EXTREME WEATHER EVENTS AND CROP PRICE SPIKES IN A CHANGING CLIMATE

Illustrative global simulation scenarios

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Agriculture is highly sensitive to climate variability and weather extremes. Various impact studies have considered the effects on global food production and prices of projected long-run trends in temperature, precipitation and CO_2 concentrations caused by climate change. But an area that remains underexplored is the impact on food prices that may result from an expected increase in the frequency and intensity of extreme weather events. This study uses a global dynamic multi-region computable general equilibrium (CGE) model to explore the potential impacts on food prices of a number of extreme weather event scenarios in 2030 for each of the main exporting regions for rice, maize, and wheat.

CONTENTS

ABBREVIATIONS

CO_2	Carbon dioxide
CGE	Computable general equilibrium
FAO	UN Food and Agriculture Organization
AR4	Fourth Assessment Report of the IPCC
GCM	General circulation model
GDP	Gross domestic product
GTAP	Global Trade Analysis Project
ha	Hectare
hg	Hectogram
IDS	Institute of Development Studies
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
OECD	Organization for Economic Co-operation and Development
SACU	Southern African Customs Union
SRES	IPCC Special Report on Emission Scenarios
SSA	Sub-Saharan Africa

1 INTRODUCTION

Agriculture is highly sensitive to climate variability and weather extremes, such as droughts, floods and severe storms. Climate change is set to impact significantly on food and hunger in the future. Various climate change impact studies have considered the effects of projected long-run trends in temperature, precipitation and CO_2 concentrations on crop yields, and a number of studies have explored the prospective consequences of these trends for agricultural production and global food prices. But an area that remains underexplored is the potential impact of climate change on food price volatility, that is, the nature of food price fluctuations around the long-run trends that will result from the predicted increases in extreme weather events in the future.

Recent research by the Institute of Development Studies (IDS) published at the launch of Oxfam's Growing a Better Future (GROW) campaign suggested a strong upward trend in world market prices of the main traded staple crops over the next 20 years, with a significant portion of the increase caused by climate change (Willenbockel 2011). Research by the International Food Policy Research Institute (IFPRI), the UN Food and Agriculture Organization (FAO) and others (Nelson *et al.* 2010; Foresight 2011; van der Mensbrugghe *et al*. 2011; Hertel, Burke and Dobell 2010) also projects agricultural price increases as a result of climate change and population growth in combination with low agricultural productivity growth.

The present study intends to build on the earlier analysis by looking further at the potential impact of climate change on food prices – focusing in particular on the impact of extreme weather events on price fluctuations. This is a gap in research that we need to understand, given the potentially devastating impact of sudden food price hikes on access and livelihoods in low-income countries. For people in poverty, the challenge of volatility is not the same as that arising from long-run food price trends. Temporary price spikes are unpredictable over longer horizons, and low-income countries and poor and vulnerable people cannot absorb or adjust to sudden shocks easily.

The analytical framework employed in the core of this study is a global dynamic multi-region computable general equilibrium (CGE) model. The model distinguishes 22 geographical regions including the main net-exporters of staple crops and eight sub-Saharan African (SSA) regions. This geographical aggregation structure supports a quantitative assessment of the impact of adverse extreme weather shocks in the crop-exporting regions on prices faced by consumers in the SSA sub-regions that are of particular interest for Oxfam. In a first stage, the model will be used to generate long-run baseline projections for the evolution of production, consumption, trade and prices by region and commodity group up to 2030 using essentially the same assumptions about the key drivers of change – population growth, labour force growth, total factor productivity growth in agricultural and non-agricultural sectors – as in Willenbockel (2011). The baseline projections take account of climate change impacts on agricultural productivity due to changes in projected *means* of temperature and precipitation, but do not take account of potential additional impacts due to extreme weather events. In a second stage, the model is used to simulate the additional impacts of idiosyncratic adverse temporary shocks to crop productivity in each of the main exporting regions for rice, maize and wheat (North America, Oceania, South America, and, in the case of rice, additionally India and Other East Asia) on prices, production and consumption in 2030 across the regions distinguished in the model. A further simulation scenario combines the poor-harvest shocks with the simultaneous imposition of taxes on exports of staple crops. Finally, the direct impact of extreme weather events in the sub-Saharan African regions is simulated.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) anticipates with 'high confidence' that 'projected changes in the frequency and severity of extreme climate events will have more serious consequences for food and forestry production, and food insecurity, than will changes in projected means of temperature and precipitation'

(Easterling *et al*. 2007). However, the current state of climate science does not allow us to predict with high confidence to what extent the intensity and frequency of extreme weather events in individual regions of the world will change over the coming decades. In the presence of high uncertainty about future outcomes, an exploratory ‘what-if’ scenario analysis appears to be a suitable approach.[1] The aim is to explore the potential magnitude of the short-run price impacts of a selected range of hypothetical extreme weather shocks. These hypothetical weather shocks are assumed to take place in 2030, but the results are not meant to provide forecasts or point predictions for that particular year.

The size orders for the assumed crop yield impacts due to extreme weather events are conservatively based on historical observations of yield deviations from trend in bad harvest years over the last three decades for each of the regions of interest. In plain language, the basic logic of this approach can be stated as follows. Extreme weather shocks on agricultural yields of this order of magnitude have been observed in the past. Climate science suggests that similar shocks might recur more frequently in a future hotter climate. So, let us explore the potential future food price impacts of a range of such shocks.

The report is organized as follows. In order to provide a scientific underpinning for the assumed extraordinary shocks to crop yields in the main crop-producing regions in the simulation scenarios, Section 2 gives a concise non-technical overview of the current state of science concerning projections of changes in the frequency of extreme events due to anthropogenic climate change, with a focus on the geographic regions of particular interest for the present study. Section 3 contains a short informal outline of the global simulation model and the benchmark database. Section 4, in conjunction with Appendix 1, details the assumptions underlying the simulation scenarios. Section 5 presents the results of the simulation analysis.

2 CLIMATE CHANGE AND EXTREME WEATHER EVENTS: A BRIEF REVIEW OF THE CURRENT STATE OF SCIENCE

In order to provide a tentative scientific underpinning for the assumed extraordinary shocks to crop yields in the main crop-producing regions in the simulation scenarios, this section contains a concise non-technical overview of the current state of science concerning climate model based projections of the links between anthropogenic climate change and changes in the frequency of extreme events, with a particular focus on the geographic regions of particular interest for the present study. Section 2.1 summarizes the IPCC Fourth Assessment Report (AR4) of 2007 in this respect, while Section 2.2 turns to pertinent recent studies post-AR4 studies.

To maintain a proper perspective, it is worth keeping the IPCC definition of extreme weather events in mind:

> *'An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density function. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. Single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).'*
>
> (Solomon *et al*. (eds.) 2007: 945–6)

Note that this section is *not* concerned with climate change impacts on agriculture associated with the gradual changes in the long-run *mean values* of temperature and precipitation.

2.1 EXTREME WEATHER EVENTS IN THE IPCC FOURTH ASSESSMENT REPORT

2.1.1 The global picture

The type, frequency and intensity of extreme events like heat waves, droughts or floods are expected to change as earth's climate changes, and these changes could occur even with relatively small mean climate changes. Changes in some types of extreme events have already been observed, e.g. increases in the frequency and intensity of heat waves and heavy precipitation events (Meehl *et al*. 2007).

It is very likely that heat waves will be more intense, more frequent and longer lasting in a future warmer climate. The European heat wave of 2003 is an example of the type of extreme heat event, lasting from several days to over a week, that is likely to become more common in a warmer future climate.

Intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas that experience increases in mean precipitation. Even in areas where mean precipitation decreases (most subtropical and mid-latitude regions), precipitation intensity is projected to increase, but there would be longer periods between rainfall events. There is a tendency for drying of the mid-continental areas during summer, indicating a greater risk of droughts in those regions. Precipitation extremes increase more than does the mean in most tropical and mid- and high latitude areas.

More specifically: in a warmer future climate, most Atmosphere-Ocean General Circulation Models (GCMs) project increased summer dryness and winter wetness in most parts of the northern middle and high latitudes. Summer dryness indicates a greater risk of drought. Along with the risk of drying, there is an increased chance of intense precipitation and flooding due to the greater water-holding capacity of a warmer atmosphere. This has already been observed and is projected to continue because, in a warmer world, precipitation tends to be concentrated into more intense events, with longer periods of little precipitation in between. Therefore, intense and heavy downpours would be interspersed with longer relatively dry periods. Another aspect of these projected changes is that wet extremes are projected to become more severe in many areas where mean precipitation is expected to increase, and dry extremes are projected to become more severe in areas where mean precipitation is projected to decrease.

In concert with the results for increased extremes of intense precipitation, even if the wind strength of storms in a future climate did not change, there would be an increase in extreme rainfall intensity. In particular, over land in the northern hemisphere, an increase in the likelihood of very wet winters is projected over much of central and Northern Europe due to the increase in intense precipitation during storm events. This suggests an increased chance of flooding over Europe and other mid-latitude regions due to more intense rainfall and snowfall events producing more runoff. Similar results apply for summer precipitation, with implications for more flooding in the Asian monsoon region and other tropical areas. The increased risk of floods in a number of major river basins in a future warmer climate has been related to an increase in river discharge with an increased risk of future intense storm-related precipitation events and flooding. Some of these changes would be extensions of trends already underway.

There is evidence from modelling studies that future tropical cyclones could become more severe, with greater wind speeds and more intense precipitation. Studies suggest that such changes may already be underway; there are indications that the average number of Category 4 and 5 hurricanes per year has increased over the past 30 years. Some modelling studies have projected a decrease in the number of tropical cyclones globally due to the increased stability of the tropical troposphere in a warmer climate, characterized by fewer weak storms and greater numbers of intense storms. A number of modelling studies have also projected a general tendency for more intense but fewer storms outside the tropics, with a tendency towards more extreme wind events and higher ocean waves in several regions in association with those deepened cyclones. Models also project a poleward shift of storm tracks in both hemispheres by several degrees of latitude.[2]

2.1.2 Expectations of extreme weather events in the main staple crop-exporting regions and sub-Saharan Africa

Chapter 11 of the IPCC Fourth Assessment Report (Christensen *et al*. 2007) contains regionally disaggregated estimates of the probabilities of extremely warm, extremely wet and extremely dry seasons for the A1B scenario and for the time period 2080 to 2099, derived from simulations of 21 global climate models. An ‘extremely warm’ summer is defined as follows. Examining all the summers simulated in a particular realisation of a model in the 1980 to 1999 control period, the warmest of these 20 summers can be computed as an estimate of the temperature of the warmest 5 per cent of all summers in the control period. The period 2080 to 2099 simulations are then examined, and the fraction of the summers exceeding this warmth determined. This is referred to as the probability of extremely warm summers. The results are tabulated after averaging over models, and similarly for both extremely low and extremely high seasonal precipitation amounts. Values are only shown when at least 14 out of the 21 climate models agree on an increase or a decrease in the extremes. By construction, values smaller (larger) than five per cent indicate a decrease (increase) in the frequency of extremes compared with the 1980–99 control period.

Table 2.1 reports the 2080–99 probabilities for the main crop-exporting regions and for SSA, which are of particular interest for the present study.

Table 2.1: Probabilities of extremely warm, wet and dry seasons 2080–99 suggested by IPCC GCM model projections *(in per cent)*

Region	Sub-region	Season	Extreme warm	Extreme wet	Extreme dry
North America	West	DJF	80	18	3
		MAM	87	14	-
		JJA	100	3	-
		SON	95	17	2
	East	DJF	78	24	-
		MAM	86	23	2
		JJA	98	-	-
		SON	97	19	-
	Central	DJF	71	7	4
		MAM	81	19	15
		JJA	93	-	-
		SON	91	11	-
South America	Amazon	DJF	93	27	4
		MAM	100	18	-
		JJA	100	-	-
		SON	100	-	-
	South	DJF	100	-	-
		MAM	98	8	-
		JJA	95	-	-
		SON	99	-	-
Australia	North	DJF	89	-	-
		MAM	92	-	3
		JJA	94	3	-
		SON	98	-	-
	South	DJF	95	-	-
		MAM	90	-	6
		JJA	95	-	17
		SON	95	-	15
Asia	East	DJF	96	18	2
		MAM	98	35	2
		JJA	100	32	1
		SON	10	20	3
	South	DJF	99	14	-
		MAM	100	32	1

Region	Sub-region	Season	Extreme warm	Extreme wet	Extreme dry
		JJA	96	29	3
		SON	100	39	3
Sub-Saharan Africa	West	DJF	100	21	4
		MAM	100	-	-
		JJA	100	19	-
		SON	100	15	-
	East	DJF	100	25	1
		MAM	100	15	4
		JJA	100	-	-
		SON	100	21	3
	South	DJF	98	11	-
		MAM	100	-	-
		JJA	100	1	23
		SON	100	1	20

Note: DJF: December to February, MAM: March to May, JJA: June to August, SON: September to November.
Source: Adapted from Christensen et al. (2007: Table 11.1). See main text for explanations.

For example, an extremely warm June to August (JJA) season in a region is defined as a JJA season with an average temperature as high or higher than observed during the hottest JJA season over the period 1980–1999; i.e. the frequency of its occurrence was once in 20 years (probability of 5 per cent) in the historical control period. A rise to 100 per cent – such as that reported for East Asia in Table 2.1 – means that from 2080 onwards every JJA season will be extremely warm in this sense. Similarly, the figure of 17 per cent for extremely dry JJA seasons in Southern Australia means that droughts of an intensity observed only once in 20 years in this season in the past would recur every five to six years in the 2080/90s.

It is worth emphasizing that the blanks in Table 2.1 do not indicate the absence of changes in extreme wet or extreme dry events in the model projections. Rather, these blanks reflect the absence of a 2/3 majority agreement about the sign of projected changes across the 21 global models included in the synopsis. In particular, projections concerning extreme events in the tropics remain uncertain.

In addition to the synopsis of GCM results reproduced in Table 2.1, Chapter 11 of the IPCC Fourth Assessment Report (Christensen *et al*. 2007) provides region-by-region reviews of results from existing climate projection studies including results from regional climate models (RCMs). These regional reviews generally include short sections specifically addressing projections of extreme weather events as summarized in the following paragraphs for the main crop-exporting regions and SSA. For the convenience of readers, these paragraphs also pinpoint significant increases in the projected frequency of extreme dry or wet *seasons* according to Table 2.1.

North America

Longer duration, more intense, more frequent heat waves/hot spells in summer are *very likely* in Western USA. Continental drying and associated risk of drought in summer over mid-latitude continental interiors is *likely*. Diffenbaugh *et al.* (2005) find that the frequency and magnitude of extreme temperature events changes dramatically under SRES A2, with an increase in extreme hot events and a decrease in extreme cold events. In their regional climate model simulations covering the entire USA, they also find widespread increases in extreme precipitation events under SRES A2.[3]

The majority of GCM projections suggest an increased frequency of extreme wet seasons except for the summer (JJA) season across North America, as well as an increased frequency of extreme dry summers in central North America (Table 2.1).

South America

Little research is available on extremes of temperature and precipitation for this region. Table 2.1 suggests that essentially all seasons and regions are extremely warm by this criterion by the end of the century. In the Amazon region, models project extremely wet seasons in about 27 per cent (18 per cent) of all DJF (MAM) seasons in the period 2080 to 2099. Significant changes are not projected in the frequency of extremely wet or dry seasons over Southern parts of South America. On the daily time scale, Hegerl *et al.* (2004) project more intense wet days per year over large parts of South-Eastern South America and central Amazonia and weaker precipitation extremes over the coasts of North-East Brazil.

Australia and New Zealand

Increased frequency of extreme high daily temperatures in Australia and New Zealand, and a decrease in the frequency of cold extremes is *very likely*. Extremes of daily precipitation are *very likely* to increase, except possibly in areas of significant decrease in mean rainfall (Southern Australia in winter and spring). Increased risk of drought in southern areas of Australia is *likely*.

Where GCMs simulate a decrease in average rainfall, it may be expected that there would be an increase in the frequency of dry extremes (droughts). Whetton and Suppiah (2003) examine simulated monthly frequencies of serious rainfall deficiency for Victoria, which show strong average rainfall decreases in most simulations considered. There is a marked increase in the frequency of rainfall deficiencies in most simulations, with doubling in some cases by 2050. Using a slightly different approach, likely increases in the frequency of drought have also been established for the states of South Australia, New South Wales and Queensland (McInnes *et al.* 2003; Hennessy *et al.* 2004). Mullan *et al.* (2005) show that by the 2080s in New Zealand there may be significant increases in drought frequency in the East of both islands.

The majority of GCM projections show an increased frequency of extreme dry seasons for South Australia except for the DJF period.

East Asia and South Asia including India

It is *very likely* that heat waves/hot spells in summer will be of longer duration, more intense and more frequent in East Asia. There is *very likely* to be an increase in the frequency of intense precipitation events in parts of South Asia and in East Asia. Extreme rainfall and winds associated with tropical cyclones are *likely* to increase in East Asia, South-East Asia and South Asia.

Table 2.1 suggests significant increases in the frequency of extreme wet seasons across East and South Asia.

Sub-Saharan Africa

Research on changes in extremes specific to Africa, in either models or observations, is limited. A general increase in the intensity of high-rainfall events, associated in part with the increase in atmospheric water vapour, is expected in Africa, as in other regions. As in most tropical regions, all seasons are extremely warm by the end of the 21st century, with very high confidence under the A1B scenario. Although the mean precipitation response in West Africa is less robust than in East Africa, the increase in the number of extremely wet seasons is comparable in both, increasing to roughly 20 per cent (i.e., 1 in 5 of the seasons are extremely wet, as compared with 1 in 20 in the control period in the late 20th century). In Southern Africa, the frequency of extremely dry austral winters and springs increases to roughly 20 per cent, while the frequency of extremely wet austral summers doubles in this ensemble of models. Significant increases in the frequency of extreme dry seasons are also projected for the Sahel zone (DJF and MAM).[4]

2.1.3 Links between extreme weather events and agricultural productivity in the IPCC Fourth Assessment Report

Reflecting the predominant focus in the literature at the time, the IPCC AR4 chapter addressing climate change impacts on food production (Easterling *et al*. 2007) deals almost exclusively with estimates of effects of changes in the long-run *means* of temperature and precipitation on crop yields and livestock productivity. Nevertheless, it is emphasized that:

> *'Projected changes in the frequency and severity of extreme climate events will have more serious consequences for food and forestry production, and food insecurity, than will changes in projected means of temperature and precipitation (high confidence).' (Easterling et al. 2007)*

More frequent extreme events may lower long-term yields by directly damaging crops at specific developmental stages, such as temperature thresholds during flowering, or by making the timing of field applications more difficult, thus reducing the efficiency of farm inputs (e.g. Porter and Semenov 2005).

