# Climate Change and Agriculture

## Report prepared for CCICED Taskforce on Rural Development and its Energy, Environment and Climate Change Adaptation Policy

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# 1 Introduction

This report examines the link between climate change and potential shifts in agricultural trade flows. The aim is to first identify the broad conclusions of the existing literature in relation to climate change and agriculture, and to examine some of the government policies that are motivated by climate change. This survey provides background to a later part of the report that examines the issue of how trade flows will be affected by changes in climate and increased urbanisation, with the aim of determining whether the institutions and markets of nations (in the developing world particularly) are ready to cope with changes that are likely in the coming decades. Results are reported with a particular focus on China.

The next section of this report consists of a short review of the key literature on the potential effects of climate change on agriculture, and, consequently, on economic outcomes. Section 3 covers some of the existing government policies that are related directly or indirectly to climate change, and which are likely to play an important role in whether resources are allocated efficiently. Section 5 outlines the modelling methodology and baseline while section 6 presents results of the modelling and is designed to shed light on the long run trade and macroeconomic environment in which Chinese rural development policy will need to be made.

# 2 The Impact of Climate Change on Agricultural Production – Review of the Evidence

This section reviews various published studies of the impacts of changes in the climate on agricultural production. The aim in the discussion is to give a sense of the literature's broad conclusions. The approach taken here has been to discuss various thematic issues rather than proceeding study by study.

The majority of the published climate change research relating to agriculture concludes that food production will be sufficient to meet the world's needs for the remainder of this century (see for example Darwin et al. 1995; Fischer et al. 2005, and Parry et al. 2004). The conclusion holds for a range of climate change, agricultural productivity growth and income and population growth scenarios. The other key conclusion from the research is that the impacts of climate change will not be uniform across the globe: land suitable for agricultural production will expand in some regions and decline in others.

Climate change impacts on agriculture have been considered since at least the late 1970s, so the science is certainly not in its infancy. Darwin (1995) refers to a survey of climate experts in National Defence University (1978). Nevertheless, anticipating the response of agricultural production and trade flows to climate change remains complex.

It can be reasonably certain that climate change will alter temperature and precipitation in many regions, but the resulting yield impacts on agricultural products are less clear. For example, it is known that some crops benefit from higher atmospheric concentrations of $CO_2$ in laboratory settings, but in in-field settings it is likely that competition from weeds will increase also. Improvements in farming practices and the introduction of new cultivars will result in as-yet-unknown productivity gains, and will probably extend the range of crops into arid areas. Of course, there is also uncertainty about precisely how much food will be needed, given that future income growth and population growth can only ever be based on projections. In addition, estimates of urbanisation rates are required to assess the likely loss of arable land at the fringes of cities. There are other factors to consider also. Climate change motivates government responses in line with public sentiment. Mandates and other policies covering renewable energy sources and afforestation will affect the availability of land for food production. Overlaying all of these factors is the actions of farmers, who will no doubt respond to climate and price signals – and myriad other signals also – in ways that are hard to predict. Given the interdependence of factors, it is not surprising that — as Fischer et al. (2005) point out — many studies focus on particular aspects of the issue or on a particular region. Studies implementing combined ecological-economic frameworks on a global scale are less common but arguably make more valuable contributions.

There are some findings that come across so consistently in a review of the literature that they should almost be considered climate change 'facts'. One is that it is likely that there will be a sufficient area of land suitable for agriculture for the remainder of this century and the second is that costs and benefits of climate change are unlikely to be evenly distributed around the world.

## 2.1 Shifts in the availability of agricultural land

The consistent finding is that areas suitable for agricultural land will increase in northern Europe, North America, northern China and parts of east Asia, and will decrease in tropical regions. Essentially, arable land will shift to areas of higher latitude. Within these broad shifts, local impacts such as soil conditions, type of crop grown, prevailing management regimes, and various other factors will be important drivers of whether land is suitable for agriculture (Kurukulasuriya and Rosenthal 2003).

Darwin (1995) finds that warming in mountainous and arctic areas will increase the quantity of land suitable for forestry and farming in these areas, but that reduced soil moisture in tropical areas (caused by warming) will decrease the amount of available agricultural land. These findings are broadly representative of more recent literature. Rosenzweig and Hillel (1995) find that middle and higher latitude areas will benefit from longer growing seasons. Fischer et al. (2005) project gains to 2080 in arable land in North America of about 40 per cent (over the 360 million hectares under the baseline climate), in the Russian Federation (of 64 per cent over 245 million hectares), in northern Europe (of 16 per cent over 45 million hectares), and in east Asia (of 10 per cent over 150 million hectares). The same study finds that less land is likely to be suitable for agriculture in northern and southern Africa because of increased heat and water stress.

In terms of the suitability of land for crop cultivation, Fischer et al. (2005) classify parts of the world's existing land surface as being either too cold (13.2 per cent of land area), too dry (26.5 per cent), too steep (4.6 per cent), too wet (2.0 per cent) or of poor soils (19.8 per cent) (Table 2.1). By the 2080s, the proportion of the earth's surface that is too cold will fall by eight percentage points to 5.2 per cent, and the share that is too dry will increase to 29 per cent. The study uses a combined ecological-economic framework that simulates new crop calendars and other aspects of altered cropping operations based on temperature, precipitation and soil moisture.

**Table 2.1: Share of global land area constrained by various factors**

| Constraint to crop cultivation | Share of global land surface | |
|---|---|---|
| | Current | Under climate change in 2080s |
| | % | % |
| Too cold | 13.2 | 5.2 |
| Too dry | 26.5 | 29.0 |
| Too steep | 4.6 | 1.1 |
| Too wet | 2.0 | 5.7 |
| Poor soils | 19.8 | 24.5 |

Source: Fischer et al. (2005).

### 2.1.1 Impacts on crop productivity

Parry et al. (2004) find that most climate change scenarios exert a slight to moderate (0 to -5 per cent) negative impact on simulated world crop yields once the beneficial effects of higher concentrations of $CO_2$ and farm-level adaptations are taken into account (Table 2.2). However, developing economies bear the brunt of the decreases. Crop yields in developing economies decline across all scenarios, by as much as 7 per cent and never less than 2 per cent .On the other hand, economies of the developed world stand to gain in crop productivity by up to 8 per cent on average.

**Table 2.2: Effects on crop productivity of various climate change scenarios (percentage change from the reference case unless otherwise stated)**

| | A1FI | A2a | A2b | A2c | B1a | B2a | B2b |
|---|---|---|---|---|---|---|---|
| $CO_2$ concentration (ppm) | 810 | 709 | 709 | 709 | 527 | 561 | 561 |
| World (%) | -5 | 0 | 0 | -1 | -3 | -1 | -2 |
| Developed (%) | 3 | 8 | 6 | 7 | 3 | 6 | 5 |
| Developing (%) | -7 | -2 | -2 | -3 | -4 | -3 | -5 |

Source: Parry et al. (2004)

A similar finding of declining crop yields in developing economies is reported in Fischer et al. (2005). They find decreases in attainable wheat production in developing economies are in the order of 15 to 45 per cent, specifically for south Asia (20 to 75 per cent), southeast Asia (10 to 95 per cent), and South America (12 to 27 per cent); and the almost complete elimination of land suitable for wheat production in Africa. Under four of the five scenarios studied, China's potential for cereal production is projected to increase by 5 to 23 per cent. Results for India, Brazil and Thailand vary according to the simulation.

Tsigas, Frisvold and Kuhn (1997) provide country- and commodity-detail, but the overall conclusion that developed economies tend to increase agricultural productivity still holds. For example, Canada and Australia stand to gain in productivity across all crops considered (except rice in the case of Australia) (Table 2.3). ASEAN nations and Mexico are projected to suffer large losses in productivity.

