%	6.2%
Cotton	Chile	0.0%	0.6%	0.6%	0.5%	1.6%	1.5%
Cotton	China	0.1%	4.8%	4.4%	-4.9%	3.3%	2.7%
Cotton	E17	-0.2%	5.8%	4.6%	9.9%	21.8%	19.1%
Cotton	EG4	0.0%	2.6%	2.4%	1.9%	6.6%	6.2%
Cotton	EU7	0.0%	2.6%	2.4%	2.0%	6.6%	6.2%
Cotton	India	0.0%	-3.4%	-4.1%	1.7%	-3.3%	-4.3%
Cotton	Japan	0.0%	1.4%	1.3%	1.1%	3.7%	3.5%
Cotton	Korea	0.0%	2.6%	2.4%	1.9%	6.6%	6.2%
Cotton	Mexico	0.0%	0.3%	0.2%	1.5%	2.2%	2.1%
Cotton	Australia-NZ	-1.8%	-237.1%	32.9%	143.4%	-276.5%	216.8%
Cotton	Russia	0.0%	2.6%	2.4%	1.9%	6.6%	6.2%
Cotton	United States	-0.2%	-4.1%	-0.7%	5.1%	-2.3%	4.1%
Cotton	South Africa	-0.2%	1.9%	2.0%	3.8%	7.7%	7.8%
Maize	Brazil	0.6%	5.7%	2.5%	4.3%	13.9%	8.0%
Maize	Canada	0.4%	2.4%	4.7%	3.0%	6.4%	10.0%
Maize	Chile	0.3%	5.8%	5.7%	2.4%	12.7%	12.3%
Maize	China	1.0%	4.3%	1.0%	-20.0%	-12.8%	-17.5%
Maize	E17	0.6%	2.6%	3.7%	3.5%	6.4%	8.4%
Maize	EG4	0.8%	6.4%	7.3%	7%	16%	18%
Maize	EU7	0.4%	-1.6%	-0.8%	1.1%	-2.5%	-1.3%
Maize	India	0.5%	-3.3%	-5.9%	1.9%	-3.7%	-7.5%
Maize	Japan	0.0%	-3.5%	-2.8%	-1.5%	-8.1%	-6.7%
Maize	Korea	0.4%	3.8%	3.6%	2.1%	8.4%	7.9%
Maize	Mexico	0.5%	0.2%	1.8%	3.7%	3.0%	6.1%
Maize	Australia-NZ	0.5%	7.1%	6.3%	3.4%	15.7%	14.1%
Maize	Russia	0.3%	-6.3%	-4.6%	-0.9%	-14.8%	-11.4%
Maize	United States	-1.5%	-5.6%	-2.4%	6.6%	-2.0%	3.4%
Maize	South Africa	0.4%	0.1%	-3.5%	3.0%	2.8%	-3.1%
Milk	Brazil	0.0%	-0.3%	-0.2%	-0.3%	-0.7%	-0.7%
Milk	Canada	0.0%	0.1%	0.0%	0.1%	0.2%	0.2%
Milk	Chile	0.0%	-0.2%	-0.2%	-0.1%	-0.3%	-0.3%
Milk	China	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%
Milk	E17	0.0%	0.2%	0.2%	0.2%	0.6%	0.5%
Milk	EG4	0.0%	0.2%	0.2%	0.2%	0.6%	0.5%
Milk	EU7	0.0%	0.1%	0.1%	0.1%	0.3%	0.2%
Milk	India	0.0%	-0.1%	-0.1%	0.0%	-0.2%	-0.1%
Milk	Japan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Milk	Korea	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
Milk	Mexico	0.0%	0.1%	0.1%	0.0%	0.3%	0.2%
Milk	Australia-NZ	0.0%	0.1%	0.0%	0.2%	0.3%	0.2%
Milk	Russia	0.0%	0.1%	0.1%	0.1%	0.2%	0.2%
Milk	United States	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%