A number of simulation studies have developed specific aspects of increased climate variability within climate change scenarios. Rosenzweig *et al*. (2002) computed that, under scenarios of increased heavy precipitation, production losses due to excessive soil moisture would double in the USA by 2030 to $3bn per year. Monirul and Mirza (2002) computed an increased risk of crop losses in Bangladesh from increased flood frequency under climate change. Yields of grains and other crops could decrease substantially across the African continent because of increased frequency of drought, even if potential production increases due to increases in CO_2 concentrations.

However, much uncertainty remains in terms of how changes in frequency and severity of extreme climate events with climate change will affect agriculture and other sectors. [5]

2.2 BEYOND THE FOURTH ASSESSMENT REPORT: RECENT STUDIES

2.2.1 Overview

In the most recent studies published over the last five years, confidence in projections for extremes remains weaker than confidence in projections of long-run trends in mean temperature and precipitation. Moreover, projections of changes in temperature extremes tend to be more consistent across climate models than for precipitation extremes.

Temperature extremes

Recent studies by Kharin *et al.* (2007), Sterl *et al.* (2008), and Orlowsky and Seneviratne (2011) among others cited below are based on larger model ensembles than the earlier work cited in the AR4, and broadly confirm the AR4 conclusions with respect to temperature extremes.

Precipitation extremes

The most recent analyses of global and regional climate model simulations likewise confirm the AR4 assessment, but also reinforce the large uncertainties in projections of changes in heavy precipitation in some regions.

Floods: Bates *et al.* (2008) suggest that projected increases in the frequency of heavy precipitation events imply an enhanced risk of rain-generated floods in the affected regions. However, there is still only a small number of regional or continental-scale studies of projected changes in floods as cited below in section 2.2. Likewise, there is only a small number of projections of flood changes at the catchment or river basin scale in the literature. Several studies have been undertaken for catchments in Europe and North America, while very few such studies are available for basins in Asia (Asokan and Dutta 2008; Dairaku *et al.* 2008), South America (Nakaegawa and Vergara 2010) and Africa. Flood probability is generally projected to increase in catchments with an increase in precipitation intensity, but uncertainty is still large with respect to changes in the magnitude and frequency of floods.

Droughts: Recent work on drought projections highlights the need to differentiate between different types of drought and to distinguish between short and longer term drought events. Burke and Brown (2008) employ four different drought indices and show that an index based solely on precipitation suggests little change in the proportion of the global land surface in drought, while other indices, which include a measure of the atmospheric demand for moisture, show a significant increase. Orlowsky and Seneviratne (2011) arrive at similar conclusions; see also Sheffield and Wood (2008) and Sillmann and Roeckner (*2*008).

2.2.2 Post-AR4 projections of extreme weather events for the main staple crop-exporting regions

The following synopsis provides a concise selective summary of key findings of post-AR4 studies concerning projections of changes in extreme weather events for the regions of interest. Again, the synopsis focuses in particular on results that are robust across a range of simulation studies.

Post scriptum: The core content of this study, including this section, has been completed prior to the official publication of the full IPCC Special Report on Extreme Events (SREX) in 2012 and therefore contains no references to the SREX. However, many of the studies cited are also cited in the SREX and the interpretations of the findings from these studies appear to be closely similar.

North America

Gutowski *et al.* (2008) suggest that abnormally hot days and nights and heat waves are very likely to become more frequent by the end of the 21st century. For a mid-range scenario of future greenhouse gas emissions, an extremely hot day with a current return period of 20 years would occur every three years by the middle of the century over much of the continental USA and every five years over most of Canada. Hirabayashi *et al*. (2008) find a higher likelihood of hydrological droughts towards 2070. Seager *et al*. (2007; 2009) project more frequent multi-year drought events in the American South-West. Reduced cool season precipitation promotes drier summer conditions by reducing the amount of soil water available for evapotranspiration in summer seasons. Orlowsky and Seneviratne (2011) report more frequent and longer heat waves and more frequent droughts in Texas and New Mexico. Similarly, Sheffield and Wood (2008) project more frequent droughts in south-western parts of the USA. The simulations by Karl *et al*. (2008) likewise suggest more frequent and longer heat waves.

South America

Climate model simulations by Hirabayashi *et al*. (2008) show a higher likelihood of hydrological droughts towards 2070 and an increase in the risk of floods in tropical parts of South America. Orlowsky and Seneviratne (2011) project an increase in the number of extremely hot days and an associated increase in heat wave frequency in most parts of South America. Their simulation results also show an increase in consecutive dry days and soil moisture droughts in the North-

East of Brazil and in Central America. Kharin *et al*. (2007) report projected increases in the number of extremely hot days for the sub-continent.

Australia and New Zealand

Alexander and Arblaster (2009) report projected increases in heat wave duration over the 21st century in the interior of Australia. Hirabayashi *et al.* (2008) find a higher likelihood of hydrological droughts towards 2070 in central and Western Australia. Suppiah *et al.* (2007) report projections of significant increases in the number of days above 35°C or 40°C. Simulations by Orlowsky and Seneviratne (2011) indicate an increase in the number of extremely hot days and heat waves. Studies by Kharin *et al*. (2007) and Mullan *et al*. (2008) likewise confirm the finding of an increase in the number of extremely hot days.

South Asia and East Asia

Hirabayashi *et al*. (2008) find a higher likelihood of hydrological droughts towards 2070 in parts of South Asia as well as an increase in the risk of floods in most humid monsoon regions. Orlowsky and Seneviratne (2011), Clark *et al*. (2011) and Rajedran *et al*. (2008) report increases in the number of extremely hot days over East Asia and South Asia.

Sub-Saharan Africa

Hirabayashi *et al*. (2008) find a higher likelihood of hydrological droughts towards 2070 in central and Southern Africa as well as increases in the risk of floods in tropical Africa. The simulation analysis of Orlowsky and Seneviratne (2011) indicates an increase in the frequency of heat waves, an increase in extreme precipitation events in East Africa and an increase in the number of consecutive dry days and soil moisture droughts, except in South-East Africa. Sheffield and Wood (2008) likewise find an increase in consecutive dry days and soil moisture droughts except in South-East Africa. Shongwe *et al*. (2011; 2009) project an increase in extreme precipitation events over East Africa and an increase in consecutive dry days and soil moisture droughts, except in South-East Africa.

Three recent country-level modelling studies for Ethiopia, Ghana and Mozambique (World Bank 2010a, 2010b, 2010c and 2010d; Robinson, Strzepek and Willenbockel 2012; Arndt *et al*. 2010) suggest that the frequency of extreme weather events in the form of both droughts and floods with significant economic impacts appears to rise noticeably well before 2050. In each of these studies, a dynamic CGE model with multiple agro-ecological zones is linked to an interrelated ensemble of specialist models that serve to translate regionalized climate projections from global circulation models up to 2050s into hydrological impacts, crop and livestock productivity effects, hydro-power generation and road infrastructure impacts. In each of these studies, the adverse economic impacts due to temporary weather extremes appear to be more important than the impacts due to gradual shifts in the means of temperature and precipitation. For example, the projections for Ethiopia suggest substantial gross domestic product (GDP) losses because of the costs of coping with damage caused by extreme weather events, especially floods, from the 2030 decade onwards.

Like the other two SSA studies, the Ethiopia study uses climate projections from four different GCMs, ranging from ‘dry’ to ‘wet’ future climates across the range of GCMs in terms of annual means. However, annual averages do not account for seasonal changes and the potential for increased flooding due to changes in daily and monthly scale precipitation processes in the midst of an annually drier climate. It is noteworthy that all four GCM projections for Ethiopia suggest increases in precipitation intensity at the daily and weekly scale. This implies more flooding even in the ‘dry’ scenarios.

All three studies report a measurable increase in agricultural income volatility well before 2050 compared with a hypothetical baseline without climate change. In all studies, damage to the road infrastructure due to extreme weather events plays a major role beside the impacts on crop yields and livestock productivity. The global track of the World Bank (2010a) ‘Economics of

Adaptation to Climate Change' study estimates the annual adaptation costs for all developing countries directly attributable to an increased frequency of extreme weather events up to 2050s to be on the order of $6.4bn to $6.7bn.

2.3 CONCLUSION

The research based on climate model projections reviewed above indicates that, on a global scale, the frequency of extreme weather events is bound to rise with rising mean temperatures. Most of these projections refer to the last decades of the 21st century, but this does of course not mean that the probabilities remain unchanged over coming decades and then abruptly jump to higher levels in the 2080s. Rather, the dominantly linear response of GCMs to CO_2 forcings entails gradual increases in the frequencies of weather extremes over the decades.[6] As noted earlier, the IPCC AR4 points out that such changes could already occur with relatively small mean temperature changes.

Moreover, greenhouse gas emissions over the past decade have grown more rapidly than previously projected, and so the projections based on the AR4 emission scenarios may materialize earlier than previously expected. As emphasized in van der Mensbrugghe *et al*. (2011), the emission scenarios used in the AR4 were generated around 2000 and have significantly underestimated both actual output and emission growth over the last decade, notwithstanding the recent financial crisis. If this pattern continues, it puts the world on a trajectory of much higher temperature changes than the AR4 median of about 3°C by the end of the century and a 2.5°C increase is more likely to be reached in 2050 rather than in 2080.[7] Correspondingly, the extreme weather event projections in the AR4 for the last decades of the 21st century could materialize far earlier than previously suggested.

The current state of climate science does not allow us to infer the precise changes in the probability density functions for weather variables over the coming decades for particular geographical regions, but the research reviewed in this section lends support to the hypothesis that the tails of these probability distributions tend to become gradually thicker over time.[8]

The hypothetical what-if scenarios presented in Section 5 are not based on any specific assumptions about the likelihood of the simulated extreme weather shocks. However, the present section intends to provide a tentative general motivation for an engagement with these scenarios.

3 METHODOLOGY OF THE SIMULATION ANALYSIS

3.1 THE MODEL

The GLOBE model is in the tradition of multi-country, trade-focused computable general equilibrium (CGE) models developed to analyse the impact of global trade negotiations and regional trade agreements (McDonald *et al.* 2007). This study uses a dynamized version of GLOBE. The model consists of a set of individual country or region models that provide complete coverage of the global economy and are linked through international trade in a multi-region model system. It solves the *within* country models and *between* country trade relationships simultaneously. The country models simulate the operation of factor and commodity markets, solving for wages, land rent, profits and commodity prices that achieve supply–demand balance in all markets. Each country engages in international trade, supplying exports and demanding imports. The model determines world prices that achieve supply–demand balance in all global commodity markets, simulating the operation of world markets.

Multi-country CGE models like GLOBE represent the whole economy, including the agricultural sector. Their strength is that they include the value chain from crops, processing and distribution, and finally, to demand for food by households. They also incorporate links between agricultural and non-agricultural sectors, and the links between production, factor payments, and household income. Multi-country CGE models are well suited to analysis of policies or scenarios that will change the volume and structure of production, demand, and international trade, and the allocation of factors of production throughout the economy.

The model is initially calibrated to the GTAP 7.1 database (Narayanan and Walmsley (eds.) 2008) which combines detailed bilateral trade and protection data, reflecting economic linkages among regions, with individual country input–output data which account for intersectoral linkages within regions, for the benchmark year 2004. For the present study, we use a 22-region, 12-sector commodity group aggregation of the GTAP database. Table 3.1 shows the regional disaggregation of the model. The model distinguishes eight food commodity groups (Wheat, Maize/Other Coarse Grains, Paddy rice, Processed rice, Other crops, Livestock products, Processed meat products and Other processed food), and four non-food sectors (Extraction, Non-food manufacturing, Trade and transport services and Other services).

In a first stage, the model is used to generate long-run baseline projections for the evolution of production, consumption, trade and prices by region and commodity group at a decadal temporal scale for 2010, 2020 and 2030, using essentially the same assumptions about the key drivers of change (population growth, labour force growth, total factor productivity growth in agricultural and non-agricultural sectors) as in Willenbockel (2011). The baseline projections take account of climate change impacts on agricultural productivity due to changes in projected *means* of temperature and precipitation for 2030, but do not take account of potential additional impacts due to extreme weather events.

As detailed in Section 2, the IPCC Fourth Assessment Report predicts with high confidence that 'projected changes in the frequency and severity of extreme climate events have significant consequences for food production *in addition* to impacts of projected mean climate' (Easterling *et al.* 2007, emphasis added). In line with this assessment, the model is used in a second stage to simulate the additional impacts of idiosyncratic adverse temporary shocks to crop productivity in each of the main exporting regions for rice, maize and wheat (North America, Oceania, South America, and, in the case of rice, additionally India and Other East Asia) on prices, production and consumption in 2030 across all regions distinguished in the model. A further simulation scenario combines the poor harvest shock for North America with the simultaneous imposition of taxes on exports of staple crops. Finally, the direct impact of extreme weather events in the SSA regions will be simulated.

Table 3.1: Geographical aggregation of the model

Code	Region	Notes
Europe	Europe	including Ukraine, Belarus
Russia	Russian Federation	
NAmerica	North America	USA, Canada
Oceania	Oceania	Australia, New Zealand, Rest of Oceania
HIAsia	High-Income Asia	Japan, Hong Kong, Singapore, South Korea, Taiwan
China	China	
OEAsia	Other East + South-East Asia	Cambodia, Indonesia, Lao, Malaysia, Philippines, Thailand, Vietnam, Rest of East Asia, Rest of South East Asia
India	India	
OSAsia	Other South Asia	Bangladesh, Pakistan, Sri Lanka, Rest of South Asia
CAsia	Central Asia + Middle-East	Kazakhstan, Kyrgyztan, Azerbaijan, Armenia, Georgia, Rest of FSU, Turkey, Iran, Rest of Western Asia
Andean	Andean South America	Bolivia, Colombia, Ecuador, Peru
Brazil	Brazil	
OSAmerica	Other South America	Argentina, Chile, Venezuela, Uruguay, Paraguay, Rest of South America
CAmerica	Central America + Caribbean	Costa Rica, Guatemala, Nicaragua, Rest of Central America, Caribbean, Mexico
NAfrica	North Africa	Egypt, Morocco, Tunisia, Rest of North Africa
Nigeria	Nigeria	
Senegal	Senegal	
RWAfrica	West Africa	Rest of Western Africa
CAfrica	Central Africa	Cameroon, CAR, Chad, Congo, Equatorial Guinea, Gabon, Angola, DR Congo
EAfrica	East Africa	Ethiopia, Madagascar, Mauritius, Tanzania, Uganda, Rest of Eastern Africa
Mozambq	Mozambique	
SSEAfrica	South + South-East Africa	South Africa, Botswana, Rest of Southern African Customs Union (SACU), Malawi, Zambia, Zimbabwe

4 THE SIMULATION SCENARIOS

4.1 OVERVIEW

Ten simulation scenarios are considered in this study: a dynamic baseline scenario projection towards 2030 and nine extreme weather event scenarios for 2030.

A. The dynamic baseline scenario

In a first stage, the model is used to generate long-run baseline projections for the evolution of production, consumption, trade and prices by region and commodity group for 2030 using essentially the same assumptions about the key drivers of change (population growth, labour force growth, total factor productivity growth in agricultural and non-agricultural sectors) as in Willenbockel (2011). The baseline projections take account of climate change impacts on agricultural productivity due to changes in projected *means* of temperature and precipitation (see Appendix 2), but do not take account of potential additional impacts due to extreme weather events.

B. Extreme weather event scenarios for 2030

In a second stage, the model is used to simulate the additional impacts of idiosyncratic adverse temporary shocks to crop productivity in each of the main exporting regions for rice, maize and wheat on prices and consumption in 2030 with a particular focus on the SSA regions distinguished in the model. A further simulation scenario combines the poor-harvest shock in North America with trade policy responses in developing countries. Finally, the direct impact of extreme weather events in each of the SSA regions is simulated. Nine separate extreme weather scenarios are considered:

1. Poor harvest in North America
2. Poor harvest in Oceania
3. Poor harvest in South America
4. Simultaneous poor harvests in India and East Asia
5. Poor harvests in West Africa
6. Poor harvests in Central Africa
7. Poor harvests in East Africa
8. Poor harvests in Southern Africa
9. Poor harvest in North America with trade policy responses by developing countries

4.2. ASSUMED YIELD SHOCKS FOR THE EXTREME WEATHER EVENT SCENARIOS

The yield shocks associated with the extreme weather events are determined on the basis of observed annual yield variability over the period 1979–2009. For each of the crop export regions, we identify a historical year characterized by a particularly large negative yield deviation from the long-run trend for the main export crop and simultaneous negative yield deviations from trend for the other staple crops. The simulation scenarios assume that the impact of the simulated extreme weather event in 2030 on crop yields is of the same magnitude as in this historically observed bad-harvest year.

By using historically observed shocks, the present approach captures the fact that a given weather shock hits different crops differently, because of differences in sensitivity to weather variations across crops, and because different crops are typically grown in different sub-regions of a model region. Basing the yield shocks on observed size orders of shocks by region entails that the analysis captures intra-regional and cross-crop differences in the share of irrigated production, provided these shares do not change dramatically over time; e.g. the yield shocks for rice are generally lower than those for maize and wheat, because a large proportion of rice is typically grown on irrigated land.

For example, in the case of North America, this historical year is 1988 – a year characterized by extreme droughts in some of the main crop-growing regions of the USA.