**Table 2.3: Climate change impacts on productivity by country and commodity (percentage change from the reference case)**

| Commodity | Canada | United States | Mexico | EU | China | ASEAN | Australia | Rest of World |
|---|---|---|---|---|---|---|---|---|
| Rice | 0 | 1 | -24 | 0 | -3 | -8 | -12 | -8 |
| Wheat | 27 | -2 | -31 | 8 | 16 | 0 | 8 | 5 |
| Other grains | 15 | -16 | -35 | 1 | -14 | -33 | 5 | -3 |
| Other crops | 26 | 14 | -18 | 15 | 13 | -11 | 9 | 2 |
| Regional average | 24 | 2 | -24 | 11 | 3 | -11 | 8 | -1 |

Source: Tsigas, Frisvold and Kuhn (1997) as reported in Hertel and Randhir (1999)

One of the confounding factors making it difficult to assess the yield affect of changed temperatures, precipitation rates and the concentration of carbon dioxide is that these factors are likely to affect the growth and distribution of weeds and other pests and disease also. In laboratory testing it has been found that various crops respond well to higher concentrations of carbon dioxide in the environment. Elevated $CO_2$ levels are more likely to benefit $C_3$ crops such as wheat, rice, barley, root crops and legumes than $C_4$ crops such as corn, sorghum, millet and sugar cane (Kurukulasuriya and Rosenthal 2003). Reasons for the increased productivity include higher rates of photosynthesis (Parry et al. 2004) and more efficient water use because higher concentrations of $CO_2$ reduce stomatal openings. For a review of the direct effects of $CO_2$ on crops see Tubiello and Ewert (2002).

It is worth noting that $CO_2$ fertilisation effects may be relatively large. For example, Reilly and Hohmann (1993) report a climate change scenario under which $CO_2$ fertilisation and farmer adaptation together actually lead to an increase in net global welfare. IPCC (1996) estimates that a doubling of atmospheric concentrations of carbon dioxide would result in yield improvements in the range of 10 to 30 per cent.

#### 2.1.1.1 *Climate variability*

A common theme in the agriculture and climate change literature is that the likelihood and severity of extreme events will increase over time. Burton (1997), for example, considers that 'it is extremely unlikely that significant shifts in the means of weather distributions will take place without shifts in the tails'. Slater et al. (2007) point out that under four IPCC SRES scenarios (A1FI, A2, B1, and B2) there is an increase in extreme events such as floods and droughts even in the short term. Apart from the difficulties that extreme events present in-field to crop yields, such events can also affect essential infrastructure, thereby increasing the costs of moving agricultural products to market.

#### 2.1.1.2 *The importance of adaptation*

It is interesting that while the impacts of climate change on the availability of agricultural land are projected to be fairly dramatic in some regions, the resulting effect on crop and livestock yields are usually estimated to be substantially less. This is because of farmer adaptation. Darwin (1995) states that 'farmer adaptations are the main mechanisms for keeping up world food production under global climate change'. There is little doubt that for studies to be insightful they need to consider the likelihood of farmer adaptation to avoid overstating the damages of climate change (see, for example, Mendelsohn et al. 1994). Whether land is employed for food production is not just a factor of whether the land would conceivably be suitable for growing crops or rearing livestock. In the majority of cases, the decision about what to do with an area of land is informed by the most profitable use of that land.

Adaptation to climate change in agriculture can take many forms. Some studies look at adaptations farmers can make at the farm level in terms of changing planting dates and increasing the area sown to crops (Darwin 1995). Others take a more aggregated, regional level view with regards to the introduction of new cultivars or community irrigation projects.

Darwin (1995) finds that farmers may be able to offset from 79 to 88 per cent of the 19 to 30 per cent reduction in world cereals supply attributable to climate change by selecting the most profitable mix of inputs and outputs on existing cropland. Further, the study finds that more than 97 per cent of the original negative impacts could be mitigated by 'adjustments in domestic markets and international trade' while still holding cropland fixed. When cropland is allowed to vary, famers increase the area under cultivation by 7.1 to 14.8 per cent, leading ultimately to an increase in cereals production in the range of 0.2 to 1.2 per cent.

Darwin (1995) is an interesting study from a methodological point of view also. It was among the first to link climate change impacts on agricultural productivity to the economic adaptations that farmers make, and to consider the fact that farmers must compete with other resource users. The economic adaptations considered include that farmers can adopt alternative production systems or change the area of land devoted to farming. The demand for land by crops, livestock and forestry are considered simultaneously to avoid land being allocated twice.

Adaptation policies need not be restricted to changing farmer practices. In some cases, the most efficient response might be to abandon previously-profitable agricultural land. Government policies that provide long-term information about the likely shifts in the distribution of land can help farmers plan ahead and position themselves for opportunities in other industries. Policies that ease transition from one industry to another are also likely to be important (Darwin 2001). Continuing to support agriculture in areas where it is no longer feasible may only be appropriate where there really are no alternative options for communities (in the short term) and there are well documented cases where such policies have been destructive to the environment and led ultimately to the failure of the agricultural system in any event.

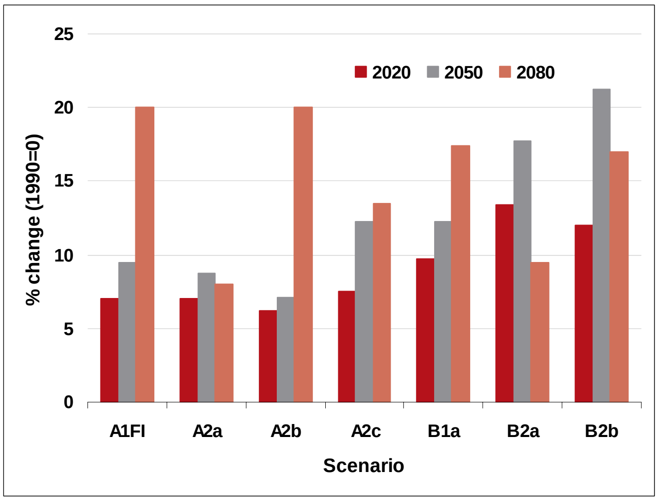
Climatic Change Editorial (2000) presents a contrarian view regarding the likelihood that adaptation will serve to mitigate a large share of yield losses caused by climate change. For all farmers, long term shifts in productivity are only one factor among many that are considered. Local market movements, government agricultural policies, changes in terms of trade, changing technology and farming inputs, environmental regulations, changes in the resource base and changes in management practices are also very important. Adapting solely to climate change is not an efficient strategy if these other factors mean that the industry is likely to decline even without climate change. The paper also emphasises that the risks faced by farmers in developing and developed countries are different when it comes to trying new production processes. In particular, developing country farmers typically face larger downside risks with the failure of a new practice. Whereas a failed attempt at introducing a new cultivar for a developed-economy farmer might result in reduced income, for a developing economy farmer a failed experiment might result in a significant food shortage. Also, various adaptation options require some upfront investment in capital that pays for itself over many years through greater efficiencies. For example, the installation of irrigation infrastructure could easily involve a large upfront cost that a developing economy farmer could not meet without government intervention to improve the functioning of capital markets.

It is definitely the case that institutional settings are important to achieving growth in agricultural output. However, some of the pessimism contained in Climate Change Editorial (2000) seems misplaced in light of the significant improvements in much of the developing world's agriculture during the green revolution.

#### *2.1.1.3 Welfare impacts*

Parry et al. (2004) conclude that, for the most part, the world appears to be able to continue to feed itself under various IPCC Special Report on Emission Scenarios (SRES) scenarios during the rest of this century. The study considers wheat, rice, maize and soybeans (that together account for 85 per cent of cereal exports), and uses the Basic Linked System as described in Fischer et al. (1996). The production functions incorporate crop responses to changes in temperature and precipitation with current management practices; crop responses to temperature and precipitation changes with farm-level and regional adjustments; and crop responses to carbon dioxide fertilisation. They find increases in cereal prices across all scenarios, of as much as 20 per cent by the 2080s (Figure 2.1).