Milk	South Africa	0.0%	0.0%	0.0%	0.1%	0.2%	0.1%
Potatoes	Brazil	0.1%	0.6%	1.9%	3.1%	3.7%	6.1%
Potatoes	Canada	0.1%	0.3%	3.4%	3.1%	3.1%	8.5%
Potatoes	Chile	0.1%	13.7%	12.7%	3.4%	30.2%	28.1%
Potatoes	China	0.1%	3.3%	2.0%	-11.2%	-6.1%	-8.4%
Potatoes	E17	0.1%	-11.8%	-7.3%	2.6%	-18.8%	-10.5%
Potatoes	EG4	0%	-13%	-13%	2.0%	-22.0%	-22.4%
Potatoes	EU7	0.0%	-3.2%	-1.1%	2.8%	-4.4%	-0.2%
Potatoes	India	0.2%	3.4%	2.4%	2.5%	7.8%	6.1%
Potatoes	Japan	0.1%	0.8%	-0.6%	1.9%	2.8%	0.3%
Potatoes	Korea	0.1%	-1.1%	-1.2%	2.3%	-0.2%	-0.4%
Potatoes	Mexico	0.1%	2.9%	-3.6%	3.0%	7.8%	-3.8%
Potatoes	Australia-NZ	0.1%	2.7%	2.1%	2.1%	6.3%	5.3%
Potatoes	Russia	0.1%	3.5%	3.1%	2.5%	8.4%	7.7%
Potatoes	United States	-1.9%	-0.3%	1.5%	2.4%	5.4%	8.9%
Potatoes	South Africa	0.0%	2.0%	1.3%	2.4%	5.9%	4.5%
Rice	Brazil	0.0%	0.3%	1.5%	3.6%	4.2%	6.4%
Rice	Canada	0.0%	2.9%	2.9%	2.3%	7.4%	7.2%
Rice	Chile	0.0%	8.4%	8.4%	2.9%	18.7%	18.5%
Rice	China	0.0%	2.1%	2.1%	-4.4%	-0.9%	-1.0%
Rice	E17	0.0%	7.9%	7.2%	4.5%	19.7%	18.2%
Rice	EG4	-0.1%	5.1%	4.7%	4.4%	13.9%	12.9%
Rice	EU7	0.0%	3.5%	3.7%	2.2%	8.9%	9.3%
Rice	India	0.0%	-3.8%	-4.3%	-2.4%	-8.7%	-9.2%
Rice	Japan	0.0%	3.4%	3.6%	1.8%	8.3%	8.5%
Rice	Korea	0.0%	1.7%	1.6%	2.1%	5.3%	5.0%
Rice	Mexico	0.0%	1.8%	1.9%	2.6%	5.8%	5.8%
Rice	Australia-NZ	0.0%	-2.4%	2.0%	3.6%	-0.1%	7.0%
Rice	Russia	0.0%	3.8%	4.3%	3.3%	10.7%	11.6%
Rice	United States	-0.1%	-7.3%	0.4%	5.0%	-8.4%	5.5%
Rice	South Africa	0.0%	2.9%	2.8%	2.3%	7.4%	7.1%
Sub-fruits	Brazil	-2.4%	-148.0%	-112.7%	-0.4%	-10.5%	-8.1%
Sub-fruits	Canada	0.1%	3.4%	3.2%	0.6%	3.5%	3.3%
Sub-fruits	Chile	0.0%	5.2%	5.4%	-1.3%	24.7%	25.7%
Sub-fruits	China	1.1%	124.7%	114.9%	0.4%	2.6%	2.4%