This conservative approach to the determination of the size order of the yield shocks ensures that the shocks remain strictly within the observed range of historical year-to-year variability. However, in the case of the India and Other East Asia shock scenario, the historically observed yield shocks in Table 4.1 have occurred in different (adjacent) years, while the simulation analysis assumes hypothetically that shocks of the observed magnitudes occur simultaneously across both regions in the same year. A partial justification for this assumption is given by the fact that the historical annual rice yield deviations from trend over the period 1979 to 2009 for India and Other East Asia are significantly positively correlated (correlation coefficient 0.37). We are not suggesting that this historically observed correlation will be rising in the future as a result of climate change. The purpose of this exploratory what-if scenario is to illustrate the potential impacts of the simultaneous occurrence of multiple stressors for the case of the two main rice-exporting regions.

Table 4.1 shows the assumed yield shocks for each of the crop export regions along with the historical year in which yield deviations from trend of this size have been observed.

In each case, adverse weather events are the only plausible explanation for the huge drop in average yields over the whole geographical region: Farmers do not suddenly forget their skills in growing crops from one year to another and then suddenly regain it the year after. Note that yield is a measure of physical output per unit of land on which the crop is planted. Given the absence of war or civil war, there must be a ‘bio-physical’ explanation. None of the regions had a war or country/sub-continent-wide civil war in that particular year, and localized natural disasters (earthquakes, tsunamis, volcano eruptions) cannot possibly explain yield reductions of this order over large geographical scales.

Table 4.1: Shocks to staple crop yields in the extreme weather event scenarios
(Percentage deviation from 2030 baseline yields)

Region	Main export staple crop	Year*	Maize	Wheat	Rice
North America	Wheat	1988	-24.8	-18.2	-0.8
South America	Maize	1990	-17.3	-8.0	-9.0
Oceania	Wheat	2002	-4.2	-44.3	-4.3
India	Rice	1979	-7.4	-4.9	-16.9
Other East Asia	Rice	1980	-9.1	-18.3	-13.5
West Africa		1983	-19.1	-11.5	-4.2
Central Africa		2004	-6.2	-19.3	-5.2
East Africa		1992	-25.9	-13.1	-3.8
Southern Africa		1995	-42.4	-23.9	-10.0

**Historical year in which negative deviations of annual yields from long-run trends over the period 1979 to 2009 of this size have been observed. Source: Author's calculations based on FAOSTAT annual yield data.*

In the case of the shocks for North America, India and Australia, it is straightforward to show that a major drought was the cause of the yield drops. The scale of the 1988 North American drought[9] has been extensively documented, the nation-wide drought in India of 1979 has been described as the worst of the 20th century (Weisman 1987) prior to the drought of 1987, and the 2002/03 drought in Australia is on record as one of the worst in history.[10] For each of these regions, the results from climate model simulation studies reviewed in Sections 2.1.2 and 2.2.2 point to a rising frequency of drought events over the course of the 21st century.

It is less straightforward to map particular extreme events to the other broad aggregate regions (Brazil, Andean and Other South America, Other East Asia) in the model. In these cases it is the conjunction of regional events – which might be a drought in one sub-region and a flood or a dry spell during the decisive periods of the growing season in another – that determine average annual yields over the aggregate region.

Thus, for South America in 1990, the International Disaster Database EM-DAT[11] records major flooding events in Southern Brazil, Argentina, Paraguay, Chile, Peru and Colombia, but also severe droughts in Bolivia and Peru. As noted in Section 2, little research with a focus on future weather extremes is available for this region, but the few available studies cited above suggest rising probabilities of both flooding and drought events, particularly in the tropical regions of the sub-continent.

For Other South East Asia in 1980, EM-DAT reports a conjunction of regional floods in Indonesia, the Philippines, Thailand and Vietnam, but also a drought in the Philippines. For this region, the evidence from GCM projections reported in Table 2.1 above suggest a significant increase in the frequency of extremely wet seasons associated with an increase in the risk of floods in humid monsoon regions.

In the case of SSA, for Western Africa 1983 was a year of severe drought across the whole region, afflicting Benin, Burkina Faso, Cote d'Ivoire, Ghana, Gambia, Liberia, Guinea, Guinea-Bissau, Mali, Mauretania, Niger, Nigeria, Senegal and Togo. For the Eastern Africa regions of the model, 1992 was a drought year for Ethiopia, Kenya, Tanzania, Madagascar and Mozambique. For Central Africa, the EM-DAT database records major floods in Angola and the Central African Republic and a drought in Angola. For the South and South-East African regions, 1995 droughts are recorded for South Africa (Nebo district), Namibia, Zambia, Zimbabwe and the South-East of Swaziland, while severe local flooding events occurred in

Malawi and Botswana. For these regions, the climate projections reviewed in Section 2 again tend to suggest a rising risk of drought and flooding events over the course of the 21st century.

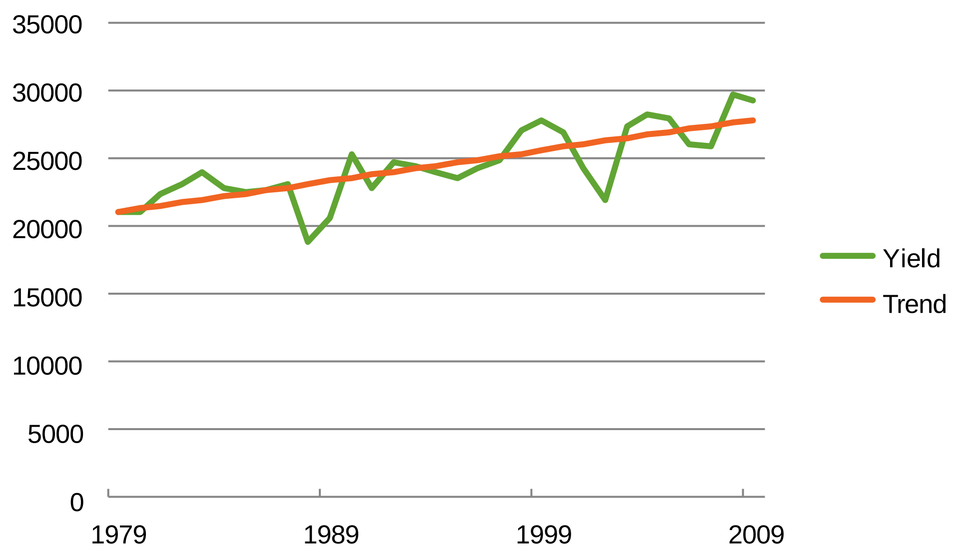
In these cases, the rationale for the simulation approach adopted here is this: observed severe yield drops averaged over the whole region due to a conjunction of extreme events in different sub-regions have occurred in the past. Such conjunctions become more likely in a changing climate. Hence it is reasonable to consider the implications of such conjunctions in the future.

The example below illustrates the determination of the yield shocks for the case of North American wheat.

Example: North America – wheat

Figure 4.1 displays annual wheat yields in North America for the past years up to 2009 (Source: FAOSTAT Production database). The trend growth path in the figure has been determined by fitting a linear trend to the time series and the annual deviations reported in Table 4.2 are measured relative to the trend path.

Figure 4.1: Annual yield of wheat in North America 1979–2009 *(In hectogram per hectare)*



Source for annual yields: FAOSTAT production database.

Table 4.2: Annual yield variability for wheat – North America 1979 to 2009

Year	Yield (hg/ha)	Trend yield (hg/ha)	Deviation from trend (%)	Annual growth rate (%)
1979	21028	21075	-0.2	
1980	21027	21302	-1.3	0.0
1981	22327	21530	3.7	6.2
1982	23142	21757	6.4	3.7
1983	23965	21985	9.0	3.6
1984	22811	22212	2.7	-4.8
1985	22606	22440	0.7	-0.9
1986	22758	22667	0.4	0.7
1987	23074	22894	0.8	1.4
1988	18925	23122	-18.2	-18.0
1989	20631	23349	-11.6	9.0
1990	25294	23577	7.3	22.6
1991	22857	23804	-4.0	-9.6
1992	24730	24032	2.9	8.2
1993	24496	24259	1.0	-0.9
1994	24067	24487	-1.7	-1.8
1995	23569	24714	-4.6	-2.1
1996	24361	24942	-2.3	3.4
1997	24934	25169	-0.9	2.4
1998	27030	25397	6.4	8.4
1999	27836	25624	8.6	3.0
2000	26965	25852	4.3	-3.1
2001	24363	26079	-6.6	-9.6
2002	21892	26307	-16.8	-10.1
2003	27408	26534	3.3	25.2
2004	28197	26761	5.4	2.9
2005	27961	26989	3.6	-0.8
2006	26023	27216	-4.4	-6.9
2007	25918	27444	-5.6	-0.4
2008	29665	27671	7.2	14.5
2009	29230	27899	4.8	-1.5

5 SIMULATION ANALYSIS

5.1 THE 2030 BASELINE

The 2030 baseline projection serves as the benchmark for the extreme weather event simulations considered in Section 5.2. That is, in each of these simulations it is assumed that the extreme weather shock takes place in 2030 and the impacts are reported as deviations from this baseline. It is worth re-emphasizing that the baseline projections take account of climate change impacts on agricultural productivity due to changes in projected regional *means* of temperature and precipitation, using the same assumptions as in Willenbockel (2011: Section 4).[12]

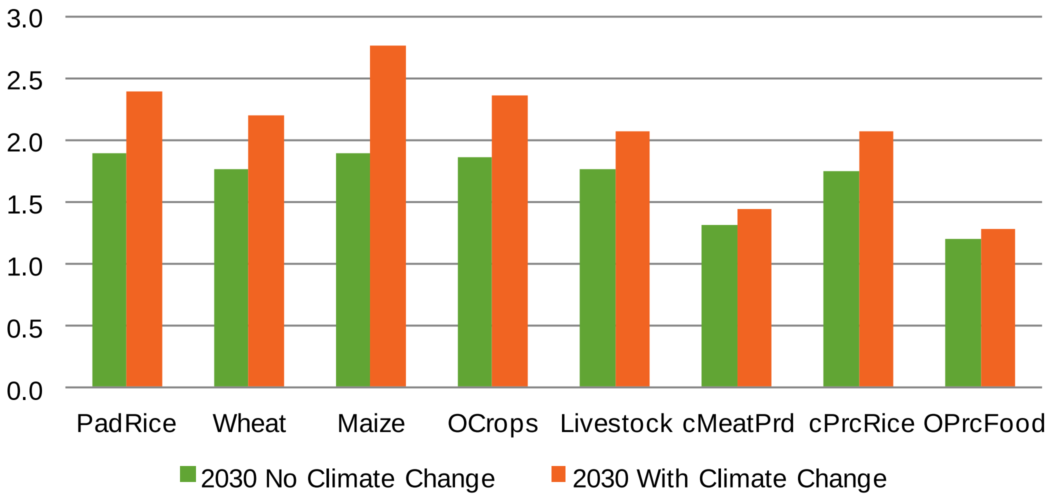
Details of these dynamic long-run projections are reported in this earlier study. Here, the focus is on features of the benchmark projections that are essential for the interpretation of the results reported in Section 5.2.

Figure 5.1 displays the baseline average world market food price projections for 2030 with and without climate change impacts on agricultural productivity due to changes in projected regional *means* of temperature and precipitation. The model trend price projections for 2010 that start from the observed 2004 GTAP benchmark equilibrium are normalized at unity. Given that the purpose of the baseline is to provide a long-run trend projection, these 2010 prices are long-run trend prices and thus deliberately exclude the actual observed short-run deviations from the trend paths in 2010.[13] In contrast, the extreme weather event simulations in section 5.2 are concerned with temporary price fluctuations around the trend.

Compared with 2010 trend prices, the average world market export price for wheat rises by 120 per cent towards 2030. The average world market price of processed rice is projected to rise by 107 per cent and the corresponding figure for maize is 177 per cent. The price index of processed food other than rice and meat is projected to rise by around 30 per cent over the next two decades.

Table 5.1 shows the projected changes in domestic user price indices (defined over domestic and imported commodities) for crops over the period 2010 to 2030 in the SSA regions.

Figure 5.1 Average world market baseline food price projections for 2030 *(Model projection for 2010 = 1.00)*



Note: Paddy rice (PadRice); Other crops (OCrops); Meat products (MeatPrd); Processed rice (PrcRice); Other processed food (OPrcFood).

Table 5.1: Change in domestic user price of crops in SSA regions – baseline 2010 to 2030 *(Change relative to 2010 trend prices in per cent)*

	PadRice	Wheat	Maize	OCrops	PrcRice
Nigeria	36.8	62.1	58.1	27.8	44.2
Senegal	48.3	89.0	73.2	38.0	39.2
RWAfrica	66.8	49.9	89.2	31.7	18.6
CAfrica	71.6	61.0	79.1	43.2	22.1
EAfrica	50.6	47.0	65.1	35.9	38.3
Mozambq	52.7	62.7	81.3	34.0	54.9
SSEAfrica	125.9	62.9	129.5	65.8	58.9

Notes: The table shows changes in price indices defined over domestic and imported commodities. Prices are relative to each region's overall consumer price index (CPI). Paddy rice (PadRice); Other crops (OCrops); Processed rice (PrcRice).

Table 5.2 shows the shares of the various main food exporting regions in total global food exports by commodity group projected for 2030. For instance, 57 per cent of worldwide wheat exports, and 44 per cent of global maize and other coarse grain exports, are predicted to be of North American origin by 2030. Likewise, important for the interpretation of the results in Section 5.2 are the baseline regional origin shares for sub-Sahara African staple crop imports displayed in Table 5.3. For example, 95.1 per cent of Nigeria's projected 2030 baseline wheat imports are of North American origin. Table 5.4 decomposes SSA food commodity exports by sub-region of origin. For example, 66 per cent of SSA total exports of maize and other coarse grains are produced in South and South-East (SSE) Africa.

Table 5.2: Projected origin shares in global food exports – 2030 baseline *(In per cent. Last column: Global export volume in $ billion at projected 2030 prices.)*

	NAmerica	Oceania	SAmerica	India	OEAsia	NAfrica	SSA	Other	Sum	Volume
PadRice	29.4	1.3	12.9	4.3	7.6	7.3	2.0	35.0	100	55.9
Wheat	57.1	11.3	6.3	1.3	0.0	0.4	0.4	23.3	100	1094.9
Maize	44.2	7.8	12.9	1.1	1.5	0.2	2.4	29.9	100	915.7
OCrops	21.5	2.3	25.3	1.2	3.9	1.4	11.6	32.8	100	8224.1
Livestock	17.7	22.5	2.9	0.3	1.9	0.6	4.9	49.2	100	1393.7
MeatPrd	18.2	14.6	10.5	7.8	0.9	0.2	1.8	45.9	100	1746.7
PrcRice	14.4	2.0	2.4	15.3	39.9	2.3	3.1	20.7	100	284.4
PrcFood	11.1	4.2	9.3	1.0	9.4	0.9	3.1	61.0	100	8407.4

Note: Paddy rice (PadRice); Other crops (OCrops); Meat products (MeatPrd); Processed rice (PrcRice); Other processed food (OPrcFood).

Table 5.3: Origin shares in sub-Saharan African regions' crop imports – 2030 baseline

		NAmerica	OEAsia	India	SAmerica	NAfrica	SSA	Other	Sum
Nigeria	**PadRice**	0.000	0.933	0.003	0.000	0.008	0.007	0.048	1.00
	Wheat	0.951	0.000	0.000	0.009	0.000	0.000	0.039	1.00
	Maize	0.002	0.014	0.021	0.050	0.150	0.466	0.297	1.00
	PrcRice	0.016	0.316	0.018	0.000	0.000	0.000	0.650	1.00
Senegal	**PadRice**	0.799	0.065	0.000	0.125	0.000	0.000	0.011	1.00
	Wheat	0.026	0.000	0.000	0.045	0.000	0.005	0.925	1.00
	Maize	0.015	0.001	0.000	0.683	0.000	0.165	0.136	1.00
	PrcRice	0.082	0.568	0.003	0.057	0.005	0.000	0.286	1.00
RWAfrica	**PadRice**	0.465	0.447	0.000	0.001	0.000	0.052	0.035	1.00
	Wheat	0.342	0.000	0.000	0.037	0.001	0.004	0.615	1.00
	Maize	0.065	0.000	0.000	0.060	0.004	0.799	0.071	1.00
	PrcRice	0.236	0.372	0.001	0.000	0.011	0.076	0.303	1.00
CAfrica	**PadRice**	0.072	0.321	0.002	0.020	0.003	0.111	0.470	1.00
	Wheat	0.216	0.000	0.000	0.136	0.001	0.003	0.645	1.00
	Maize	0.279	0.000	0.000	0.075	0.001	0.542	0.102	1.00
	PrcRice	0.097	0.556	0.004	0.001	0.003	0.096	0.244	1.00
EAfrica	**PadRice**	0.078	0.104	0.000	0.000	0.763	0.007	0.047	1.00
	Wheat	0.358	0.000	0.089	0.123	0.000	0.040	0.389	1.00
	Maize	0.260	0.002	0.020	0.064	0.002	0.537	0.115	1.00
	PrcRice	0.034	0.180	0.038	0.000	0.095	0.011	0.642	1.00
Mozambq	**PadRice**	0.659	0.334	0.000	0.000	0.000	0.001	0.005	1.00
	Wheat	0.531	0.000	0.000	0.465	0.001	0.000	0.003	1.00
	Maize	0.310	0.001	0.000	0.074	0.000	0.612	0.003	1.00
	PrcRice	0.000	0.656	0.001	0.000	0.000	0.003	0.339	1.00
SSEAfrica	**PadRice**	0.005	0.273	0.003	0.031	0.006	0.624	0.059	1.00
	Wheat	0.281	0.000	0.000	0.201	0.002	0.335	0.180	1.00
	Maize	0.070	0.000	0.000	0.206	0.001	0.695	0.028	1.00
	PrcRice	0.009	0.310	0.012	0.007	0.001	0.434	0.228	1.00

Note: Paddy rice (PadRice); Processed rice (PrcRice).