**Figure 2.1: Changes in cereal prices under various climate change scenarios with $CO_2$ effects**




Source: Parry et al. 2004

Juliá and Duchin (2007) use a linear programming model to examine how shifts in the distribution of agricultural land result in changes in regional comparative advantage in the production of agricultural commodities. Taking 1990 regional consumption levels as the reference case, they investigate the changes in regional production and prices that would allow these consumption levels to be met with a different distribution of land. In this way they emphasise the main adaptation strategies of changing the cropping mix and changing the area of land dedicated to agricultural production. They show small but consistent increases in world prices of grains, livestock and other agricultural products because of climate change, but point out that there will be other factors contributing to future price changes, such as productivity gains that they do not account for.

Fischer et al. (2005) investigate the impact of a range of climate change scenarios using their economic-ecological modeling framework. The range of cereal price increases is in the range of 2 to 20 per cent for scenarios using the HadCM3 climate projections, in the range of 4 to 10 per cent for CSIRO projections and less for the remaining circulation models. Benefits of climate change to agriculture are again shown to accrue to developed nations. In North America, agricultural GDP is 3 to 13 per cent higher than without climate change by the 2080s. Under one scenario, the region of the Former Soviet Union gains 23 per cent. Western Europe loses consistently under all scenarios, and developing nations generally lose also. Asian agricultural GDP falls by about 4 per cent and African GDP by about 2 to 9 per cent relative to the reference case.

Various studies going as far back as the early 1990s make an interesting distinction between the welfare impacts of climate change on consumers and producers. These studies emphasise the important fact that nations that are net food exporters may benefit from higher world food prices by more than their local populations suffer by way of the same higher food prices. Reilly and Hohmann (1993) show that large agricultural exporters can gain on net from climate change (in terms of agricultural production at least) as projected higher agricultural prices generate larger surpluses for domestic producers relative to the loss of welfare incurred by domestic consumers. They find that the climate change effects on agriculture are likely to lead to a net welfare gain for Argentina, for example. However, they also find that despite Japan enjoying yield improvements in two of the three scenarios they explored, the benefit of these to Japanese domestic producers is swamped by losses to consumers from higher prices.

Hertel and Randhir (1999) decompose welfare effects into three parts: a climate change effect, a terms of trade effect and an allocative effect (Table 2.4). The latter accounts for welfare losses caused by production moving to more heavily subsidised agricultural systems such as those of Europe and the United States. Note that climate impacts are projected to be positive for welfare in developed economies such as Canada, the United States, the European Union and Australia but generally negative for developing economies (with the exception of China).

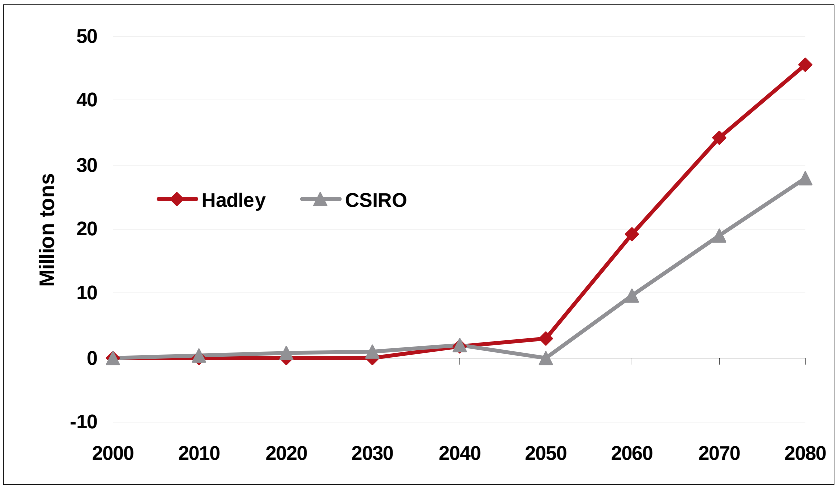
**Table 2.4: Decomposition of welfare effects by Hertel and Randhir (1999)**

| | Climatic impact | Allocative effects | Terms of trade effects |
|---|---|---|---|
| Canada | 4209 | -1093 | -487 |
| USA | 883 | 1002 | 43 |
| Mexico | -7691 | -36 | -520 |
| EU | 24519 | -9523 | 2239 |
| China | 1702 | 223 | 393 |
| ASEAN | -6263 | 491 | -417 |
| Australia | 737 | 48 | -102 |
| ROW | -6629 | -1230 | -1143 |
| World average | 11467 | -10118 | 0 |

Fischer et al. (2005) look specifically at nations that the Food and Agriculture Organization currently considers food insecure. Over 70 per cent of the world's population resides in these 80 nations. They estimate that about 1 to 3 billion people will lose on average 10 to 20 per cent of their potential cereal production as a result of future climate change.

Another way of approaching the welfare question is to estimate the benefits of mitigation. Tubiello and Fischer (2007) find that mitigation strategies that stabilise $CO_2$ concentrations at 550ppm by 2100 reduce the global costs of climate change by 75 to 100 per cent relative to an unmitigated scenario of over 800ppm by 2100. Cereal production (in terms of world total) is essentially unchanged whether mitigation is attempted or not out to about 2050, although thereafter to 2080 the benefits of mitigation begin to dominate (Figure 2.2). The authors explain this by suggesting that the response of crops to elevated $CO_2$ compensates for the stronger climate signal in the unmitigated scenario until 2050, but thereafter $CO_2$ benefits have reached saturation and the strong climate signal takes over.

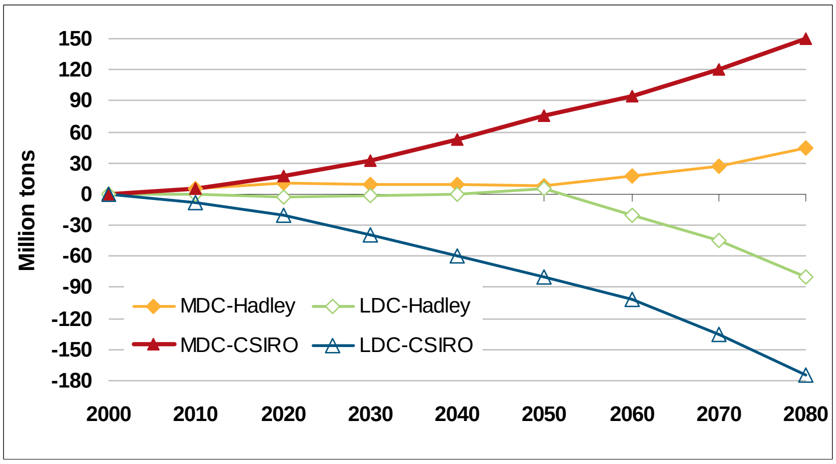
**Figure 2.2: Global effect of mitigation on cereal production**




Source: Tubiello and Fischer (2007)

As usual, the global net effect hides differences at the regional level. For example, assuming that no mitigation takes place, the authors estimate that less developed nations (LDCs in Figure 2.3) will experience a reduction in cereal production, and moderately developed economies (MDCs), an increase. Mitigation could postpone the impact on LDCs for half a century under the Hadley scenario.