Sub-fruits	E17	-0.1%	1.8%	-6.9%	-0.1%	0.0%	-1.8%
Sub-fruits	EG4	-0.1%	4.2%	-8.6%	0.1%	0.6%	-1.2%
Sub-fruits	EU7	-0.1%	-0.2%	1.7%	-1.0%	-1.4%	3.2%
Sub-fruits	India	1.9%	82.8%	75.0%	-0.5%	2.3%	2.0%
Sub-fruits	Japan	0.0%	4.4%	3.9%	-0.1%	2.3%	2.0%
Sub-fruits	Korea	0.0%	5.2%	5.3%	0.5%	5.1%	5.2%
Sub-fruits	Mexico	-1.9%	-55.3%	-51.0%	-0.4%	-7.0%	-6.5%
Sub-fruits	Australia-NZ	0.0%	3.3%	3.1%	-0.1%	4.7%	4.5%
Sub-fruits	Russia	0.0%	4.2%	4.1%	-0.4%	3.1%	3.0%
Sub-fruits	United States	0.0%	40.2%	37.3%	0.2%	3.0%	2.8%
Sub-fruits	South Africa	-0.2%	-2.8%	3.4%	-0.8%	-6.3%	5.2%
Temp-fruits	Brazil	0.4%	-3.9%	-1.2%	-0.5%	-9.0%	-3.6%
Temp-fruits	Canada	0.2%	2.3%	2.3%	0.0%	4.0%	4.1%
Temp-fruits	Chile	0.6%	14.1%	14.8%	0.6%	25.3%	26.7%
Temp-fruits	China	0.4%	1.0%	0.9%	0.4%	1.3%	1.2%
Temp-fruits	E17	0.4%	-2.1%	-0.2%	-0.3%	-5.1%	-1.5%
Temp-fruits	EG4	0.3%	-0.9%	-1.8%	-0.4%	-2.7%	-4.2%
Temp-fruits	EU7	0.3%	-0.4%	1.0%	-1.1%	-2.7%	0.0%
Temp-fruits	India	0.5%	1.1%	1.0%	0.6%	1.8%	1.5%
Temp-fruits	Japan	0.3%	0.5%	0.4%	0.1%	0.4%	0.3%
Temp-fruits	Korea	0.4%	0.9%	1.0%	0.3%	1.1%	1.3%
Temp-fruits	Mexico	0.5%	-3.9%	-4.1%	0.3%	-8.1%	-8.4%
Temp-fruits	Australia-NZ	0.3%	-1.5%	-0.2%	0.3%	-2.8%	-0.7%
Temp-fruits	Russia	0.3%	1.7%	1.9%	-0.1%	2.3%	2.6%
Temp-fruits	United States	-5.0%	-3.7%	-3.7%	-0.5%	1.9%	2.0%
Temp-fruits	South Africa	0.3%	-1.3%	-1.2%	-1.3%	-4.3%	-4.1%
Sugarcane	Brazil	0.0%	1.6%	2.1%	0.1%	2.8%	3.6%
Sugarcane	Canada	0.0%	0.4%	0.6%	0.0%	0.8%	1.2%
Sugarcane	Chile	0.0%	2.2%	2.5%	0.1%	4.5%	5.3%
Sugarcane	China	0.0%	0.4%	0.7%	0.0%	0.7%	1.1%
Sugarcane	E17	0.0%	0.5%	2.0%	-0.4%	0.1%	3.4%
Sugarcane	EG4	0.0%	0.2%	1.1%	-0.8%	-1.2%	0.9%
Sugarcane	EU7	0.0%	0.4%	1.4%	-0.2%	0.6%	2.7%