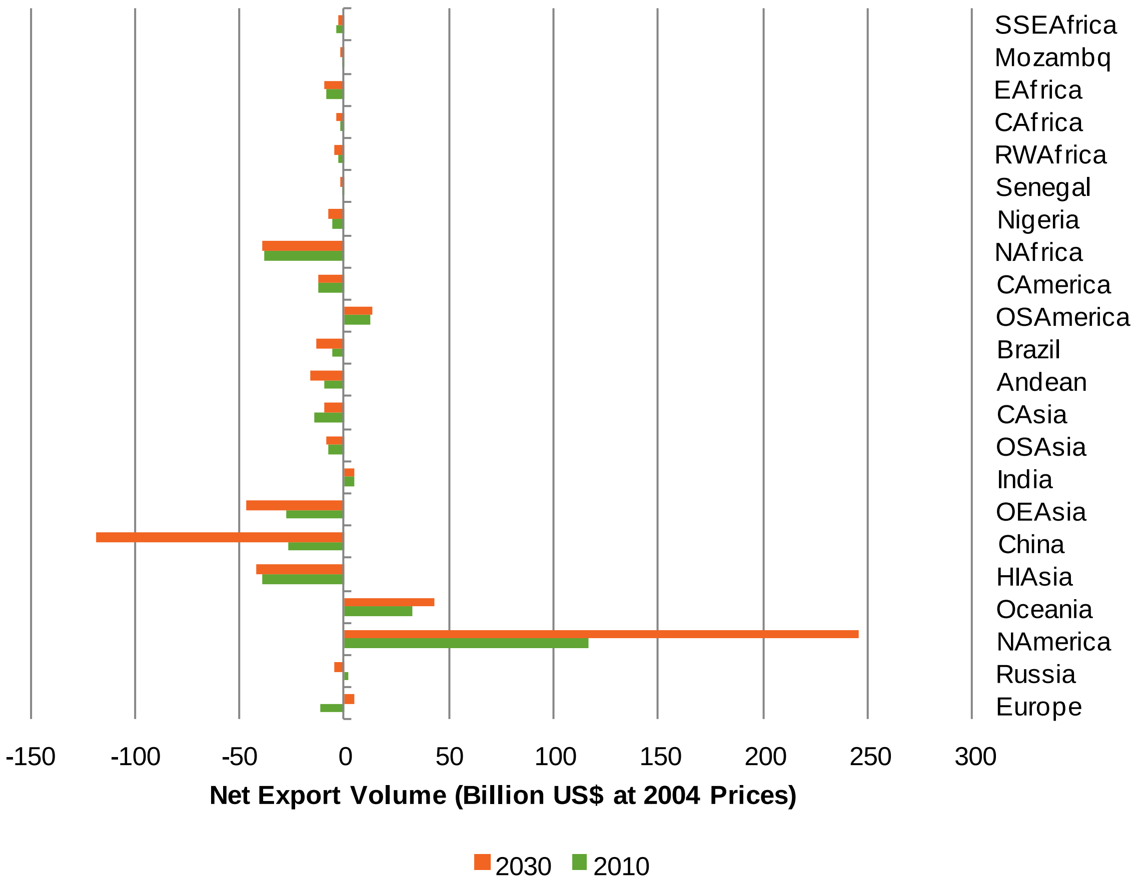
Table 5.4: Projected origin shares in sub-Saharan African exports – 2030 baseline *(In per cent. Last column: total SSA export volume in $ billion at projected 2030 prices.)*

	Nigeria	Senegal	RWAfrica	CAfrica	EAfrica	Mozambq	SSEAfrica	Sum	Value
PadRice	5.4	7.0	33.5	1.2	20.5	1.5	31.0	100	1.1
Wheat			1.7		34.7		63.6	100	4.8
Maize	0.2	0.5	7.1	2.4	22.4	1.4	66.0	100	21.6
OCrops	2.4	0.6	40.7	7.2	21.2	1.1	26.8	100	952.3
Livestock	0.4	1.3	5.3	1.3	54.3	0.1	37.3	100	68.6
MeatPrd		0.5	1.7	1.6	24.5	0.1	71.6	100	31.1
PrcRice		11.3	4.6	0.6	4.9	0.4	78.2	100	8.8
OPrcFood	2.0	4.9	27.2	2.7	20.5	0.9	41.7	100	263.5

Note: Paddy rice (PadRice); Other crops (OCrops); Meat products (MeatPrd); Processed rice (PrcRice); other processed food (OPrcFood).

Figure 5.2 displays net export quantities – i.e. exports minus imports valued at constant prices – of wheat in 2010 and 2030. North America is, and will remain, by far the largest wheat exporter and its wheat exports expand strongly between 2010 and 2030 in the baseline simulation. Oceania and Other South America also raise their wheat exports. All African and Asian regions, except India, as well as Europe are net importers of wheat. Between 2010 and 2030, China's wheat import volume overtakes the import volumes of North Africa and High-income Asia. Russia turns from a wheat exporter to a wheat importer between 2010 and 2030. Wheat imports to SSA also expand, but the quantities remain small from a global perspective.

Figure 5.2: Net export volume of wheat 2010 and 2030 *(US$ billion at constant 2004 market prices)*



Note: Net exports are exports minus imports.

Figure 5.3 shows the geographical pattern of trade in maize and other coarse grains. The main exporters in 2010 are North America, Brazil and Other South America, while the main importers are high-income Asia, Central Asia/Middle-East and Central America. The sub-Sahara African regions, except West Africa, are net importers of maize. The main rice exporters are Other East Asia, India and North America, while the main net importers are high-income Asia, Central Asia and – notably – Western Africa. In relative terms, China exhibits the largest increase in rice imports from 2010 to 2030 in the baseline scenario (Figure 5.4).

Further information relevant for the interpretation of results, including shares of food commodities in household expenditure and the import shares in total domestic demand by region, are provided in Appendix 1.

Figure 5.3: Net export volume of maize and other coarse grains 2010 and 2030 *(US$ billion at constant 2004 market prices)*

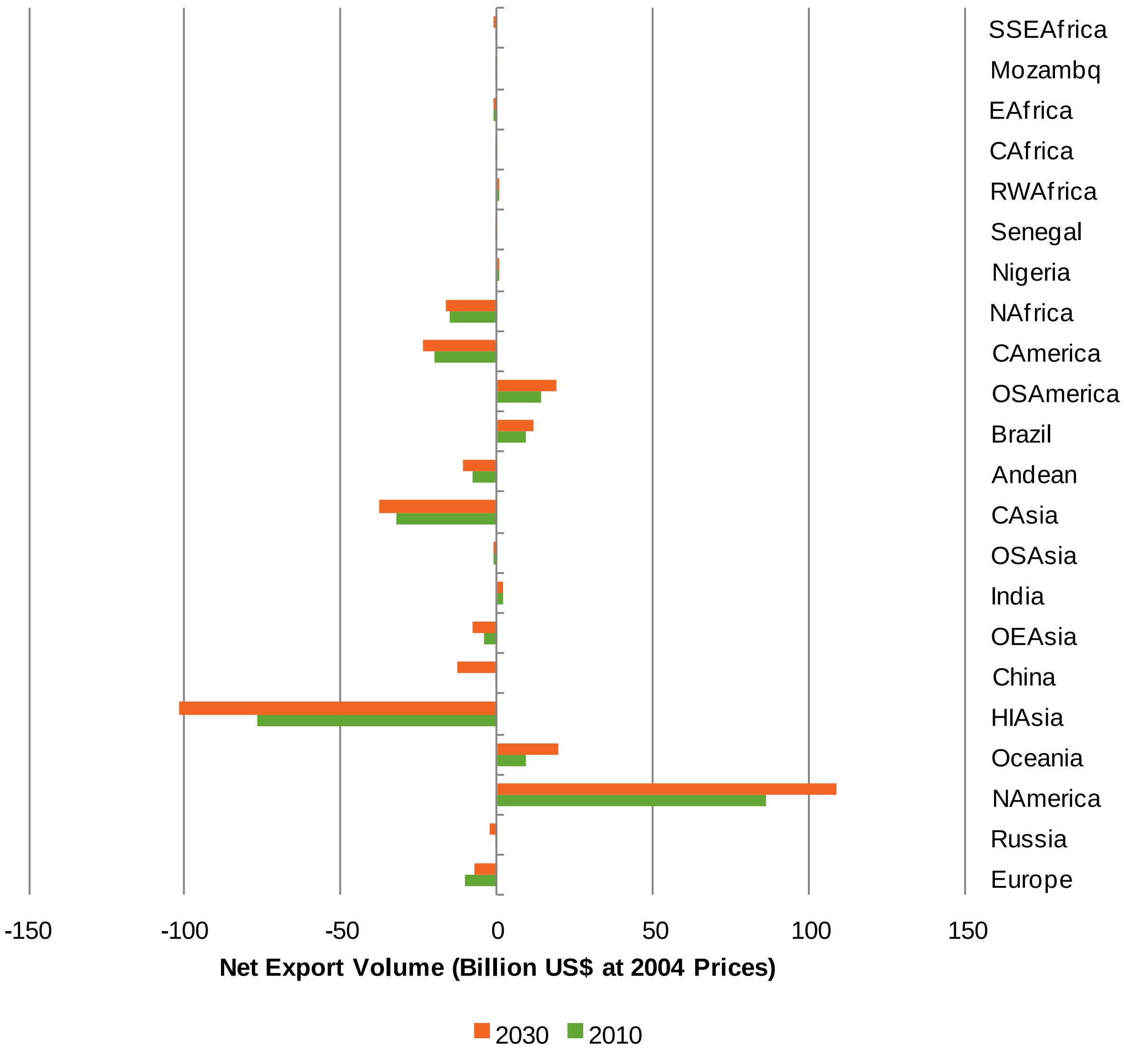
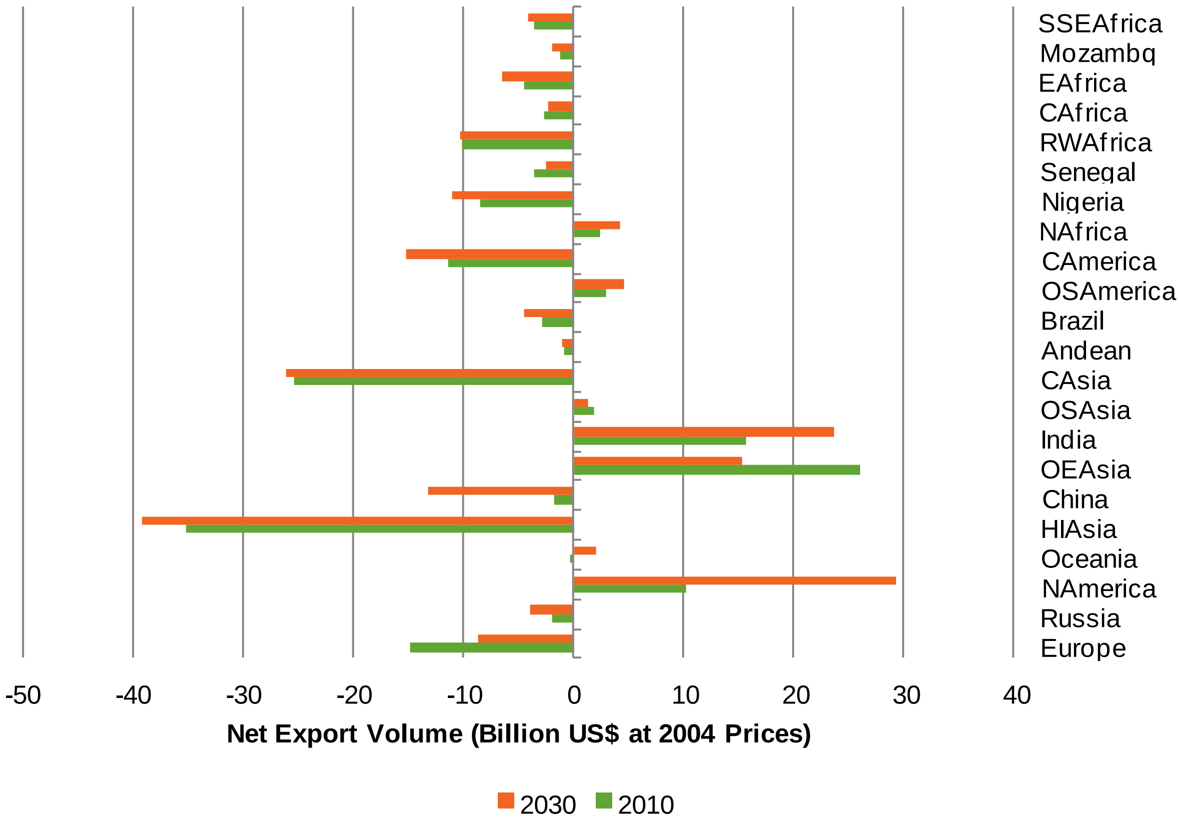


Figure 5.4: Net export volume of rice 2010 and 2030 *(US$ billion at constant 2004 market prices)*



Note: The figure shows net trade flows of processed plus paddy rice.

5.2 EXTREME WEATHER EVENT SCENARIOS

We now turn to the simulation of the temporary extreme weather shocks in the main staple crop-exporting regions and in SSA. In each case, it is assumed that the shocks to crop yields shown in Table 4.1 above take place in 2030 and hit farmers by surprise after planting decisions have been executed. That is, in the model, the 2030 baseline land allocations across crops are kept fixed and do not respond to the unanticipated shock. This assumption implies that the effective general equilibrium supply elasticities for agricultural production in this short-run scenario are lower than the effective long-run elasticities of the dynamic baseline scenario.

Table 5.5: Impact on average world market export price *(Percentage deviation from 2030 baseline)*

Scenario	Wheat	Maize	Rice
North America Shock	32.9	139.7	-1.4
Australia-NewZealand Shock	11.1	0.3	-0.1
South America Shock	1.8	11.7	0.7
India-OEAsia Shock	0.1	2.4	25.6
West Africa Shock	0.0	0.2	0.0
Central Africa Shock	0.4	0.0	0.0
East Africa Shock	0.4	0.5	0.0
Southern Africa Shock	0.3	2.6	0.1

As shown in Table 5.5, a drought in North America of a similar scale to the historical drought of 1988 would have a dramatic temporary impact on the world market export prices for maize and a strong impact on world market price for wheat.

A bad harvest year across South America with similar average yield deviations from trend as actually observed in 1990 has a significant impact on the world market price for maize but little impact on the other staple crop prices.

Conversely, the simulated Australia drought has a significant impact on the world market price for wheat but little impact on the other crop prices, as can readily be explained by the magnitudes of the assumed yield shocks and the region's market shares in global exports of rice, maize and wheat reported in Section 5.1.

A simultaneous occurrence of poor harvests in Other East Asia and India would raise the global average export price for processed rice temporarily by more than 25 per cent above its long-run trend level. To assess the relative contribution of the two regional shocks to this price impact, we have also simulated the India and the Other East Asia yield shocks separately from each other. These additional simulations (not tabulated here) show that the Other East Asia shock alone raises the world market export price for rice by 17.2 per cent and the India shock viewed in isolation would raise the world rice price by around 7 per cent. In other words, the Other East Asia shock accounts for about two-thirds of the total joint impact on rice prices reported in Table 5.5. These relative contributions to the total impact can be explained by inspecting the relations between the 2030 baseline net export flows for rice in Figure 5.4 and the projected shares in global rice exports reported in Table 5.2.

Not surprisingly, given the low weight of sub-Sahara African staple crop trade flows in global staple crop trade, a bad harvest year in any of the SSA regions due to a conjunction of regional droughts and floods would have only marginal impacts on global average staple crop prices.

Table 5.6: Impact on export prices of directly affected regions *(Percentage deviation from 2030 baseline)*

Scenario	Export price of	Wheat	Maize	Rice	PrcFood
North America Shock	NAmerica	43.8	233.5	0.9	9.1
Australia Shock	Oceania	22.0	3.7	0.6	0.0
South America Shock	OSAmerica	7.6	34.7	15.6	2.0
	Andean	2.5	36.9	9.2	2.0
	Brazil	2.6	37.2	9.3	2.4
India-OEAsia Shock	India	3.0	24.5	39.2	1.9
	OEAsia	2.4	22.3	31.2	2.5

The model treats crops produced in different world regions appropriately; not as identical commodities with a uniform price but as imperfect substitutes in demand. For example, Indian rice is different from rice grown in South America and the detailed composition of North American exports of maize and other coarse grains certainly differs from that of, say, Oceanian maize and other coarse grain exports. Therefore Table 5.6 also reports the impact on the region-specific export prices for the crops grown in the regions directly hit by the simulated extreme weather events. As expected, these region-specific direct export price effects are generally stronger than the global average effects. Table 5.6 also shows to which extent the crop price impacts feed through to the export prices of other processed foodstuffs (PrcFood).

Table 5.7: Elasticity of region's export price to productivity shock *(Percentage increase in a region's average export price associated with an unexpected one per cent drop in crop productivity)*

Export price of	Wheat	Maize	Rice
North America	2.4	9.4	1.1
Oceania	0.5	0.9	0.1
South America	0.9	2.0	1.6

Table 5.7 generalizes the price impact results by showing the impact of a one per cent productivity drop in a region on the export price of crops grown in that region.