**Figure 2.3: Regional impacts of climate change on cereal production**




Source: Tubiello and Fischer (2007)
**MDC – moderately developed countries; LDC – less developed countries.**

### *2.1.1.4 Allowing for uncertainty in estimates*

Climate change science involves uncertainty, but many studies focus on mean estimates of crop productivity shocks or temperature changes. Hertel and Randhir (1999) extend work by Tsigas, Frisvold and Kuhn (1997) by introducing uncertainty to crop productivity outcomes under climate change. Interestingly, their study finds that the inclusion of uncertainty can change conclusions about the sign of net welfare effects. In some cases, the standard error of estimates is so large relative to the means that the sign of the effect is indeterminate (Table 2.5).

**Table 2.5: The effect of uncertainty on climate change impacts**

| | Mean welfare impact | Standard deviation of welfare impact |
|---|---|---|
| | **1992 US$m** | **1992 US$m** |
| Canada | 2628 | 326 |
| USA | 1927 | 2356 |
| Mexico | -8341 | 1602 |
| EU | 17225 | 2354 |
| China | 2309 | 1978 |
| ASEAN | -6212 | 897 |
| Australia | 682 | 116 |
| ROW | -9004 | 3611 |

Source: Hertel and Randhir (1999)

In the same study, the authors argue that 'restrictive trade practices jeopardize the ability of world markets to lower the global costs of climate change'. Existing policies of taxing agricultural output in developing nations and subsidising agriculture in developed economies leads to an inefficient concentration of production in developed economies that could be exacerbated by climate change as arable land shifts to higher-latitude areas. They assume a doubling of atmospheric $CO_2$ concentrations and apply the resulting shocks to a general equilibrium model of world trade and production. They find that trade liberalization significantly reduces the costs of climate change.

Potential conflicts between national climate change policies and national responsibilities under World Trade Organization agreements are raised by Rich (2004) and World Bank (2007), among others. The potential conflict lies in the possibility that domestic carbon taxes could be augmented by border tax adjustment arrangements whereby imports from nations where a different carbon tax rate is applied (or none at all) are taxed, while at the same time exports do not face any tax.

#### *2.1.1.5 Flow on effects to associated resources*

It should be kept in mind that shifts in demand for agricultural land will have flow-on effects to demand for energy and water. Where these resources are already relatively scarce, increased competition is likely to exacerbate social frictions. Reduction in precipitation is likely to intensify aquifer exploitation for agriculture and place additional burdens on other surface and groundwater resources.

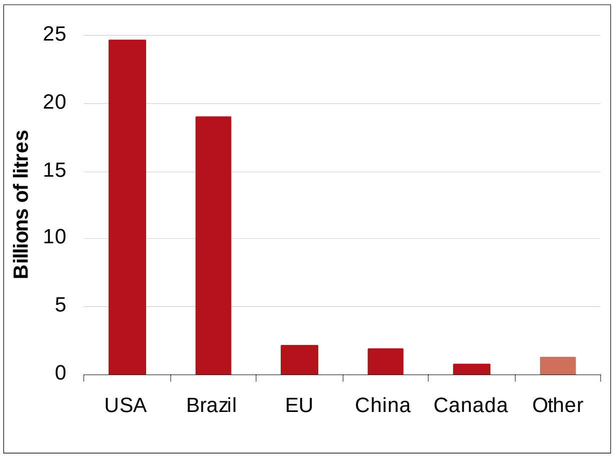
# 3 Selected Climate Change Related Policies Influencing Land Use Choices

This section describes some government policies that are motivated by the potential future costs of climate change. These policies affect how arable land is allocated to agriculture, forestry or some other use. The motivation for many of the policies is to ensure that the efficient amount of each activity takes place, given that there is no widespread carbon pricing mechanism. In addition, governments typically have other motives for introducing these policies, including providing support to domestic industries or alleviating concerns about food or energy security. In other words, not all of them are motivated entirely by climate change issues. If implemented properly (in the sense that they send the intended signals to the targeted economic agents) then these policies can lead to more efficient outcomes.

## 3.1 Biofuels policy

Governments in Brazil and the United States have promoted the use of biofuels (principally ethanol) since at least the 1970s when OPEC tightened world oil supplies. World production of fuel ethanol in 2007 was 49.6 billion litres. The largest producer is the United States (producing almost 25 billion litres of fuel ethanol in 2007), followed by Brazil which produced 19 billion litres (Figure 3.1). Other large producers are the European Union, China and Canada, contributing 2.2 billion litres, 1.8 billion litres and 0.8 billion litres respectively.

**Figure 3.1: Fuel ethanol production by nation or region in 2007**




US ethanol production is based almost entirely on corn with about 22 per cent of US corn production being converted to ethanol (Birur et al. 2008). Very small amounts of barley, cheese whey, sugar cane bagasse and the wastes of potato, wood and brewery production processes are also used (RFA website). Growth in ethanol capacity in the United States has been dramatic (Table 3.1). From January 2007 to January 2008, US fuel ethanol production capacity grew by 44 per cent, from 20.8 billion litres to 29.9 billion litres. By December 2008 it had grown by another 40 per cent to 41.8 billion litres.

**Table 3.1: US fuel ethanol production capacity and capacity growth**

| | Jan-00 | Jan-01 | Jan-02 | Jan-03 | Jan-04 |
|---|---|---|---|---|---|
| Annual production capacity (billion litres) | 6.6 | 7.3 | 8.9 | 10.2 | 11.7 |
| Growth in annual production capacity (%) | 3 | 10 | 22 | 15 | 15 |

| | Jan-05 | Jan-06 | Jan-07 | Jan-08 | Dec-08 |
|---|---|---|---|---|---|
| Annual production capacity (billion litres) | 13.8 | 16.4 | 20.8 | 29.9 | 41.8 |
| Growth in annual production capacity (%) | 18 | 19 | 27 | 44 | 40 |

Source: Changing the Climate: Ethanol Industry Outlook 2008, Renewable Fuels Association.

The various US government programs that assist in making ethanol more profitable are almost certainly at least partly responsible for the increase. The US *Food, Conservation, and Energy Act of 2008* (also known as the US Farm Bill 2008) amends the *Internal Revenue Code* to provide a subsidy of 45 cents per gallon of ethanol distributed (down from 51 cents per gallon in earlier *Bills*). The subsidy can be claimed as either an income tax credit or an excise tax credit, but the latter is more popular because it is more straightforward and immediate.

The United States imposes a tariff on imported ethanol of 54 cents per gallon through the *Ethanol Import Tariff Act of 1980*. The tariff began at 40 cents per gallon in 1980. de Gorter et al. (2007) claim that the initial motivation was to completely offset a related excise tax exemption on imports but over time the tariff has risen above the excise tax exemption of 51 cents per gallon, so the overall effect is of a net tariff of about 3 cents per gallon. Tariff-free provisions of the Caribbean Basin Initiative mean that about one-third of Brazilian ethanol exported to the United States is routed through the Caribbean where the ethanol is transformed from 5 per cent water content to 1 per cent water content, thereby satisfying rules-of-origin provisions (de Gorter et al. 2007).

The US *Energy Independence and Security Act of 2007* amends the *Clean Air Act 1990* to mandate consumption of renewable fuels. The mandate is implemented as a schedule of renewable fuel targets that must be met each year, rising from 11.1 billion gallons in 2009 to 36 billion gallons in 2022 (Table 3.2). Government agencies estimate energy consumption for the following year and determine the additive to fuels that is required to ensure the renewable fuel target is met. Birur et al. (2008) state that the target for 2022 is equivalent to about 15 per cent of gasoline consumption in the United States.