Sugarcane	India	0.0%	-1.8%	-2.7%	0.1%	-3.2%	-5.1%
Sugarcane	Japan	0.0%	0.8%	1.1%	-0.2%	1.5%	2.0%
Sugarcane	Korea	0.0%	0.7%	0.9%	0.2%	1.5%	1.8%
Sugarcane	Mexico	0.0%	-1.8%	-1.0%	0.0%	-3.7%	-2.0%
Sugarcane	Australia-NZ	0.0%	3.4%	4.4%	-1.0%	5.3%	7.3%
Sugarcane	Russia	0.0%	1.5%	1.9%	0.0%	3.1%	3.9%
Sugarcane	United States	0.0%	1.2%	1.7%	-0.2%	2.3%	3.3%
Sugarcane	South Africa	0.0%	1.2%	0.2%	-0.2%	2.6%	0.7%
Vegetables	Brazil	0.4%	-3.2%	-2.1%	3.4%	-3.5%	-1.6%
Vegetables	Canada	0.3%	6.0%	6.1%	2.8%	14.5%	14.8%
Vegetables	Chile	0.3%	7.6%	8.0%	2.9%	17.0%	17.7%
Vegetables	China	0.5%	2.2%	2.2%	-4.4%	-1.1%	-1.2%
Vegetables	E17	0.4%	-0.9%	0.8%	3.1%	0.6%	3.9%
Vegetables	EG4	0.3%	-1.2%	-2.4%	2.1%	-0.8%	-2.8%
Vegetables	EU7	0.3%	1.6%	3.0%	2.0%	4.4%	7.1%
Vegetables	India	0.6%	-4.4%	-5.8%	4.5%	-3.8%	-6.1%
Vegetables	Japan	0.3%	2.2%	2.4%	1.8%	5.7%	6.1%
Vegetables	Korea	0.3%	1.1%	1.3%	1.8%	3.3%	3.7%
Vegetables	Mexico	0.4%	-2.6%	-2.6%	3.3%	-1.8%	-1.8%
Vegetables	Australia-NZ	0.4%	0.2%	1.3%	2.8%	2.7%	4.6%
Vegetables	Russia	0.4%	3.9%	4.3%	2.2%	9.3%	10.1%
Vegetables	United States	-9.2%	-8.3%	-7.7%	2.6%	4.7%	5.6%
Vegetables	South Africa	0.3%	-1.1%	-0.5%	2.8%	-0.1%	1.1%
Wheat	Brazil	-0.1%	-8.2%	-5.8%	0.0%	-20.8%	-15.0%
Wheat	Canada	0.2%	-2.4%	-1.8%	5.8%	1.3%	2.3%
Wheat	Chile	0.1%	-1.7%	-1.0%	3.6%	0.1%	1.4%
Wheat	China	0.2%	2.7%	3.3%	-18.1%	-14.0%	-13.4%
Wheat	E-17	0.3%	1.9%	1.7%	5.1%	7.3%	7.0%
Wheat	EG4	0.4%	-0.4%	-0.2%	6.3%	4.4%	4.8%
Wheat	EU7	0.0%	-2.4%	-2.1%	4.1%	-0.6%	0.1%
Wheat	India	0.3%	-5.9%	-6.9%	-2.5%	-12.1%	-13.8%
Wheat	Japan	0.1%	1.1%	1.1%	2.1%	3.9%	4.0%
Wheat	Korea	0.1%	0.7%	0.5%	2.1%	3.2%	3.0%
Wheat	Mexico	0.1%	-1.4%	-0.8%	2.3%	-0.5%	0.7%
Wheat	Australia-NZ	0.1%	-3.1%	-2.5%	3.4%	-2.4%	-1.4%
Wheat	Russia	0.3%	5.8%	6.1%	6.8%	18.5%	19.3%
Wheat	United States	-4.2%	0.0%	-1.8%	5.7%	13.2%	10.1%
Wheat	South Africa	0.1%	-2.7%	-2.1%	2.8%	-2.1%	-0.9%

1. The absolute size of trade change depends on the initial volume of trade flows, net trade changes can result in shift in the direction of trade flows, which should be accounted for when interpreting these results.

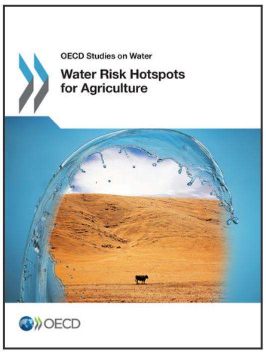
2. EG4: France, Germany, Italy, United Kingdom, E17: Austria, Belgium, Luxemburg, Netherlands, Ireland, Spain, Portugal, Greece, Czech Republic, Slovakia, Poland, Hungary, Estonia, Finland, Denmark, Sweden Slovenia; EU7: Bulgaria, Lithuania, Latvia, Croatia, Malta, Cyprus, Romania.

3. Sub-fruits are subtropical fruits, temp-fruits are temperate fruits.

Source: Results from the IMPACT simulations.

Notes

1. Andrews et al. (2004) also find that for a given exceedance probability, the ratio of the El Niño to non–El Niño annual peak floods varies from more than 10 near 32°N to less than 0.7 near 42°N.



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