Figure 5.5: Impact of North American yield shock on crop import prices in sub-Saharan African regions *(Percentage deviation from 2030 baseline)*

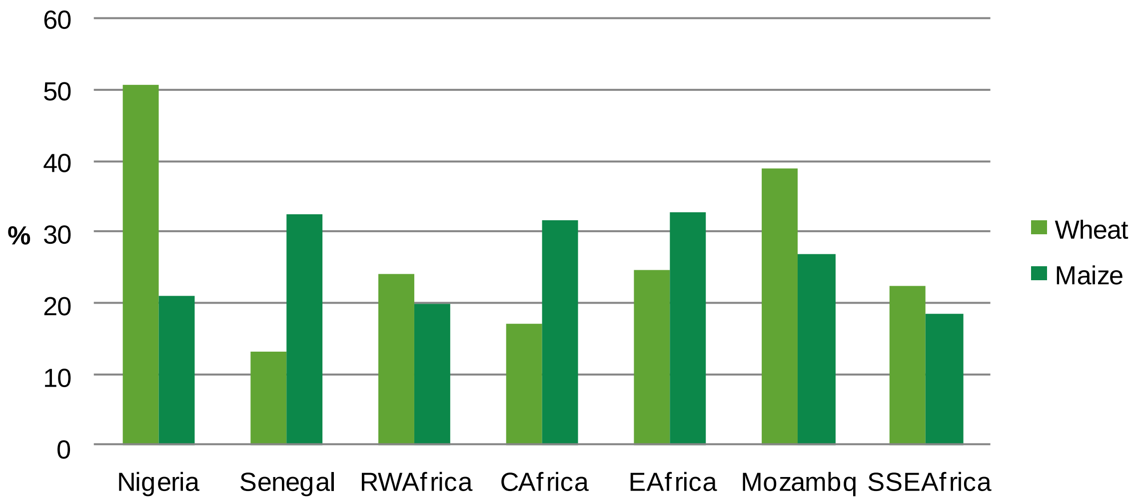
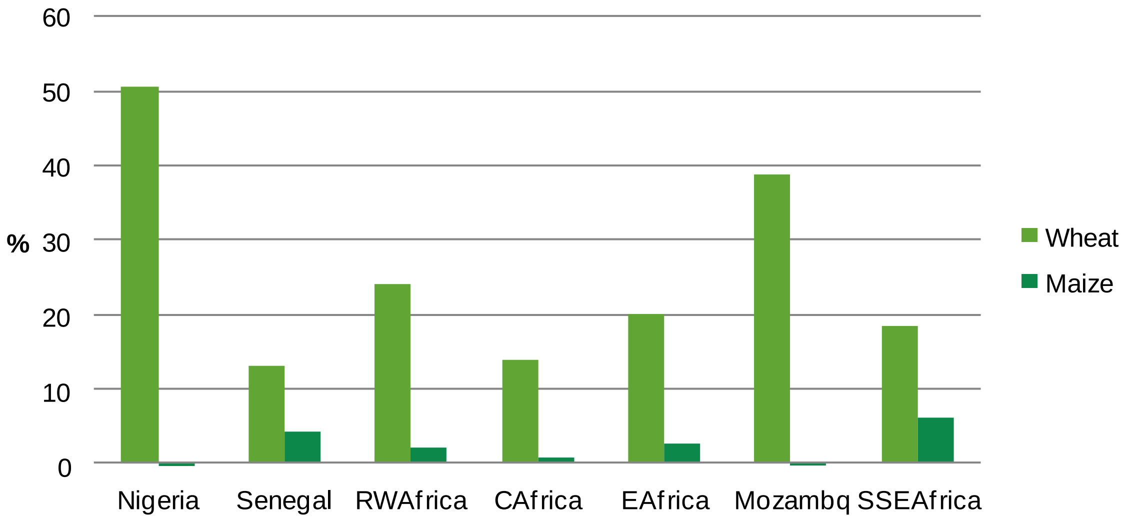


Figure 5.5 shows how the world market price spike for wheat and maize triggered by the North American drought affects the average import prices faced by consumers in the SSA regions. The differences across importing countries for the same crop are explained by the differences in the composition of these imports by region of origin. For example, as shown in Table 5.3 above, Nigeria imports 95.1 per cent of its total 2030 baseline wheat imports from North America, while Senegal receives only 2.6 per cent of its wheat imports from that source. Correspondingly, the impact on the average wheat import price in Nigeria is far stronger than in Senegal. The other cross-regional differences in Figure 5.5 can be explained along the same lines.

Figure 5.6: Impact of North American yield shock on average consumer prices in sub-Saharan African regions *(Percentage deviation from 2030 baseline)*



Note: Figure shows percentage increase for price indices defined over domestic and imported wheat and maize/other coarse grains.

The extent to which the North American drought shock feeds through to average domestic consumer prices in the SSA regions is shown in Figure 5.6 and depends primarily on the import shares of wheat and maize in total domestic demand for these crops. For instance, Nigeria's wheat demand is almost entirely covered by imports (see Appendix Table A.2), while the country is virtually self-sufficient in maize and other coarse grains. Correspondingly, the impact of the import price rise for wheat on the average domestic price for wheat is very strong, while the impact on the domestic average price for maize is virtually nil. The general pattern of high import shares for wheat and low import shares for maize and other coarse grains is also characteristic for most other SSA regions (see Appendix Table A.2). Therefore, the simulated impact of the North American drought on average domestic prices in the SSA regions is generally far smaller for maize than for wheat.

As shown in Table 5.8, the overall impacts of the North America shock on household food consumption in SSA and other low- and middle-income regions suggested by the model are far from negligible. However, it is also worth bearing in mind that impacts on household food consumption also depend on the share of a specific crop or food product in food consumption expenditure. For instance, for most of SSA, direct consumption of wheat is a small share of overall food consumption (see Appendix Table A.1), so that the impact of a significant domestic price increase for wheat may not have a significant impact on households.[14] By contrast, wheat is heavily consumed in North Africa, so price increases in the domestic market there may have a quite substantial effect on household consumption.

Table 5.8: Impact of North America drought on household real food consumption
(Percentage deviation from 2030 baseline consumption quantities)

	Wheat	Maize	OCrops	Livestock	MeatPrd	PrcRice	OPrcFood
Nigeria	-13.6	-0.2	-0.2	-0.4	-1.1	-0.5	-1.9
Senegal	-2.9	-1.3	0.1	-0.5	-0.5	-0.8	-0.2
RWAfrica	-6.7	-0.8	0.0	-0.5	-0.6	-0.7	-0.3
CAfrica	-5.2	-0.6	0.0	-0.4	-0.5	-0.6	-1.0
EAfrica	-11.4	-2.2	0.3	-0.3	-0.2	0.1	-1.1
Mozambq	-22.0	-1.5	-0.1	0.0	-0.4	-0.5	-3.8
SSEAfrica	-15.2	-5.7	0.1	-0.7	-0.3	-0.3	-0.4
India	-0.9	-2.1	0.0	-0.4	0.8	0.0	-0.2
OSAsia	-5.1	-6.1	0.1	-0.1	-5.9	0.1	-2.5
CAsia	-6.2	-11.3	-0.1	-1.6	-1.1	-0.5	-1.8
Andean	-16.1	-22.1	0.3	0.0	-0.7	-3.8	-5.8
Brazil	-9.7	-16.6	0.8	-1.4	-1.2	0.5	-1.4
OSAmerica	-11.1	-15.7	1.6	-0.4	-0.2	0.4	-2.9
CAmerica	-14.1	-16.5	0.6	-1.8	-2.9	-1.6	-6.4
NAfrica	-4.8	-14.4	0.0	-2.7	-2.1	-0.5	-3.4

Note: Other crops (OCrops); Meat products (MeatPrd); Processed rice (PrcRice); Other processed food (OPrcFood).

Figures 5.7 to 5.12 display the corresponding crop price impacts of the simulated regional extreme weather events in other major crop export regions on SSA regions. The bad harvest shock in South America by assumption affects maize yields more severely than the yields of wheat and rice (Table 4.1). The average maize import price impact is most pronounced for Senegal (Figure 5.7), because in the baseline Senegal imports nearly 70 per cent of its total maize imports from Latin America. However, since the import share in Senegal's total demand for maize and other coarse grains is small, the impact on Senegal's average market price for maize and other coarse grains remains moderate (Figure 5.10). The strongest impact of the Latin American shock on average market prices in any of the SSA regions of the model reported in Figure 5.10 occurs for wheat in Mozambique. In the baseline, Mozambique imports most of its total wheat consumption, and nearly 50 per cent of these imports are sourced from Latin America. However, the share of wheat in the country's total baseline crop demand is low. Thus, the simulation analysis suggests that a bad harvest shock in Latin America of the assumed magnitude has a moderate impact on food security in SSA.

The assumed extreme weather event scenario in Oceania hits wheat yields primarily (Table 4.1) and raises average wheat prices in SSA regions by between 4 and 12 per cent (Figure 5.11). A simultaneous yield shock in the net rice-exporting regions Other East Asia and India raises average import prices in SSA regions by 13 to 45 per cent (Figure 5.9) and average domestic market prices for rice by 6 to 43 per cent (Figure 5.12) compared with the baseline. Nigeria is hit by the strongest rice price spikes in this scenario.

Figure 5.7: Impact of South American yield shock on crop import prices in sub-Saharan African regions *(Percentage deviation from 2030 baseline)*

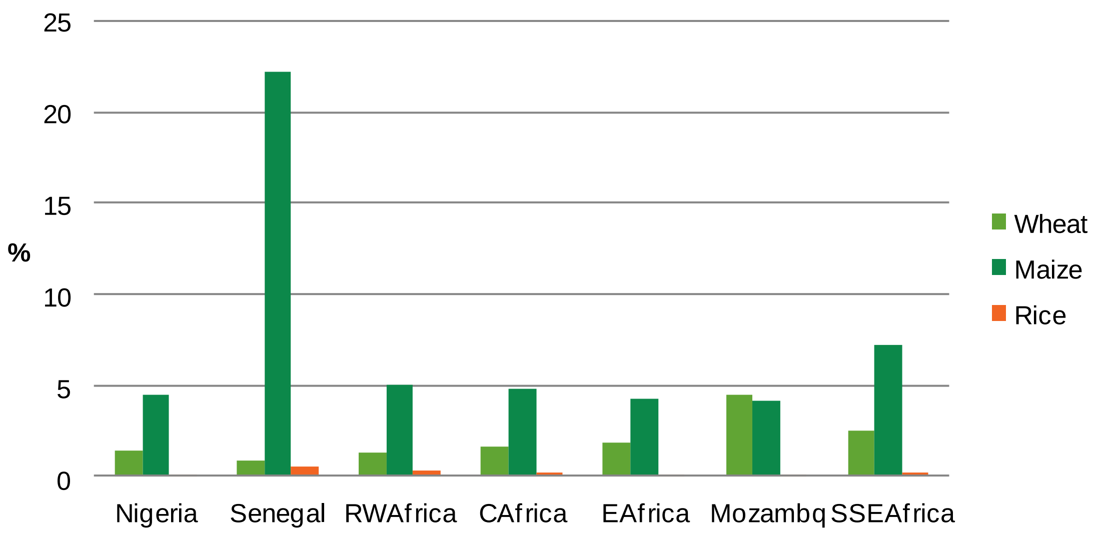


Figure 5.8: Impact of Oceanian yield shock on crop import prices in sub-Saharan African regions *(Percentage deviation from 2030 baseline)*

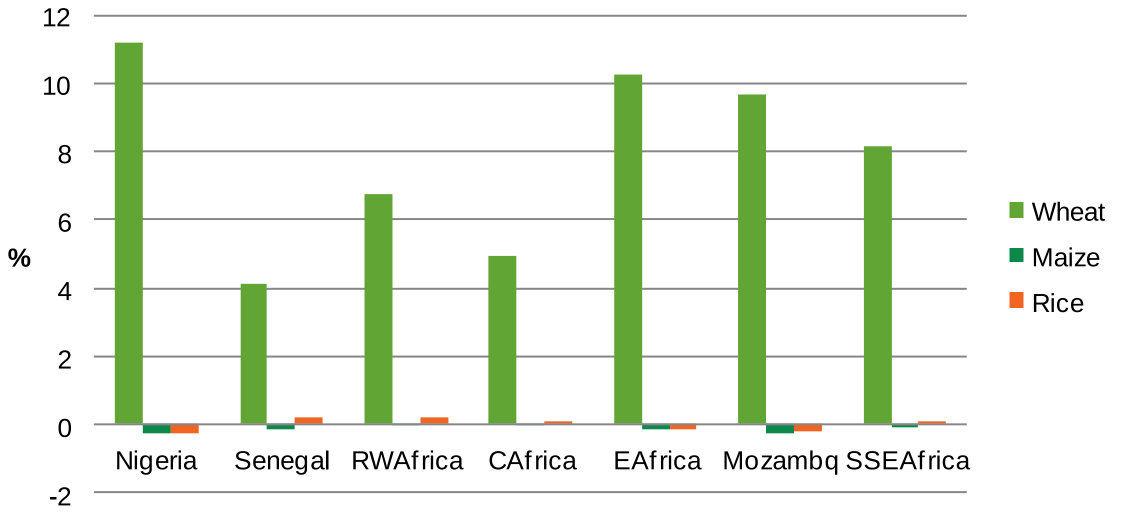


Figure 5.9: Impact of joint yield shocks in India and Other East Asia on crop import prices in sub-Saharan African regions *(Percentage deviation from 2030 baseline)*

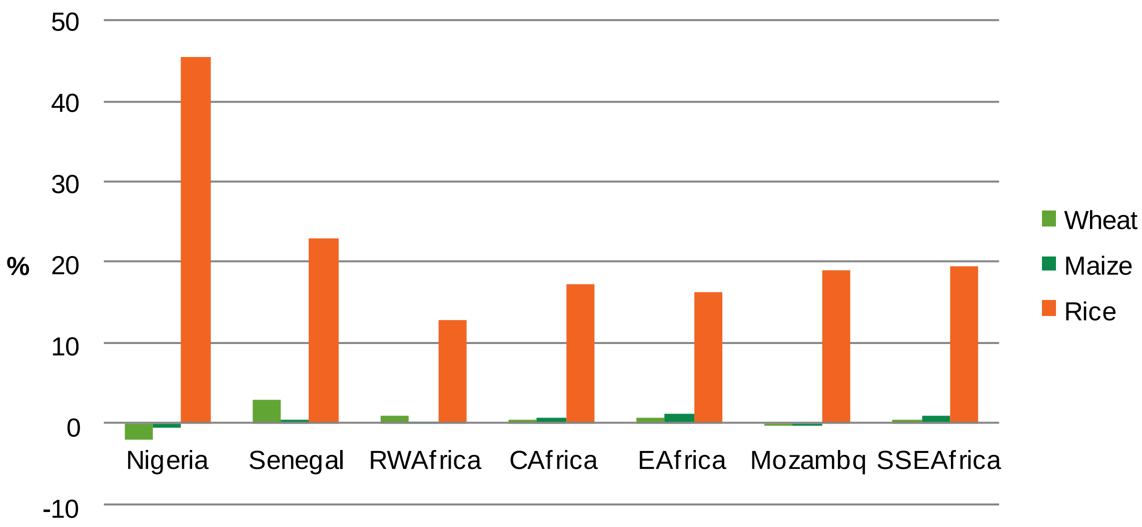


Figure 5.10: Impact of South American yield shock on average consumer prices in sub-Saharan African regions *(Percentage deviation from 2030 baseline)*

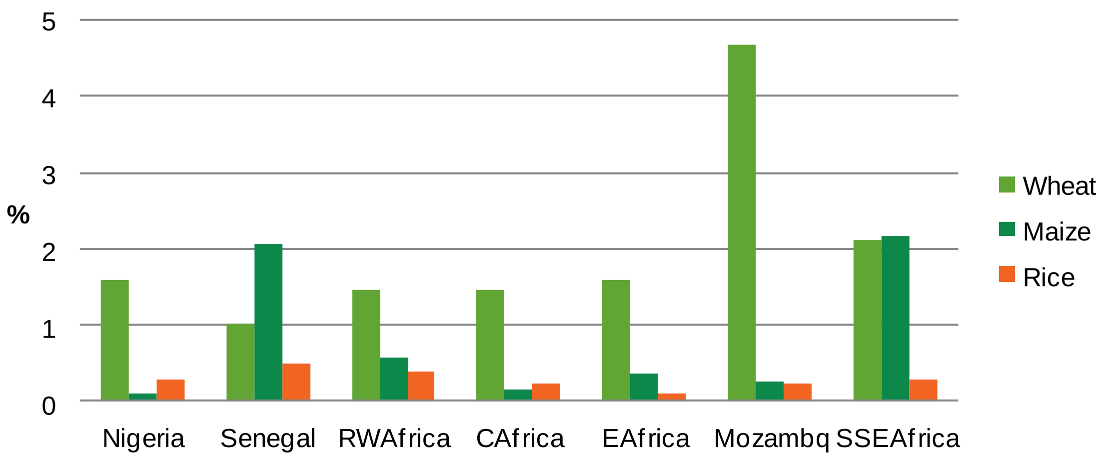


Figure 5.11: Impact of Oceanian yield shock on average consumer prices in sub-Saharan African regions *(Percentage deviation from 2030 baseline)*

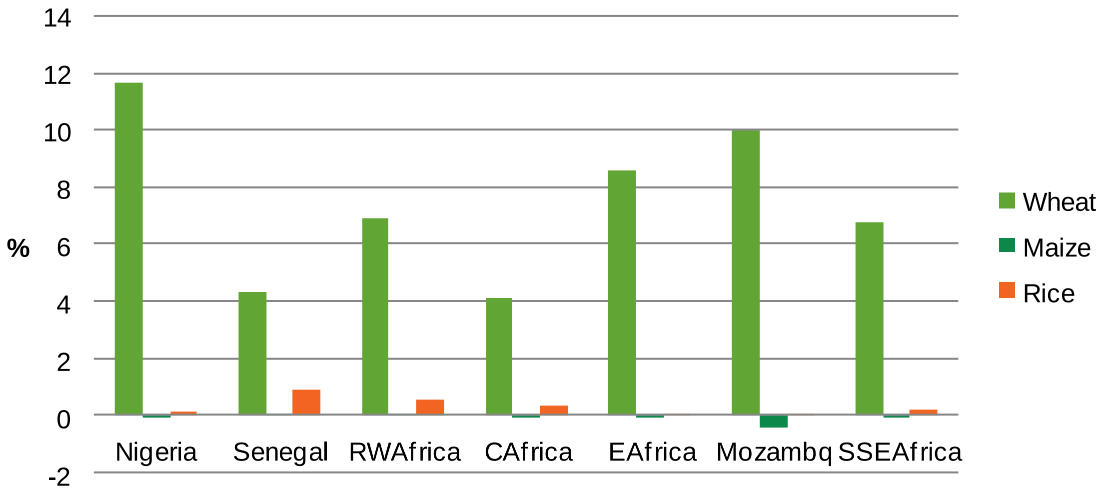
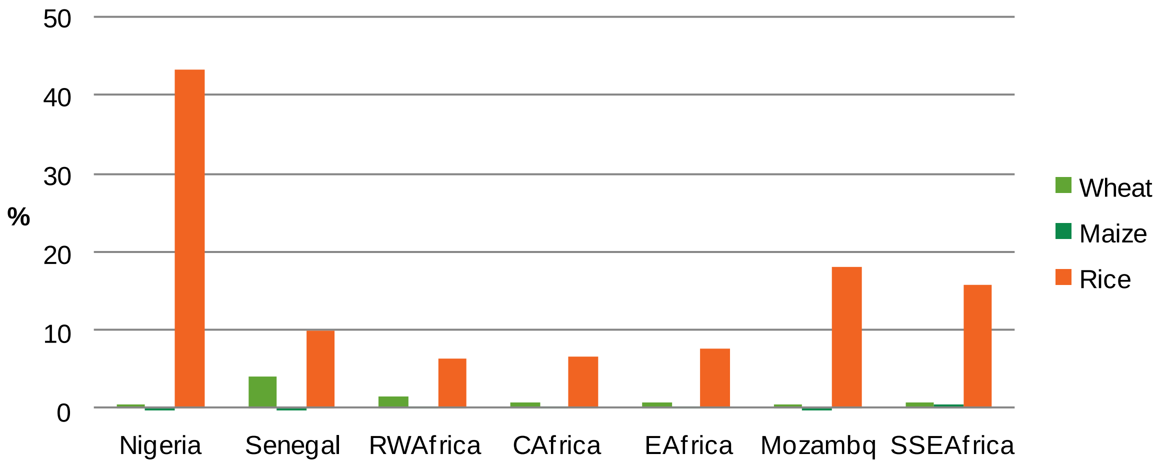


Figure 5.12: Impact of joint yield shocks in India and Other East Asia on average consumer prices in sub-Saharan African regions *(Percentage deviation from 2030 baseline)*



We now turn to a set of scenarios in which each of the sub-Saharan African regions is in turn hit by extreme weather events. Figure 5.13 displays the impacts of the assumed yield shocks (shown in Table 4.1 above) for each of the four scenarios on the average domestic consumer prices for: (a) maize and other coarse grains; (b) wheat; and (c) paddy rice for all SSA regions of the model. For example, the simulation results suggest that the recurrence of a bad harvest year in South and South-Eastern Africa with yield drops as historically observed in 1995 would drive up domestic prices for maize and other coarse grains in the region by more than 100 per cent in response to a drop in domestic production by around 35 per cent (Figure 5.14).