**Table 3.2: Schedule of renewable motor vehicle fuels mandated for use in the United States**

| Year | Mandated volume of renewable fuel | Year | Mandated volume of renewable fuel |
|---|---|---|---|
| | Billion gallons | | Billion gallons |
| 2006 | 4.0 | 2015 | 20.5 |
| 2007 | 4.7 | 2016 | 22.25 |
| 2008 | 9.0 | 2017 | 24.0 |
| 2009 | 11.1 | 2018 | 26.0 |
| 2010 | 12.95 | 2019 | 28.0 |
| `2011 | 13.95 | 2020 | 30.0 |
| 2012 | 15.2 | 2021 | 33.0 |
| 2013 | 16.55 | 2022 | 36.0 |
| 2014 | 18.15 | | |

Source: Energy Independence and Security Act of 2007

### 3.1.1 EU biofuels policy

Biodiesel is the principal renewable transport fuel in the European Union, made mostly from rapeseed oil. Bioethanol accounts for a small amount of renewable fuels, made mostly from sugar beets and wheat (Schnepf 2006). Germany is the EU's principal renewable fuels producer, producing over half of the EU's biodiesel total in 2004 (Schepf 2006) because of legislation that grants a total tax exemption for biofuels. Over the long term, it is likely that bioethanol will become more dominant in the EU than biodiesel given the production potential for cereals and sugar beets.

The EU has targets for the share of the overall fuel mix made up by renewable sources. In the transport sector, the aim is for a 5.75 per cent share of biofuels in overall fuel use by 2010 and for a 10 per cent share in 2020 provided that sustainable, 'second-generation' biofuels from non-food crops become commercially available. There are three non-mandatory directives driving the agenda:

- Biofuels directive: in 2003, the European Commission established a goal of deriving at least 2 per cent of EU transportation fuel from biofuels by the end of 2005, and of thereafter growing the biofuels share by 0.75 per cent annually until the end of 2010 when it would reach 5.75 per cent. This is non-mandatory and participation varies.
- Energy taxation directive: In 2003, the EU's framework for the taxation of energy products and electricity was amended to allow Member States to grant tax reductions and/or exemptions in favor of renewable fuels under certain conditions (Schnepf 2006)
- Fuel quality directive: Specifies the content of diesel and petrol fuels to control the release of harmful gases, but can also enable the use of higher volumes of biofuels.

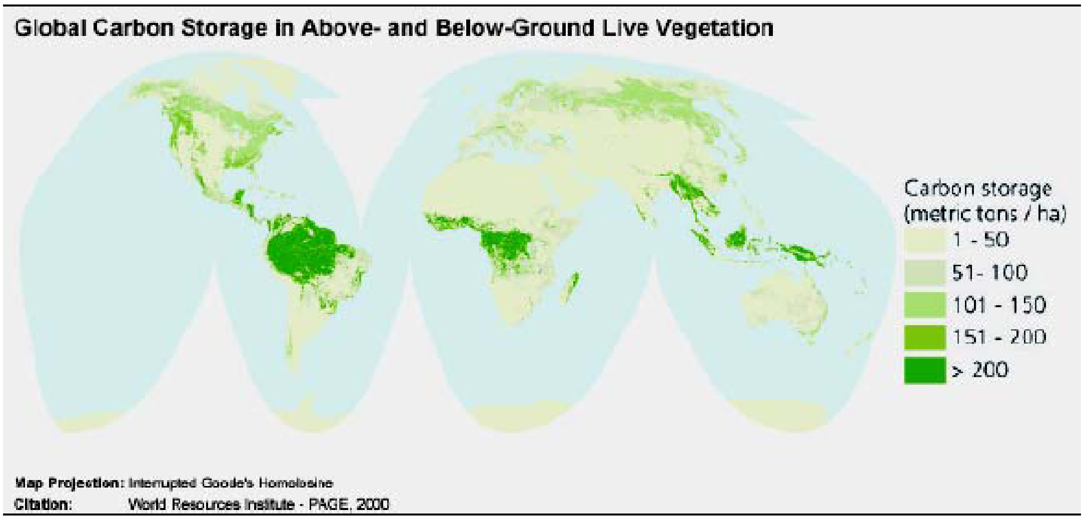
In addition to the non-mandatory directives, the Common Agricultural Policy (CAP) has payments for the production of crops dedicated to biofuels partly through a compensation payment for land set-aside (Schnepf 2006). In 2003, a new round of CAP reforms established special aid for energy crops grown on non-set-aside land.

## 3.2 Forests as stores of carbon

Deforestation and forest degradation emit trapped carbon through burning and decomposition, and IPCC WG1 estimates that annual emissions from deforestation since the 1990s is about 5.8Gt of $CO_2$, or about 20 per cent of overall $CO_2$ emissions. Policies that promote afforestation or reforestation are likely to increase in importance in the next few decades, and this has ramifications for the incentives of landowners to devote their land to agriculture. Policies designed to alter incentives toward afforestation (or at least toward reduced rates of deforestation) are likely to slow the rate at which forest is converted to agricultural uses.

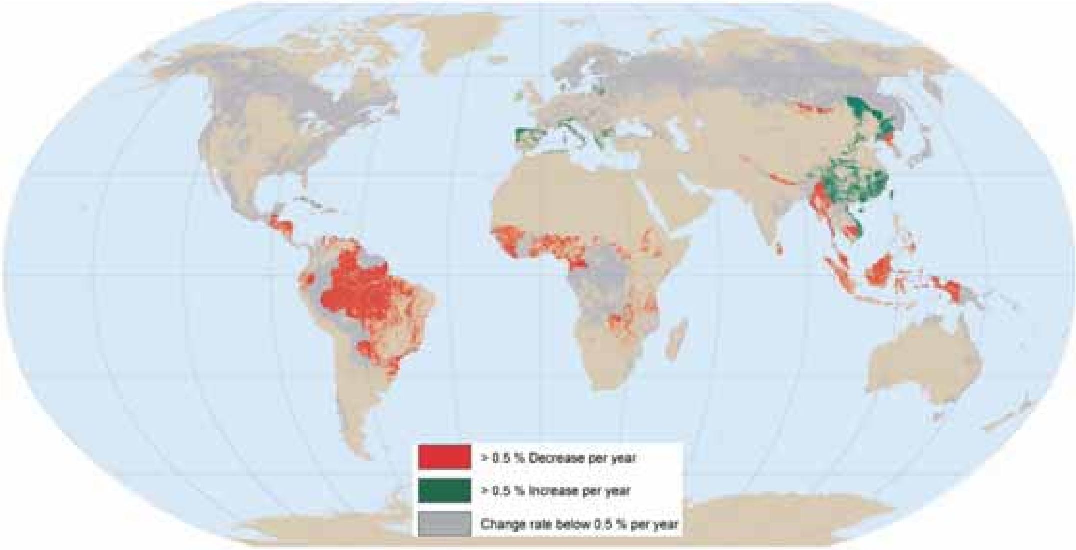
Tropical forests are thought to trap (on average) about 50 per cent more carbon per unit area than forests outside the tropics. Major above and below ground live vegetation stores of carbon are in northern South America, central-west Africa, south east Asia and North America (Figure 3.2). Deforestation and forest degradation were recognised by the IPCC WGII as the mitigation option with the largest and most immediate carbon stock impact.

**Figure 3.2: Global carbon storage in above-and below-ground live vegetation**




Deforestation is occurring most rapidly in northern South America, western Africa and south east Asia (Figure 3.3), roughly corresponding to the areas of greatest carbon stores. In the Amazon, the main causes of deforestation in the period 2000 to 2005 were removal of trees for cattle ranches (accounting for about 60 per cent of deforestation), small-scale subsistence agriculture (30 per cent), and legal and illegal logging (3 per cent). Remaining losses are caused by fires, mining, urbanisation and large-scale commercial agriculture. In China, forest areas are generally increasing rather than decreasing.

**Figure 3.3: Rates of change in forest cover**




Source: FAO Forest Resource Assessment 2005

### 3.2.1 UN approaches

Given forests' potential both for storing carbon and for releasing it upon felling, policies to change the economic incentives driving deforestation are being considered by the UNFCCC. Discussions are underway to have mitigation via forestry incorporated in the post-2012 framework of the Kyoto Protocol, including in the Clean Development Mechanism (CDM). The CDM allows Annex B nations to partly meet their Kyoto commitments by investing in lower-cost emissions-reducing activities in developing economies. The general conclusions of UNFCCC working groups, is that sufficiently robust estimates and monitoring of changes in forest cover can be made. However, questions remain about how incentive payments can be structured to ensure that payments are only made in instances where preservation would otherwise not have taken place. Issues around forest diseases and fires also need to be settled.

### 3.2.2 EU policies

The European Union aims to halt loss of global forest cover by 2030 at the latest and to reduce gross tropical deforestation by at least 50 per cent by 2020 compared to current levels. In Europe itself, the EU's CAP rural adjustment program has various elements that promote afforestation or reforestation, including support payments for the first afforestation of agricultural land and the establishment of agroforestry systems on agricultural land. There is support for ongoing maintenance of such sites also. The cost of support for similar activities in the earlier program was about 365 million Euros, relating to over 1 million hectares (EU 2007). It is easy to imagine that these policies will have ramifications for the availability of land for agriculture.

The EU has stated that it does not want deforestation credits included in its EU-ETS to avoid substantially undermining the price of carbon in the market.

### 3.2.3 US policies

The US Forest Land Enhancement Program (FLEP) was introduced in the 2002 US Farm Bill, and operates at the State level. It provides technical, educational and cost share assistance to promote forest sustainability. The United States also runs the Forest Legacy Program that focuses on acquiring partial interests in privately owned forest lands. Third, the Forest Stewardship Management Plan develops management plans for private forest landowners. Given that North America stands to inherit land with greater agricultural potential, it is important that the linkages between food production and support for forestry are considered.

# 4 Understanding the Impacts of Climate and Land Use Changes on Trade Flows

Agriculture is the most climate-sensitive of all economic sectors, and arguably the most important given that it is central to keeping the world fed. The research linking climate change and agriculture suggests that the distribution of arable land is likely to change over the coming century, with higher latitude nations generally benefiting from an increase in land area suitable for agriculture, while those closer to the tropics will lose. On balance, the conclusion in most studies is that sufficient land will be available to prevent widespread food shortages. Nevertheless, it is of great concern that some of the world's poorest regions, which already have a great number of people at risk of hunger, are going to rely increasingly on food imports. Essentially, it would appear that agricultural wealth will be redistributed from those who need it the most to those who need it the least – the wealthier nations in North America and northern Europe, among others. World trade flows may have to change substantially from what is commonly observed today, as the effects of climate change, urbanisation, and growth in income and population are felt.

Can the new potential centres of production adapt with enough speed to keep the world fed? Various studies have emphasised the importance of farmer adaptation as a crucial response to climate change. Farmers can respond to changes in climate by increasing the area of land they devote to agriculture, by changing planting and harvesting schedules or by changing the varieties of the crops that they grow. Without these steps, the yield losses from climate change are likely to be very large. But as centres of production shift, new pressures will also be brought to bear on natural resources such as water, and on the existing structures of those societies that are predominantly agrarian. In tropical regions, competition from crop production could easily aggravate direct climate-induced losses of tropical rain forests (Darwin 1995).

Over the coming half century, world population is projected to grow to about 9 billion. Large tracts of potential agricultural land will likely be sterilised by urbanisation and the spread of factories. At the same time it is likely that many governments will continue to protect their agricultural sectors, thus dampening the ability of trade flows to correct for any climate change-induced imbalances in agricultural production across regions. Further, as governments respond to climate change, policies are likely to induce additional competition for agricultural land for the production of biofuel and forest carbon mitigation. In addition, it is unclear whether global commodity transport infrastructure and markets (in developing nations in particular) are up to the challenge of moving food in the quantities that are likely to be required. Port channels, berths and associated infrastructure, road transport services, distribution points, etc are likely to come under increased strain as commodity flows change in response to climate change and regional economic growth.

A first step in determining which regions are likely to require most investment is to investigate the likely characteristics of future agricultural commodity production by region and implied flows between regions in terms of direction and size. As income and population grows, as the relative productivity of land shifts as a consequence of climate change, and as ever more land is lost to urbanisation, the demand for and supply of agricultural commodities is likely to alter fundamentally.

The ensuing parts of this report analyse how regional agricultural commodity production and trade flows are likely to change over the remainder of this century as a result of climate change, urbanisation and income growth, with a focus on inflows and outflows in developing regions with particular reference to China. It is hoped that identifying changes in regional flows will lay the foundation for future work that investigates whether the infrastructure and institutions in developing regions are ready to cope with the shifts in commodity flows that will be required to keep populations fed.

# 5 Modeling Methodology

This study uses the global general equilibrium model GTAP (Global Trade Analysis Project) to analyse the impacts of various climate stabilisation scenarios on the future trade patterns for selected agricultural commodities. The first part of the study involves projections for four baseline climate scenarios and their associated yield impacts on selected agricultural commodities and analysis of what those climate impacts might mean for agricultural trade flows. The second part of the study analyses how changes to trade policy might alter the flows of those commodities and discusses the associated benefits of trade liberalisation to food security and welfare.

The version of GTAP used by BAEconomics has been modified to solve dynamically and to include an emissions module such that the impacts of mitigation activities to reduce global emissions to the target levels can be included. This capability is particularly important in allowing analysis to be undertaken on the combined effects of climate change, mitigation, agricultural productivity changes and trade policy.

Four climate change scenarios are examined. The first corresponds to a world in which the atmospheric concentration of $CO_2$ has been stabilised at around 530 parts per million (ppm) by 2080 (hereafter C-B1). The second scenario is one in which stabilisation is achieved at 560 ppm by 2080 (hereafter C-B2). The third scenario achieves stabilisation at 710 ppm (hereafter C-A2) and the final scenario is one where more limited mitigation action is taken over the remainder of this century and the emissions concentration increases to around 810 ppm by 2080 (hereafter C-A1).

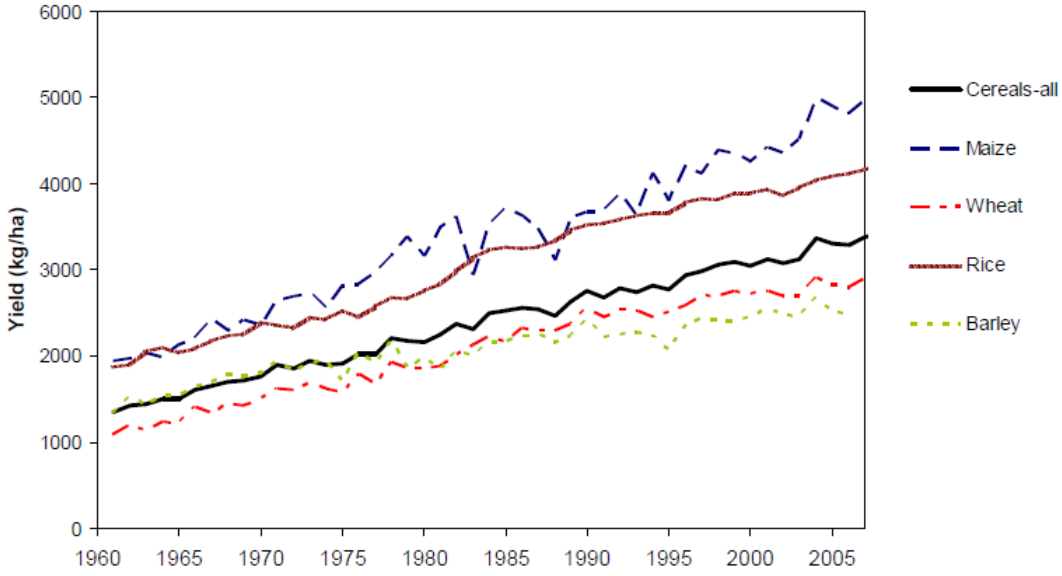
Emissions data were derived using the SRES documentation for each of the SRES marker scenarios for A2, B1 and B2, and the A1FI MiniCam scenario. The projections for these scenarios are presented in section 6. Underlying each of these emissions scenarios are associated population and economic growth scenarios that were derived from UN Population Division data and BAEconomics' world income growth model. The population and economic growth data diverge from the original SRES projections as estimates have changed substantially since the SRES scenarios were developed. However, population and economic growth have been aligned to ensure that the resulting emissions follow the SRES emissions pathways of interest in this study.