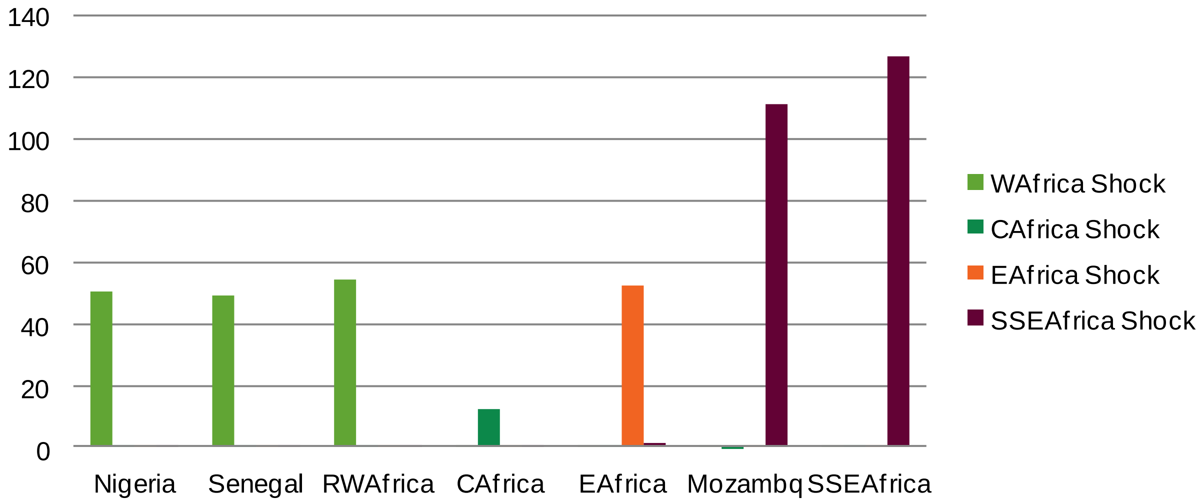
Since baseline trade flows in agricultural commodities between the four SSA regions are generally low (Appendix Table A.7), cross-regional spill-over effects between SSA sub-regions due to the extreme weather shocks remain negligible in all cases. That is, for each of the four scenarios, Figure 5.13 shows strong price impacts only in the sub-region directly hit by the shock, with only very small transmission effects to the other SSA sub-regions.

The severe impacts of the SSA shocks on the region's household food consumption displayed in Table 5.9 are based on the assumptions of no emergency aid, no domestic food commodity stocks and no additional balance-of-payment support from abroad to allow additional food imports from abroad that are not financed through export earnings. Particularly, poor households with a high share of direct household consumption of maize and other coarse grains would be badly hit under these assumptions. Figure 5.14 shows the domestic production impacts for maize and coarse grains.

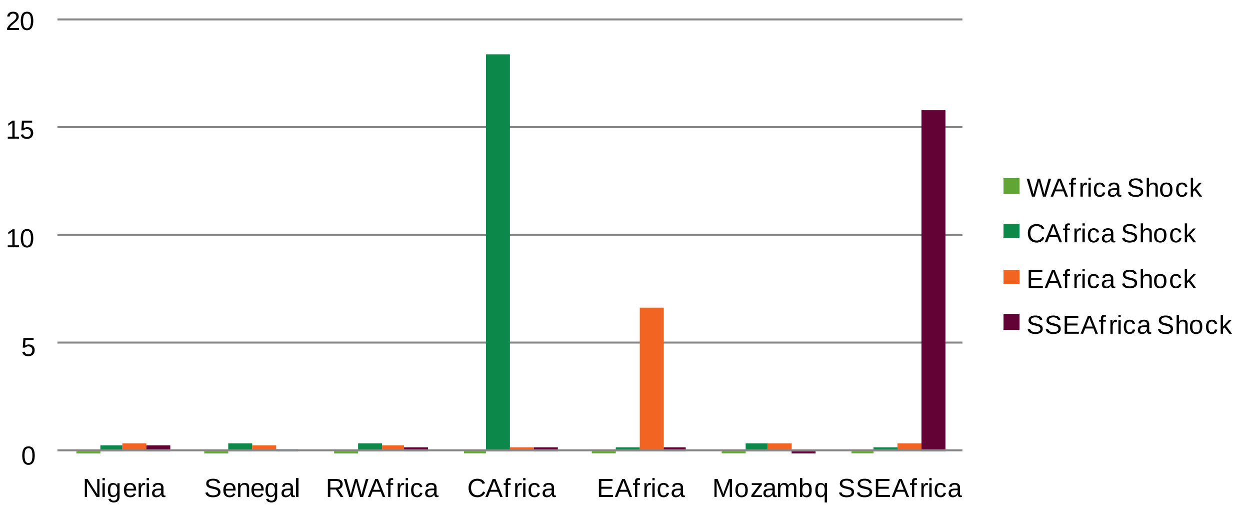
The basic message from the simulations considered up to this point can be summarized as follows. While extreme weather events in other crop-exporting regions have noticeable impacts on local prices in SSA, far more dramatic effects are to be expected from a rising frequency of droughts and floods in the region itself.

Figure 5.13: Impact of sub-Saharan African yield shocks on average consumer prices in sub-Saharan African regions

(a) Maize and other coarse grains *(Percentage deviation from 2030 baseline)*



(b) Wheat *(Percentage deviation from 2030 baseline)*



(c) Paddy rice *(Percentage deviation from 2030 baseline)*

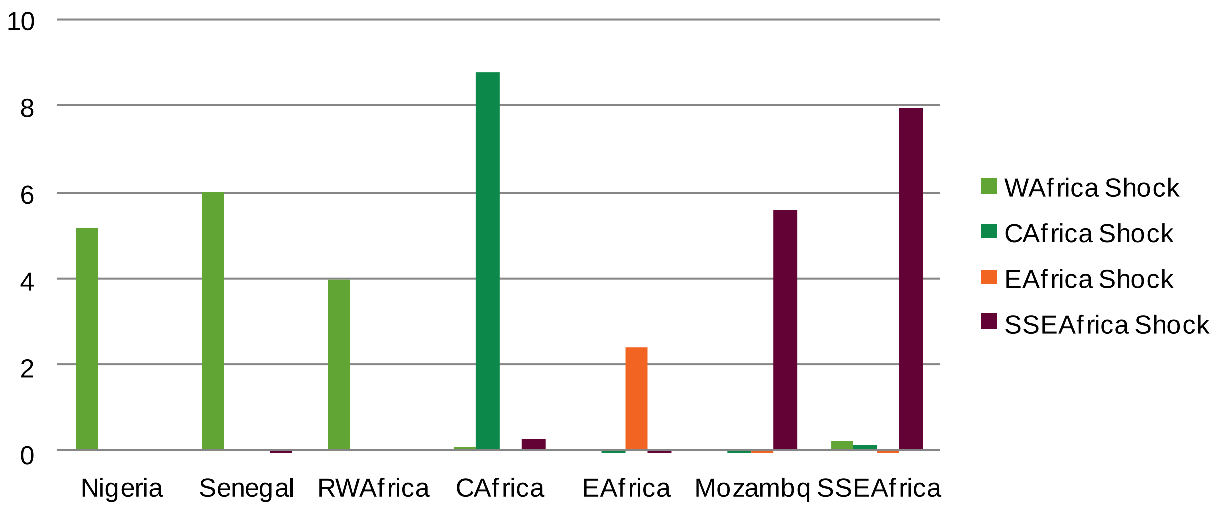
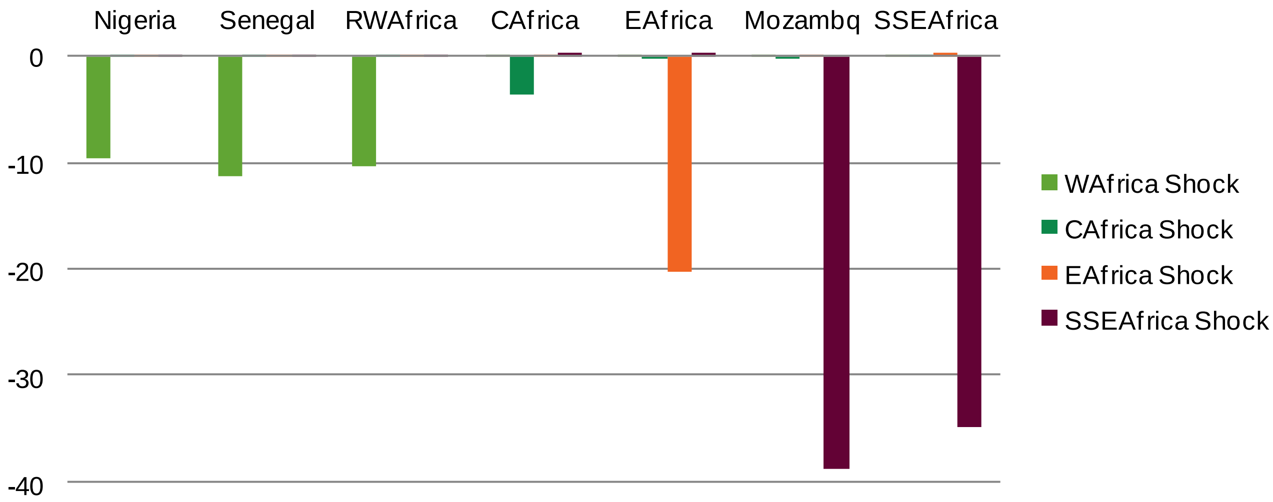


Table 5.9: Impact of sub-Saharan African shocks on sub-Saharan African household real food consumption *(Percentage deviation from 2030 baseline consumption quantities)*

	Wheat	Maize	OCrops	Livestock	MeatPrd	PrcRice	OPrcFood
West Africa Shock							
Nigeria	-0.3	-14.0	-0.4	-2.4	-0.7	-0.5	-1.9
Senegal	-0.2	-9.6	-0.4	-0.7	-0.7	-0.4	-0.8
RWAfrica	-0.3	-11.3	-0.5	-1.4	-1.1	-0.6	-1.5
Central Africa Shock							
CAfrica	-6.5	-4.3	0.2	-0.2	-0.4	-1.4	-1.7
East Africa Shock							
EAfrica	-5.4	-23.3	0.0	-0.9	-1.5	-2.5	-3.7
Southern Africa Shock							
Mozambq	1.2	-41.0	-0.6	-0.5	-1.3	-2.9	-7.0
SSEAfrica	-13.5	-54.0	1.7	-5.0	-3.4	-3.1	-4.3

Note: Other crops (OCrops); Meat products (MeatPrd); Processed rice (PrcRice); Other processed food (OPrcFood).

Figure 5.14: Impact of sub-Saharan African shocks on domestic production of maize and other coarse grains *(Percentage deviation from 2030 baseline)*



To illustrate the potential impacts of domestic policy responses to the extreme weather shock in North America, we finally consider a scenario in which developing countries with significant baseline exports of maize or wheat impose export restrictions for these crops and all developing countries reduce barriers to maize and wheat imports in order to ameliorate the adverse price shocks faced by domestic consumers. As further detailed in Section 6, during the 2007/08 food price spike, various developing countries have resorted to such trade policy measures.

In this scenario, we specifically assume that the developing regions in Table 5.10 impose a temporary export tax of 30 per cent on wheat and maize, and all developing regions cut import tariffs on these two commodities by 50 per cent.

Table 5.10: Impact of North America shock on domestic prices of maize- or wheat-exporting developing countries *(Export volumes in billion US$ at 2004 prices. Domestic price effects in per cent)*

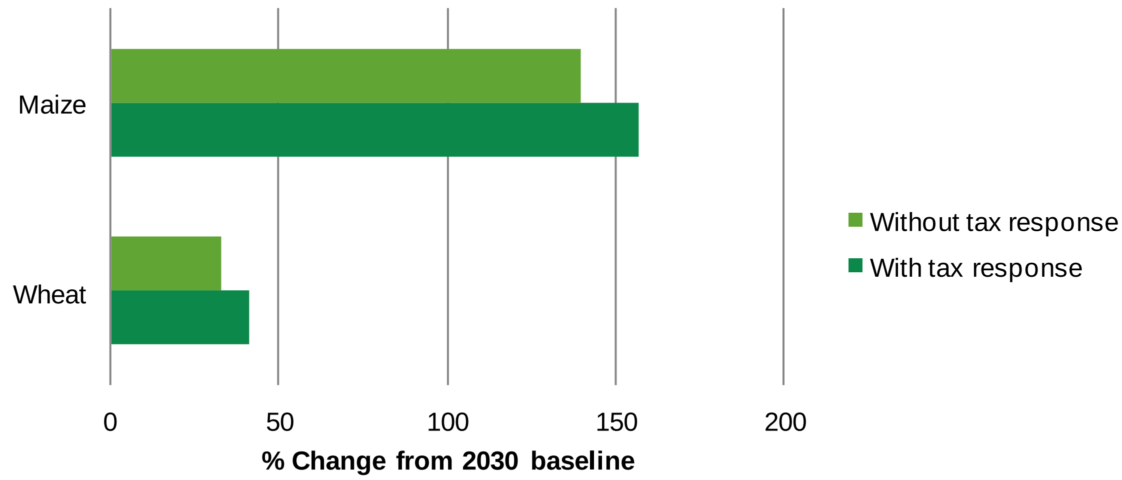
	Maize		**Wheat**	
	Export Volume 2030 Baseline	**Domestic Price Effect**	**Export Volume 2030 Baseline**	**Domestic Price Effect**
China	3.6	76.6	n	55.2
OEAsia	3.0	41.8	n	43.4
India	2.3	11.5	5.1	2.6
CAsia	7.5	31.8	21.1	13.6
Brazil	13.5	52.6	2.5	23.4
OSAmerica	25.0	55.8	23.2	31.0
CAmerica	2.5	82.2	6.4	49.1
NAfrica	n	49.1	1.9	8.0
SSEAfrica	5.0	6.2	1.5	18.5
Sum	62.3		61.7	
Share in Global Exports	20.6%		13.7%	

Note: n = very small export volume; no change in export tax assumed.

The impact on the world market export prices for wheat and maize are shown in Figure 5.15. By restricting the supply of exports while raising the demand for imports, the simulated trade policy measures raise the average export price for wheat by a further eight percentage points and for maize by a further 17 percentage points. Thus, resort to export restrictions in response to extreme weather events reinforces the global crop price impacts. In other words, the assumed trade policy responses would account for 25 per cent of the total observed average export price increase for maize and for over 12 per cent of the observed export price increase for wheat. As shown in the last row of Table 5.10, in this illustrative scenario only moderate fractions of total world exports of maize and wheat are subject to the assumed additional export taxes. Obviously, stronger export price increases would occur under the assumption of a more widespread resort to export taxes, higher export tax rates or under the assumption of total export bans. The basic message from this scenario is that even relatively moderate trade policy responses can significantly reinforce the world market price impact of an adverse weather shock.

As further detailed in Sections 6.3 and 6.4 below, the introduction of export restrictions is widely seen to be a contributing factor to the 2007/08 and 2010/11 food price spikes. The simulation results presented here – which only consider stylized policy responses to extreme weather events in North America in isolation from extreme weather shocks in other regions that actually occurred in 2007/08 – are consistent with this view.

Figure 5.15: Average world market export price impacts of North America shock with export restrictions and import stimulation in developing countries



To what extent would these trade policy responses succeed in reducing the domestic price pressures triggered by the extreme weather events? Table 5.11 shows that in most of the developing regions the additional rise in world market prices due to export restrictions imposed by other countries strictly dominates the potentially price-reducing effects of lower domestic import taxes and higher domestic supply, due to the redirection of sales from export to domestic markets. Only Other South America, the main developing export region of maize and wheat, would be able to reduce the domestic price impact of the shock significantly in this way at the expense of other regions.

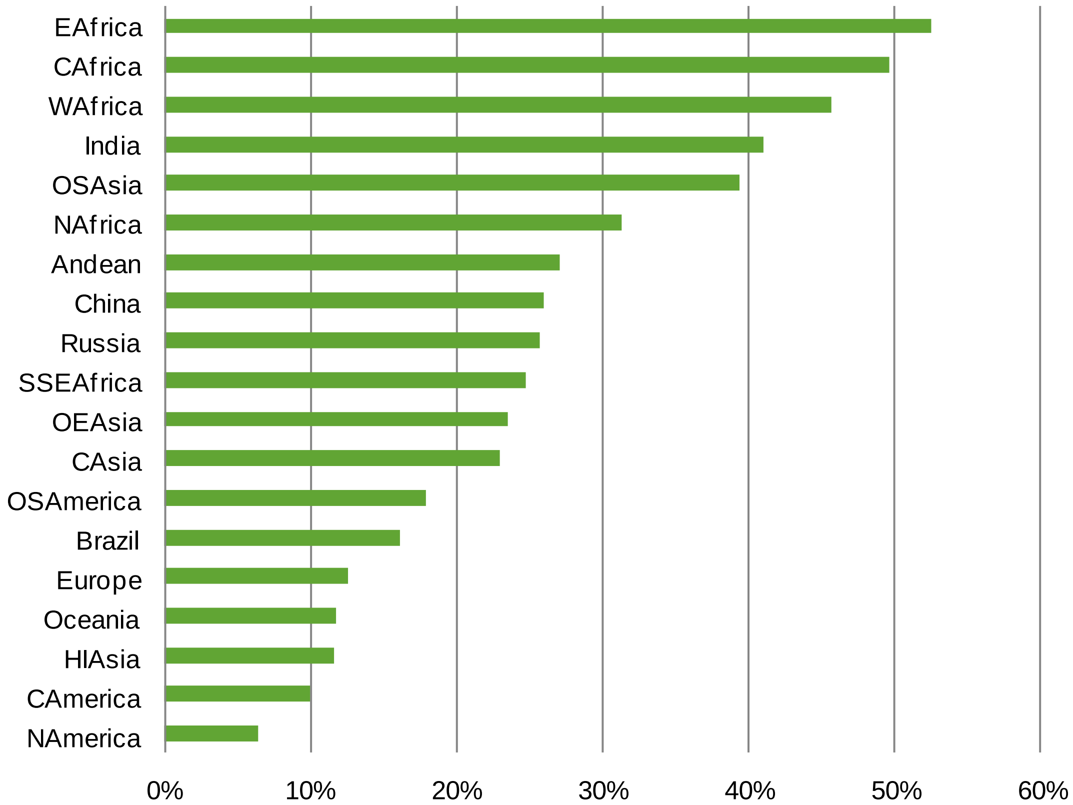
Table 5.11: Domestic price impacts of North America shock with and without export restrictions and import stimulation in developing countries *(Percentage deviations from 2030 baseline)*

	Maize		**Wheat**	
	Without	**With**	**Without**	**With**
China	76.6	74.2	55.2	64.1
OEAsia	41.8	46.8	43.4	49.8
India	11.5	6.0	2.6	0.1
OSAsia	45.7	69.7	25.0	29.2
CAsia	31.8	25.4	13.6	13.6
Andean	80.6	86.2	42.8	45.9
Brazil	52.6	31.3	23.4	48.1
OSAmerica	55.8	37.2	31.0	23.0
CAmerica	82.2	81.9	49.1	52.0
NAfrica	49.1	47.7	8.0	7.5
Nigeria	-1.9	-2.2	50.5	55.0
Senegal	4.2	5.0	13.0	15.5
RWAfrica	2.2	2.0	24.1	27.0
CAfrica	0.9	1.3	13.9	15.2
EAfrica	2.8	3.2	20.0	22.9
Mozambq	-0.2	0.1	38.8	52.2
SSEAfrica	6.2	7.1	18.5	26.1

APPENDICES

APPENDIX 1. KEY FEATURES OF BENCHMARK DATA SET

Figure A.1: Baseline shares of food consumption in total household expenditure



Source: GTAP 7.1 Database

Table A.1: Initial baseline commodity shares in household food consumption expenditure *(in per cent)*

	PadRice	Wheat	Maize	OCrops	Livestock	MeatPrd	PrcRice	OPrcFood	Total
Europe	0.0	1.0	0.3	9.8	1.8	14.9	0.3	71.9	100
Russia	0.0	1.6	0.4	12.8	15.1	27.0	0.1	43.0	100
NAmerica	0.0	0.0	0.1	8.1	2.9	18.1	0.3	70.6	100
Oceania	0.0	0.0	0.1	9.5	1.4	11.7	0.7	76.7	100
HIAsia	0.0	0.0	0.1	11.0	1.9	8.1	6.1	72.8	100
China	0.0	0.0	0.2	19.0	16.2	8.4	4.4	51.8	100
OEAsia	0.3	0.1	1.1	16.3	7.3	9.3	14.7	50.9	100
India	3.0	8.2	2.8	29.9	8.3	0.4	12.5	34.8	100
OSAsia	0.1	0.0	0.1	17.0	30.4	1.0	19.0	32.4	100
CAsia	0.7	1.9	3.6	14.9	8.0	28.9	1.6	40.4	100
Andean	0.0	0.8	2.2	17.3	5.1	19.3	5.3	50.1	100
Brazil	0.0	0.1	0.1	5.9	2.8	19.3	2.8	69.1	100
OSAmerica	0.0	0.4	1.3	7.2	6.3	16.2	0.3	68.2	100
CAmerica	0.1	0.5	4.0	19.2	7.7	10.4	2.9	55.3	100
NAfrica	0.6	13.0	4.3	22.9	4.4	11.6	1.8	41.4	100
WAfrica	3.1	1.8	7.2	47.2	6.9	4.0	7.5	22.2	100
CAfrica	0.2	0.3	12.3	18.9	3.2	11.0	2.6	51.5	100
EAfrica	0.3	1.1	11.9	26.1	7.5	6.2	3.5	43.3	100
SSEAfrica	0.1	0.2	3.6	9.0	6.2	14.8	1.0	65.1	100

Source: Own calculations based on GTAP 7.1 Database.

Note that direct household consumption of paddy rice is negligible, except in India and West Africa. Paddy rice serves as an intermediate input in the production of processed rice. Similarly, to a large extent, the other agricultural outputs – wheat, maize, other crops and livestock – enter household consumption indirectly via their use as inputs in processed food products (which include *inter alia* flour and bread). The model explicitly captures the input–output structure of food production and the associated linkage between the prices of agricultural raw outputs and processed food.

Table A.2: Initial import shares in domestic demand and crop shares in total crop demand for sub-Saharan African regions

	Import share in domestic demand (%)			Share of crop in total crop demand (%)		
	Rice	Wheat	Maize	Rice	Wheat	Maize
Nigeria	64.3	98.4	0.0	11.9	5.1	12.1
Senegal	59.5	99.8	4.9	43.5	4.0	18.1
OWAfrica	49.0	98.0	1.1	13.9	1.7	13.3
CntrlAfrica	48.4	47.3	0.7	5.9	6.5	30.1
SCntrlAfrica	60.7	28.2	1.7	6.7	3.5	33.1
Ethiopia	91.4	34.2	1.3	0.1	12.0	33.5
Madagascar	5.0	100.0	5.6	45.1	0.7	1.4
Mauritius	99.7	100.0	100.0	6.1	1.4	1.9
Tanzania	18.8	60.4	2.1	5.0	4.7	30.6
Uganda	23.7	90.2	2.6	2.1	2.1	13.7
OEAfrica	20.5	62.2	4.3	6.7	7.9	26.4
Mozambique	62.6	99.9	4.8	10.3	6.4	20.3
Zambia	23.6	20.0	2.4	3.9	4.3	29.5
Zimbabwe	38.9	82.5	66.3	3.0	9.8	27.0
Malawi	24.7	100.0	6.4	1.6	2.0	38.4
Botswana	85.2	99.4	29.8	7.7	7.0	44.8
South Africa	94.5	47.8	8.4	4.5	7.4	18.6
O SACU	74.9	56.4	27.0	3.9	9.0	23.5

Source: Author's own calculations based on GTAP 7.1 Database.

APPENDIX 2. ASSUMPTIONS FOR DYNAMIC BASELINE SCENARIO

Population and labour force growth by region is based on the UNESA (2009) global medium-variant projections and is consistent with the corresponding baseline assumptions underlying the World Bank (2010a) Economics of Adaptation to Climate Change study and the UK Government Office for Science Future of Food and Farming study (Foresight 2011). As shown in Table A.3, the global population is projected to rise to 7.7 billion by 2020 and to 8.3 billion by 2030.

The assumptions about agricultural productivity growth by country and crop type (Table 6) are based on a synopsis of the corresponding projections in Jaggard *et.al* (2010), Nelson *et al*. (2010) and the UN Millennium Ecosystem Assessment (Alcamo *et al*. 2005). Changes in agricultural land use are based on a synopsis of projections in Smith *et al*. (2010), Nelson *et al*. (2010) and Alcamo *et al*. (2010).

Growth rates of technical progress for industry and services are calibrated residually such that the growth rates of real GDP by region are approximately equal to the baseline growth projections (Table A.3) used in World Bank (2010a) and Nelson *et al*. (2010).

Table A.3: Population growth

	Population (millions)				**Population growth p.a. (%)**		
	2005	**2010**	**2020**	**2030**	**2004–10**	**2011–20**	**2021–30**
Europe	595.5	598.4	597.7	590.8	0.10	-0.01	-0.12
Russia	144.0	140.3	132.4	123.9	-0.51	-0.58	-0.66
NAmerica	332.2	348.5	379.2	405.4	0.96	0.85	0.67
Oceania	33.2	35.2	39.2	42.9	1.21	1.07	0.91
HIAsia	235.1	239.8	244.6	243.8	0.39	0.20	-0.03
China	1313.0	1351.5	1421.3	1458.4	0.58	0.50	0.26
OEAsia	576.6	613.2	678.0	730.3	1.24	1.01	0.75
India	1134.4	1220.2	1379.2	1505.7	1.47	1.23	0.88
OSAsia	383.6	420.9	499.9	574.7	1.87	1.74	1.40
CAsia	309.8	335.7	389.0	434.2	1.62	1.48	1.10
Andean	94.5	100.6	112.8	122.9	1.26	1.15	0.86
Brazil	186.8	199.0	220.0	236.5	1.27	1.01	0.73
OSAmerica	92.2	97.9	108.7	117.7	1.22	1.05	0.79
CAmerica	183.5	195.1	216.9	234.6	1.24	1.06	0.79
NAfrica	152.2	164.5	188.8	209.0	1.57	1.38	1.02
WAfrica	292.2	329.2	408.8	491.4	2.41	2.19	1.86
CAfrica	93.3	108.4	143.9	186.1	3.05	2.88	2.60
EAfrica	271.1	309.3	393.4	480.8	2.67	2.43	2.03
SSEAfrica	113.3	120.6	135.7	151.0	1.27	1.18	1.07
Total	**6536.2**	**6928.4**	**7689.4**	**8340.0**	**1.17**	**1.05**	**0.82**

Source: Aggregations of UN medium population growth projections by country.

Table A.4: Assumed baseline GDP growth rates and agricultural land area growth (In per cent)

	Baseline GDP growth p.a.			Agric land area growth	
	2004–10	**2011–20**	**2021–30**	**Per annum**	**2010–30**
Europe	3.2	2.8	2.7	0.00	0.0
Russia	5.4	4.6	4.1	0.03	0.6
NAmerica	2.9	2.8	2.8	0.00	0.0
Oceania	3.4	3.0	2.7	0.00	0.0
HIAsia	2.9	2.4	2.3	0.00	0.0
China	7.7	6.1	5.2	0.15	3.0
OEAsia	5.1	4.3	4.0	0.15	3.0
India	6.3	5.6	4.9	0.18	3.7
OSAsia	5.1	4.7	4.3	0.18	3.7
CAsia	4.3	4.2	4.0	0.38	7.9
Andean	4.4	4.2	3.9	0.60	12.7
Brazil	4.1	3.9	3.8	0.70	15.0
OSAmerica	4.4	4.1	3.9	0.80	17.3
CAmerica	3.5	3.6	3.5	0.70	15.0
NAfrica	4.4	4.1	3.7	0.38	7.9
WAfrica	4.5	4.2	3.8	0.91	19.9
CAfrica	5.1	5.0	4.7	0.91	19.9
EAfrica	4.6	4.4	3.9	0.91	19.9
SSEAfrica	3.1	3.0	2.8	0.91	19.8

Source: Willenbockel 2011.

Table A.5: Assumed baseline factor productivity growth in agriculture

	Productivity growth per annum			
	Wheat	**Rice**	**Maize**	**Other Crops**
Europe	1.05	0.76	0.79	1.10
Russia	1.12	1.2	0.88	1.18
NAmerica	0.95	0.82	0.75	1.00
Oceania	1.01	0.78	0.88	1.06
HIAsia	1.05	0.8	0.8	1.10
China	1.26	0.95	1.14	1.32
OEAsia	1.26	0.95	1.14	1.32
India	1.39	0.9	1.11	1.46
OSAsia	1.39	0.9	1.11	1.46
CAsia	1.11	0.9	0.98	1.17
Andean	1.24	1.02	1.2	1.30
Brazil	1.28	1.08	1.18	1.34
OSAmerica	1.24	1.02	1.2	1.30
CAmerica	1.24	1.02	1.2	1.30
NAfrica	1.11	0.9	0.98	1.17
WAfrica	1.5	1.1	1.4	1.58
CAfrica	1.63	0.94	1.46	1.71
EAfrica	1.63	0.94	1.46	1.71
SSEAfrica	1.55	0.97	1.49	1.63

Source: Willenbockel 2011. Note: Without climate change impacts.

The assumed baseline impacts of changes in mean temperature and precipitation on factor productivity in crop agriculture by region (Table A.6) for 2030 are based on the synthesis of recent studies in Hertel *et al.* (2010). This synthesis draws on Ainsworth *et al*. (2008), Matthews *et al*. (1995), Parry *et al*. (1999), Jones and Thornton (2003), Lin *et al*. (2005), Alcamo *et al*. (2007), Cline (2007), Xiong *et al*. (2007), Lobell and Field (2007), Tebaldi and Lobell (2008), Schlenker and Roberts (2009) and are consistent with the previous impact syntheses of Cline (2007) and Easterling *et al.* (2007).

Table A.6: Assumed impacts of climate change trends on crop productivity in 2030
(Percentage deviations in total factor productivity from 2030 baseline levels)

	Paddy rice	Wheat	Maize	Other crops
Europe	-5	-5	-17	-5
Russia	-5	-5	-17	-5
NAmerica	-10	-9	-27	-10
Oceania	-5	-5	-17	-5
HIAsia	3	-2	-6	-3
China	-12	-10	-22	-15
OEAsia	-9	-9	-15	-9
India	-15	-10	-17	-10
OSAsia	-13	-10	-17	-10
CAsia	-5	-5	-12	-5
Andean	0	0	-9	0
Brazil	-10	-10	-17	-10
OSAmerica	-10	-10	-16	-10
CAmerica	-15	-15	-12	-15
NAfrica	-5	-5	-12	-5
WAfrica	-15	-15	-22	-15
CAfrica	-15	-15	-22	-15
EAfrica	-15	-15	-22	-15
SSEAfrica	-18	-18	-35	-18

Source: Adapted from Hertel et al. (2010): Table B1 (Low Case).

The figures assume a high sensitivity of crops to warming, and a CO_2 fertilization effect at the lower end of published estimates, but do not incorporate potential additional temporary impacts due to adverse extreme weather events. The label 'Low Case' used by the authors refers to low productivity *levels* and represents the case with the largest reductions in crop productivity considered in their study.

Table A.7: Sub-Saharan African shares in total sub-Saharan African imports by crop and destination (2030 baseline)

			Origin					
			WAfrica	**CAfrica**	**EAfrica**	**SSEAfrica**	**Total SSA**	**Intra-share***
Destination	**WAfrica**	PadRice	0.05	0.00	0.00	0.00	0.05	0.99
		Wheat	0.00	0.00	0.00	0.00	0.00	1.00
		Maize	0.74	0.00	0.00	0.05	0.80	0.93
		PrcRice	0.08	0.00	0.00	0.00	0.08	0.99
	CAfrica	PadRice	0.01	0.04	0.00	0.06	0.11	0.35
		Wheat	0.00	0.00	0.00	0.00	0.00	1.00
		Maize	0.00	0.00	0.01	0.53	0.54	0.01
		PrcRice	0.00	0.00	0.01	0.08	0.10	0.03
	EAfrica	PadRice	0.00	0.00	0.01	0.00	0.01	0.80
		Wheat	0.00	0.00	0.04	0.00	0.04	1.00
		Maize	0.00	0.00	0.21	0.33	0.54	0.39
		PrcRice	0.00	0.00	0.01	0.00	0.01	0.80
	SSEAfrica	PadRice	0.00	0.00	0.00	0.62	0.62	0.99
		Wheat	0.00	0.00	0.03	0.31	0.34	0.92
		Maize	0.00	0.01	0.00	0.68	0.69	0.98
		PrcRice	0.00	0.00	0.00	0.60	0.61	0.99

Notes: For example, 80 per cent of West African global imports of maize are of SSA origin. 74 per cent of West African imports of maize are of West African origin.
**Intra-share: Share of own region in total imports of SSA origin. For instance 93 = (74/80) per cent of West African imports of paddy rice from SSA sources are imports from other West African countries.*

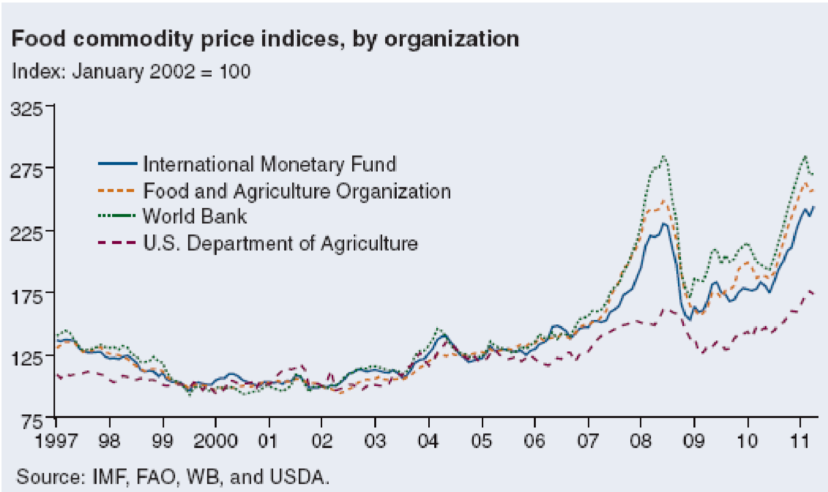
APPENDIX 3: A BRIEF REVIEW OF THE RECENT FOOD COMMODITY PRICE SPIKES

Introduction

This section supplements the preceding forward-looking analysis of potential future food price spikes as a result of extreme weather events in a changing climate with a concise backward-looking review of research into the causes of the observed recent spikes in global food commodity prices. While our main focus is on the 2010/11 hike, the underlying causal factors overlap closely with the causes of the earlier 2007/08 food price crisis. Therefore, this review also draws on studies that explore the earlier episode.