Each climate change scenario was mapped to annual productivity shocks for wheat, maize, rice, other crops and livestock by country/region. Data for the first four commodities were provided by Martin Parry and Ana Iglesias (personal communication) using the Hadley Centre's HadCM3 model, while the livestock productivity shocks were derived using the modelling framework in conjunction with shocks to pasture productivity that approximated those for wheat.

Using these data, regional agricultural commodity yields for wheat, rice, maize, other crops and livestock were projected under the four baseline climate scenarios over time. These projections were then compared with historical yields to give a sense of how much the patterns could change over time as a result of climate impacts relative to historic technical change.

Figure 5.1 provides historic worldwide trends in yields for wheat, rice and maize. The historic yield growth patterns for the commodities of interest are presented in Appendix1 in more detail for selected regions for the period 1995-2008.

**Figure 5.1: Worldwide historic yield trends for major cereals**




Source: Gallagher Biofuels Review 2008

# 6 Reference Case Projections

As discussed above this study is based on four separate climate scenarios representing stabilisation at 810ppm, 710ppm, 560ppm and 530ppm and approximated by the SRES scenarios A1FI, A2, B2 and B1 respectively. However, these four scenarios are based on different population and economic growth projections to the SRES. The projections used here are presented in the remainder of this section. By projecting agricultural yields through time under various climate change scenarios it is possible to assess the impact on per person wealth and food security on a regional basis.

The four separate economic and climate scenarios provide baselines against which to assess the impacts of trade liberalisation and other interrelated policies in the remainder of this report.

The commodity and regional aggregation used for this study is presented in Table 6.1.

**Table 6.1: Regional and commodity aggregation**

| Country | Commodity |
|---|---|
| Australia | Wheat |
| China | Rice |
| Japan | Cereal grains (including maize) |
| South Korea | Other crops |
| India | Processed food |
| Brazil | Livestock (meat and milk) |
| Argentina | Livestock products |
| EU-27 | Oil |
| North America | Gas extraction & distribution |
| Russia | Petroleum & coal products |
| Former Soviet Union | Electricity |
| Rest of South & Central America & the Caribbean | Textiles, clothing & leather |
| South & East Asia | Construction, Transport and Energy Intensive Industry |
| Middle East | Other industries & services |
| North & West Africa | |
| Central & Southern Africa | |
| East Africa | |
| Rest of the World | |
| World | |

## 6.1 Population

Population projections for the four climate scenarios were taken from the most recent UN Population Division database. The median population growth scenario was chosen as indicative for all of the scenarios and as such, projections of GDP per person are a function of different economic growth rates across regions.

Population projections by each region represented in the model are presented in Table 6.2.

**Table 6.2: Projected population by region**

| millions | 2008 | 2020 | 2050 | 2080 |
|---|---|---|---|---|
| Argentina | 39.93 | 44.49 | 51.38 | 51.15 |
| Australia | 20.78 | 23.32 | 27.94 | 25.87 |
| Brazil | 193.77 | 219.19 | 253.11 | 227.86 |
| Central and Southern Africa | 173.29 | 217.83 | 359.35 | 381.99 |
| China | 1346.79 | 1432.53 | 1402.06 | 1270.72 |
| East Africa | 346.50 | 450.95 | 744.33 | 808.46 |
| European Union | 490.96 | 493.07 | 470.83 | 424.60 |
| Former Soviet Union | 134.59 | 136.52 | 127.46 | 120.47 |
| India | 1151.60 | 1332.03 | 1592.70 | 1510.68 |
| Japan | 128.40 | 126.71 | 112.20 | 98.22 |
| Middle East | 206.23 | 259.30 | 367.66 | 415.64 |
| North America | 450.76 | 499.65 | 576.96 | 590.87 |
| North and West Africa | 444.94 | 558.56 | 832.18 | 912.29 |
| Rest of South & Central America and Caribbean | 239.16 | 278.33 | 339.15 | 339.04 |
| Russia | 141.28 | 133.10 | 111.75 | 91.13 |
| South and East Asia | 1006.55 | 1182.17 | 1504.83 | 1559.24 |
| South Korea | 48.29 | 49.39 | 44.63 | 40.04 |
| Rest of World | 126.56 | 139.59 | 156.18 | 145.52 |
| WORLD | 6690.40 | 7576.73 | 9074.70 | 9013.79 |

## 6.2 Income growth

The income growth projections for this study were developed using the SRES storylines and data as a base for income projections by country using a combination of BAEconomics' growth models and IMF data. ABARE (2006a) modelling of the A1FI scenario using GTAP data was utilised as the basis for income growth projections by region to 2050, taking into account revised population projections. For the period 2050-2100, regional economic growth rates were projected using demographic data to weight contributions to world growth. The economic projections underlying the remaining three climate scenarios were derived using growth rates indexed to the relative changes between the SRES MiniCam A1FI scenario and the MiniCam A2, B1 and B2 projections of economic growth.

The income projections developed for this study were run in combination with the population projections through the GTAP model to ensure target emissions were consistent with the SRES scenarios (and emissions concentrations) under consideration. Income growth was projected using purchasing power parity exchange rates. Tables 6.3 to 6.6 present the average regional GDP growth assumptions by scenario for selected timeframes.

**Table 6.3: Projected average annual growth in GDP (per cent) – C-A1**

| Country | 2008-2020 | 2021-50 | 2051-2100 |
|---|---|---|---|
| | % average per year | % average per year | % average per year |
| Argentina | 3.10 | 2.81 | 2.32 |
| Australia | 3.06 | 2.12 | 1.59 |
| Brazil | 3.80 | 2.81 | 2.32 |
| Central and Southern Africa | 2.74 | 2.61 | 1.90 |
| China | 5.62 | 3.25 | 2.17 |
| East Africa | 2.28 | 2.17 | 1.58 |
| EU | 2.01 | 1.82 | 0.72 |
| FSU | 4.47 | 2.40 | 1.04 |
| India | 5.88 | 4.89 | 3.66 |
| Japan | 2.11 | 1.83 | 0.97 |
| Middle East | 4.49 | 3.07 | 2.46 |
| North America | 2.90 | 2.62 | 1.88 |
| North and West Africa | 3.17 | 2.73 | 2.19 |
| Rest of South & central America and Caribbean | 3.99 | 3.21 | 2.52 |
| ROW | 3.80 | 3.20 | 2.38 |
| Russia | 3.71 | 1.98 | 1.04 |
| South and east Asia | 4.23 | 3.55 | 2.77 |
| South Korea | 3.20 | 2.10 | 1.20 |