As shown in Figure A2, food commodity prices have been gradually rising from 2002 onwards, prior to the sharp 2007/08 spike. It is important to distinguish between the medium- to long-run drivers of the underlying trend towards higher food prices and the short-run factors that triggered the acute price spikes in 2007/08 and in 2010/11. The longer-run factors are part of the explanation for the spikes, to the extent that they contributed to the emergence of a situation in which short-run shocks can trigger massive price movements.

Figure A2: Food commodity price indices 1997 to 2011



Source: Trostle et al. 2011.

Long-run factors

The main long-run factors commonly identified in the literature are the combination of (i) demand pressures associated with population and per-capita income growth, with (ii) a decline in global average yield growth rates as a result of sluggish investment in agricultural research and development, (iii) rising energy prices that not only pushed up agricultural production and transportation costs but also created incentives for (iv) a strong rise in biofuel production, and (v) a decline in the value of the US dollar against other major currencies.[15]

(i) Demand pressures associated with population and per-capita income growth

Despite the declining rate of global population growth, the world population currently continues to rise in absolute terms by about 75 million per year, entailing a concomitant expansion of global demand for food commodities and energy. Rapid per-capita income growth in a sub-set of developing countries is associated with a dietary transition towards a higher proportion of animal proteins in food consumption and an attendant rise in the demand for feedstuffs (Trostle *et al*. 2011)

(ii) Slowdown of global agricultural productivity growth

Global aggregate yield growth averaged 2.0 per cent per year over the period 1970 to 1990, but declined to 1.1 per cent between 1990 and 2007 (Trostle 2008). This agricultural productivity slowdown is commonly attributed to sluggish investment in agricultural research and development during the long period of low real food prices in the 1980s and 1990s (Piesse and Thirtle 2010; Timmer 2009; Abbott, Hurt and Tyner 2009; Headey 2010).

(iii) Rising oil prices

Between late 2001 and July 2008, the price of crude oil rose from less than US$20 to more than US$130 per barrel (Wiggins, Compton and Keats 2010), driving up the cost of fertilizer and fuel inputs, as well as raising transport costs. For instance, when the oil price doubled between January 2005 and July 2008, the world market prices of urea and di-ammonium phosphate fertilizers increased by 3 and 4.5 times respectively. Conversely, when crude oil prices subsequently declined by 44 per cent from July 2008 to June 2010, the prices of these fertilizers declined by around 65 per cent (Development Committee 2011). According to Baffes and Haniotis (2010), the price transmission links between crude oil and agricultural markets have considerably strengthened in recent years. Their estimates suggest that the pass-through elasticity from crude oil to agricultural prices has risen from 0.22 pre-2005 to 0.28 towards 2009. The emergence of biofuels has added an important new transmission channel from oil to crop prices.

(iv) Rise in biofuel production

As noted above, the rise in oil prices also affects crop prices by stimulating the demand for ethanol. Wiggins, Compton and Keats *et al.* (2010) suggest that when oil prices reach a threshold between US$60 and US$70 per barrel, US ethanol distilled from maize becomes a commercially viable alternative to gasoline. US ethanol production began to expand rapidly in 2003. Maize used for ethanol rose from 10 per cent of total US maize disappearance in 2002/03 to about 24 per cent in 2007/08 (Trostle 2008). There is a broad consensus in the literature that the rise in biofuel production contributed significantly to the observed price increases for maize over this period.[16]

(v) US dollar depreciation against other major currencies

Starting in 2002, the US dollar depreciated steadily up to April 2008, first against OECD country currencies, and later against many developing countries' currencies. This stimulated demand for US food commodity exports and put upward pressure on US export prices. Moreover, the world market prices of major crops are typically denominated in US dollars, and so the export supply prices of other exporting regions also tend to rise in dollar terms with a depreciation of the US currency (Trostle 2008, 2011; Abbott, Hurt and Tyner 2008). Based on a rough back-of-the-envelope calculation, Mitchell (2008) attributes about 10 per cent of the observed food commodity price increases between 2002 and June 2008 to the nominal US dollar depreciation over this period.

These longer term trends do not explain *per se* the sharp 2007/08 price spike, but their interplay is widely considered to establish the pre-conditions for the emergence of a spike, particularly through their impact on food commodity stocks.

The combination of demand pressures and sluggish productivity growth entailed that global food demand exceeded production for a number of years prior to the food crisis (Headey 2010; Wiggins *et al.* 2010; Development Committee 2011; Braun and Torero 2009), implying a decline in global stock levels.

Partly for this reason, but also due to policy reforms that entailed reductions in public grain stock holdings in the USA, Europe, China and a range of other countries, stocks generally declined significantly from 2000 onwards. According to Wiggins *et al.* (2010), world end-of-season stocks as a ratio of use for the three main grains fell from around 35 per cent in the late 1990s to under

20 per cent by 2005. Trostle (2008) reports that by 2007 global stock-to-use ratios for aggregate grains and oilseeds have fallen to the lowest levels since 1970.

When aggregate stocks decline to very low levels, prices become highly sensitive to even relatively small shocks and short-run disturbances (Wright 2011; Torero and von Braun 2010), that is, low stocks are associated with high price volatility (Gilbert and Morgan 2010).

Short-run triggers of the 2007/08 spike

The main short-run triggers of the 2007/08 price spike in this underlying situation of high sensitivity to shocks identified in the literature are extreme weather events in combination with trade policy responses to the sharp price rises that further exacerbated the tightness in international food commodity markets. The potential independent role of purely speculative forces as a trigger or catalyst remains subject to contentious debate.

(i) Extreme weather events

United States Department of Agriculture (USDA) data reported by Trostle (2008) indicate that 2007 was the second consecutive year of drops in global average yields for grains and oilseeds as a result of adverse weather conditions in a range of regions, and the author points out that in historical perspective two sequential years of lower global yields occurred only three other times in the last 37 years before 2008.

The extreme weather events identified for 2006 include droughts in Russia, Ukraine, Australia and South Africa. The adverse weather conditions responsible for bad harvests in 2007 enumerated by Trostle (2008) include the third year of the worst multiyear drought in a century in Australia, resulting in very low grain yields and plummeting exports; a dry spring and harvest-time floods in Northern Europe; a drought in South-East Europe; a second year of drought in the Ukraine and Russia; a late severe multi-day freeze over a large part of the US hard red winter wheat area, which killed some of the crop and reduced yields; a hot and dry summer growing season in Canada that resulted in lower yields for wheat, barley, and rapeseed; a drought in some of North-West Africa's major wheat- and barley-growing areas; a drought in Turkey that reduced yields in its non-irrigated production areas; and a late freeze followed by drought that reduced maize and barley yields.

As a result of the conjunction of these weather events, global wheat harvests in 2006/07 and 2007/08 were respectively 5 per cent and 3 per cent below 2005/06 harvests (Wiggins *et al.* 2010).

(ii) Trade policy responses

According to FAO (2011), at least 55 developing countries resorted to trade policy interventions in the course of the 2007/08 food crisis in order to mitigate the domestic impacts (see also Demeke *et al.* 2008). The measures included export taxes or reductions in export subsidies (e.g. China, Argentina, Russia, Kazakhstan, Malaysia and Indonesia), quantitative export restrictions (e.g. Ukraine and Argentina on wheat, India and Vietnam on rice), outright export bans (e.g. India, Ukraine and Serbia on wheat, India on rice other than basmati, Egypt, Vietnam and Cambodia on rice, Kazakhstan on oilseeds and vegetable oils) as well as reductions in import tariffs (e.g. India, Indonesia, Thailand, Korea and Serbia).[17]

There is a broad consensus in the literature that export restrictions in response to the acute food commodity price increases in late 2007 and early 2008 significantly reinforced the price spike, particularly in the relatively thin international rice market (Headey 2010; Timmer 2008). Braun and Torero (2009) refer to simulations with the MIRAGE model – a global CGE trade model similar to the model employed in the core of this study – that suggest that these trade restrictions can explain as much as 30 per cent of the observed increase in prices over the first half of 2008.

(iii) Other short-run factors

Further to the US dollar exchange rate trends since 2002 up to the onset of the 2007/08 spike outlined above, the dollar experienced another strong depreciation from July 2007 to July 2008. Moreover, further to the longer-run trends in US ethanol production mentioned earlier, the US Energy Policy Act of 2005 mandated new targets for renewable fuel use while discouraging the use of methyl tertiary butyl ether (MTBE) as a gasoline additive, thereby adding a further impetus to ethanol production (Trostle 2008).

The 2007/08 food commodity price spike ended in mid-2008 (Figure 6.1) with the onset of the global recession and a partial recovery of stocks. Oil prices dropped from July 2008 to December 2008 by around 70 per cent before picking up again from 2009 onwards. The dollar appreciated between mid-2008 and March 2009 before declining again for the remainder of 2009 and beyond (Trostle *et al*. 2011). Most of the long-term factors that contributed to the general rise in food commodity prices in 2002–08 discussed continue to be important underlying factors in the recent 2010/11 price surge. Overall, the situation at the onset of the 2010/11 price spike was thus very similar to that in 2007/08 (Development Committee 2011; Trostle 2011; Ortiz *et al.* 2011).

Short-run triggers of the 2010/11 spike

(i) Extreme weather events

Trostle (2011) sees a series of adverse weather events as '(p)robably the most significant factor contributing to the increase in staple food prices in 2010 and 2011'.[18] In contrast to the role of extreme weather events for the 2007/08 spike, where the shocks to harvests were spread over a three-year period, this time the weather-related yield shocks occurred over a ten-month period starting in June 2010. Consequently, expectations for world crop production dropped more quickly after June 2010 than during the 2005–07 price increases (Trostle *et al*. 2011). The 2010/11 price spikes affected a wider range of agricultural commodities compared with 2007/08, although rice price impacts were far more moderate.

The weather shocks included a severe drought with related fires in Russia and parts of Ukraine and Kazakhstan that reduced production of all 2010 crops and particularly affected wheat yields; adverse growing conditions for US maize in late summer of 2010; rain on nearly mature wheat crops in Canada and North-Western Europe that reduced the quality of much of the crop to feed grade in the summer of 2010; a drought and high temperatures associated with a La Niña weather pattern across Argentina in November 2010 that reduced the yield prospects for corn and soybean crops; rains in Australia in late 2010 and early 2011 that downgraded much of Eastern Australia's wheat crop to feed quality; further adverse drought impacts in Russia on winter wheat plantings for the 2011 harvest; dry fall, winter, and spring weather for the US hard red winter wheat crop that lowered 2011 production expectations in the South-Western Great Plains; a freeze in February 2011 that destroyed parts of Mexico's standing maize crop; and heavy and persistent spring rains in the US corn belt and the Northern Plains in the United States and Canada that delayed the planting of 2011 maize and wheat crops and led to reduced yield expectations. As a result of weather-related production shortfalls, cereal stocks of the traditional developed country exporters are estimated to have fallen by nearly 25 per cent in 2010 (Trostle *et al.* 2011; FAO-OECD 2011; Development Committee 2011).

(ii) Trade policy responses

Trade policy responses in the form of export restrictions or reduced import restrictions have again raised the amplitudes of the crop price spikes in 2011, but apparently not to the same extent as in 2008 (Development Committee 2011).

In August 2010, Russia imposed a wheat export ban in response to its wheat production shortfall. Some countries also restricted crop exports and again a number of importing countries reduced or suspended import tariffs. Moreover in late 2010, countries that usually import sufficient quantities of grain to meet their needs for 2–3 months began to contract with suppliers for imports to meet their needs for 4–6 months (Trostle *et al*. 2011).

On the decomposition of impacts

Beyond the broad qualitative assessments reviewed above, contributors to the literature generally refrain from providing systematic quantitative estimates of the relative contribution of the various causal factors to the observed price changes, since the interactions among short- and long-run factors would seem to preclude straightforward and conclusive quantitative decompositions.

For instance, Abbott *et al.* (2008) state explicitly: 'We make no attempt to calculate what percentage of price changes are attributable to the many disparate causes, and, indeed, think it impossible to do so.' Or, as Wiggins *et al.* (2010) put it: 'There is controversy over the relative contributions of the different factors. Since, however, their combined effect is multiplicative, it is probably impossible to assign fractions of blame to the different elements.'

Did the 'financialization' of commodity futures markets contribute to the observed price hikes?

As noted earlier, one contentious unresolved question subject to ongoing debate is the potential contribution of speculation in agricultural commodity futures markets to the large price fluctuations in recent years. This study does not attempt to resolve this debate, but a couple of remarks are in order.

Investments in long-only commodity index funds with significant food commodity components have certainly soared since the early 2000s. Some observers believe that the sheer size of these index investments has overwhelmed the normal functioning of these markets and has created a bubble in commodity futures prices that in turn dragged up the spot prices for food commodities.[19] Others have questioned the theoretical consistency as well as the empirical validity of this view. In particular, basic economic theory suggests that in order for future prices to drive up spot prices, one would expect to observe a build-up of food inventories, but there is no evidence that this took place in 2007/08 (Wright 2011; Wiggins *et al.* 2010). Calvo (2008) dismisses this counter-argument, but his reasoning is based on the questionable assumption of a completely inelastic food demand.[20] Granger causality tests of the relation between index investments and spot prices of grains for most periods and agricultural commodities seem to provide little support in favour of the speculation hypothesis.

With regard to direct tests of the links between index fund investments and future prices, Irwin and Sanders (2011) conclude that:

> *' …the weight of the evidence is not consistent with the argument that index funds created a bubble in commodity futures prices. Whether the wave of index fund investment simply overwhelmed normal supply and demand functions …, channeled investors' views about commodity price directions …, or integrated financial and commodity markets …, the linkage between the level of commodity futures prices and market positions of index funds should be clearly detectable in the data. Very limited traces of this linkage are visible, however. To date, no "smoking gun" has been found. Moreover, results of studies that test for a bubble component in commodity futures prices – regardless of the cause – are decidedly mixed … . Therefore, it is unclear if there was a bubble in commodity futures price from 2007–2008, and even less clear whether one was caused by index funds.'*
> *(Irwin and Sanders 2011)*

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NOTES

[1] See Reilly and Willenbockel (2011) for a review of the role of scenario approaches in global food system analysis.

[2] All propositions in Section 2.1.1 are literal citations from Meehl *et al*. (2007).

[3] The IPCC chapter on impacts for North America (Field *et al.* 2007: 624) notes: 'North American agriculture has been exposed to many severe weather events during the past decade. More variable weather, coupled with out-migration from rural areas and economic stresses, has increased the vulnerability of the agricultural sector overall, raising concerns about its future capacity to cope with a more variable climate … There is a need for improved understanding of the relationship between changes in average climate and those extreme events with the greatest potential impact on North America, including hurricanes, other severe storms, heatwaves, floods, and prolonged droughts'. The impact chapters for other world regions of focal interest for this study do not specifically address impacts of extreme weather events on agriculture.

[4] All propositions in sub-section 2.1.2 are essentially literal citations from Christensen *et al.* (2007) with the exception of the explanatory paragraph below Table 2.1 and the final paragraph.

[5] All propositions in sub-section 2.1.3 are minimally adapted literal excerpts from Easterling *et al*. (2007).

[6] 'Given the dominantly linear response of the models, the 2080 to 2099 period allows the greatest clarity of the background climate change underlying the interannual and decadal variability. In the ensemble mean AOGCM projections there is no indication of abrupt climate change, nor does the literature on individual models provide any strong suggestions of robust nonlinearities' (Christensen *et al*. 2007:853).

[7] See also New *et al*. (2011) and Thornton *et al*. (2011) in this context.

[8] For a further elaboration of this point, see Arndt *et al.* (2011).

[9] See, for example, Trenberth *et al*. (1988).

[10] See, for example, Karoly *et al.* (2003). See also Horridge *et al.* (2005).

11 Centre for Research on the Epidemiology of Disasters at the Catholic University of Louvain (www.emdat.be, accessed February 2012).

[12] These assumptions are reproduced in Appendix A.2.

[13] In other words, and as a matter of course, Figure 5.1 does *not* compare the long-run projections for 2030 with the temporary observed price peaks in 2010, as this would evidently lead to entirely misleading conclusions about the direction of the long-run crop price trends. In line with sound time series analysis methodology, the comparison is between two points along the projected long-run trend paths for the prices of interest.

[14] Note that consumption purchases of processed wheat (or maize) products such as bread are part of 'Other processed food' (OPrcFood) consumption in the GTAP database and in the model.

[15] See Trostle (2008, 2011); Trostle *et al*. (2011); FAO (2011); FAO-OECD (2011); Wiggins *et al.* (2010); Headey (2010); Abbott *et al.* (2008, 2009).

[16] See, for example, Mitchell (2008); Baffes and Haniotis (2010); Headey (2010); FAO (2011); Wiggins *et al.* (2010). Trostle (2011) points out that '(a)ttributing most of the 2002–08 rise in food commodity prices to biofuel production, however, seems unrealistic. Crop prices dropped more than 30 per cent during the last half of 2008, even though biofuel production continued to increase.'

[17] See Trostle (2008) for the examples in parentheses and Dollive (2008) for further anecdotal evidence. See Abbott and Borot de Battisti (2011) for trade policy responses of African countries.

[18] See also Development Committee (2011).

[19] See, for example, De Schutter (2010) and UNCTAD (2009). See Irwin and Sanders (2011) for further reference to proponents of this view and their influence on US regulatory reform.

[20] See Wright (2011) and Ghosh *et al*. (2011) for further discussion of this point.

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