**Table 6.4: Projected average annual growth in GDP (per cent) – C-A2**

| Country | 2008-2020 | 2021-50 | 2051-2100 |
|---|---|---|---|
| | % average per year | % average per year | % average per year |
| Argentina | 2.48 | 1.81 | 1.54 |
| Australia | 2.59 | 2.10 | 1.04 |
| Brazil | 3.04 | 1.81 | 1.54 |
| Central and Southern Africa | 2.43 | 1.96 | 1.37 |
| China | 3.45 | 2.41 | 1.47 |
| East Africa | 2.02 | 1.63 | 1.14 |
| EU | 1.29 | 1.77 | 0.97 |
| FSU | 3.60 | 1.62 | -0.10 |
| India | 4.42 | 3.93 | 2.21 |
| Japan | 1.39 | 1.90 | 0.55 |
| Middle East | 3.96 | 2.05 | 1.62 |
| North America | 2.29 | 2.44 | 1.93 |
| North and West Africa | 2.75 | 1.94 | 1.50 |
| Rest of South & central America and Caribbean | 3.24 | 2.12 | 1.73 |
| ROW | 3.16 | 2.12 | 1.54 |
| Russia | 2.99 | 1.34 | -0.10 |
| South and east Asia | 3.00 | 2.81 | 1.60 |
| South Korea | 2.16 | 1.70 | 0.40 |

**Table 6.5: Projected average annual growth in GDP (per cent) – C-B1**

| Country | 2008-2020 | 2021-50 | 2051-2100 |
|---|---|---|---|
| | % average per year | % average per year | % average per year |
| Argentina | 3.26 | 2.50 | 2.16 |
| Australia | 3.30 | 1.66 | 0.84 |
| Brazil | 3.99 | 2.50 | 2.16 |
| Central and Southern Africa | 2.85 | 2.38 | 1.79 |
| China | 4.67 | 3.02 | 1.51 |
| East Africa | 2.38 | 1.98 | 1.49 |
| EU | 2.25 | 1.17 | 0.03 |
| FSU | 2.60 | 1.06 | 1.10 |
| India | 4.61 | 4.26 | 2.50 |
| Japan | 2.41 | 0.95 | 0.40 |
| Middle East | 4.69 | 2.77 | 2.30 |
| North America | 3.14 | 2.03 | 0.95 |
| North and West Africa | 3.31 | 2.47 | 2.06 |
| Rest of South & central America and Caribbean | 4.19 | 2.88 | 2.36 |
| ROW | 3.23 | 2.10% | 1.97 |
| Russia | 2.16 | 0.87 | 1.10 |
| South and east Asia | 3.26 | 3.08 | 1.92 |
| South Korea | 2.29 | 1.72 | 0.83 |

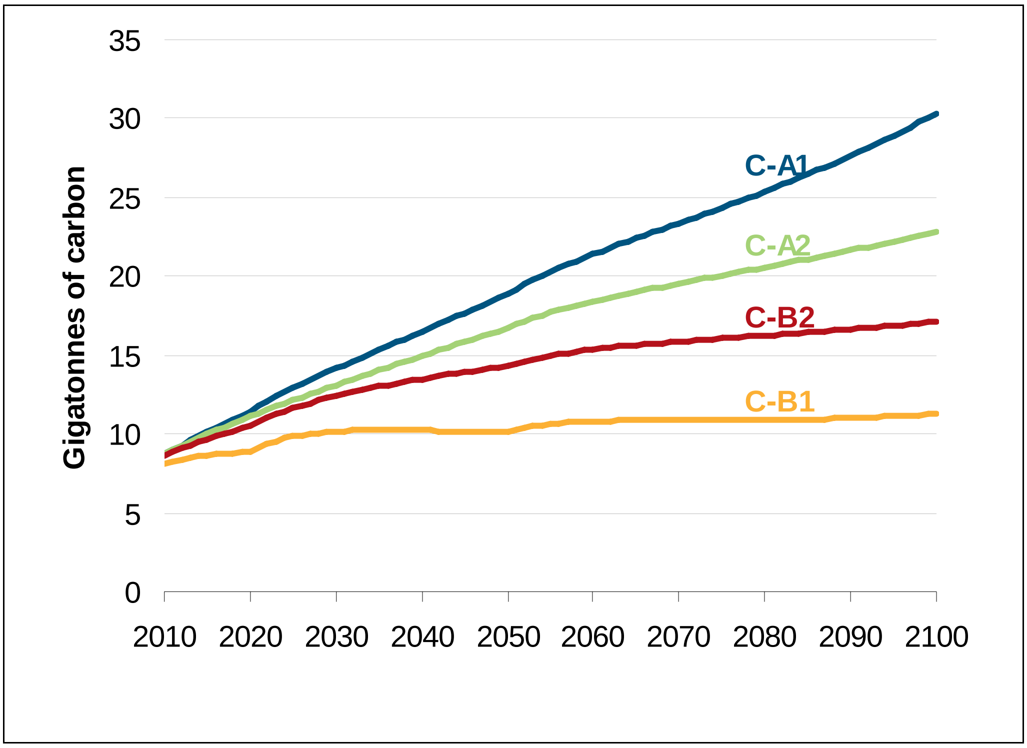
**Table 6.6: Projected average annual growth in GDP (per cent) – C-B2**

| Country | 2008-2020 | 2021-50 | 2051-2100 |
|---|---|---|---|
| | % average per year | % average per year | % average per year |
| Argentina | 1.38 | 2.01 | 1.81 |
| Australia | 2.84 | 1.60 | 0.65 |
| Brazil | 1.81 | 2.01 | 1.47 |
| Central and Southern Africa | 1.56 | 2.16 | 1.34 |
| China | 5.12 | 2.30 | 1.38 |
| East Africa | 1.44 | 1.80 | 1.16 |
| EU | 1.59 | 1.06 | 0.57 |
| FSU | 3.55 | 2.46 | 2.02 |
| India | 5.17 | 3.35 | 1.68 |
| Japan | 1.77 | 0.89 | 0.36 |
| Middle East | 2.69 | 2.43 | 2.24 |
| North America | 2.67 | 1.86 | 1.24 |
| North and West Africa | 1.93 | 2.23 | 1.77 |
| Rest of South & central America and Caribbean | 2.05 | 2.32 | 1.83 |
| ROW | 1.67 | 2.25 | 1.73 |
| Russia | 2.02 | 1.74 | 1.50 |
| South and east Asia | 4.06 | 2.71 | 1.51 |
| South Korea | 2.84 | 1.32 | 0.45 |

## 6.3 Emissions

Emissions for each of the scenarios were developed using GTAP (inclusive of an emissions module) on the basis of economic growth and population projections as well as assumptions about technical change. The emission pathways were designed to follow as closely as possible the SRES pathways using the corresponding MiniCam projections for A1FI, A2, B1 or B2 (see Figure 6.1). Emissions concentrations were ultimately aligned through these pathways to be broadly consistent with those reported on by the Hadley Centre for 810ppm, 710ppm, 560ppm and 530ppm.

**Figure 6.1: Global CO2 emissions by scenario – BAE projections**




## 6.4 Climate change and yield impacts

Four alternative climate change scenarios were examined in this study and are proxies for SRES emissions scenario pathways:

- Scenario C-A1: atmospheric $CO_2$ concentrations stabilised at 810ppm by 2100, proxy for A1FI;
- Scenario C-A2: atmospheric $CO_2$ concentrations stabilised at 710ppm by 2100, proxy for A2;
- Scenario C-B2: atmospheric $CO_2$ concentrations stabilised at 560ppm by 2100 proxy for B2, and
- Scenario C-B1: atmospheric $CO_2$ concentrations stabilised at 530ppm by 2100 proxy for B1.

The climate stabilisation scenarios used in this report are all based on the stabilisation of atmospheric carbon dioxide concentrations only. Typically, the direct physiological yield effect for different crops that results from the increment in $CO_2$ only is always positive however the effect of changes in other indirect variables such as changes in temperature and precipitation will in many circumstances offset these beneficial effects.

Table 6.7 summarises the $CO_2$ fertilisation only effects on crop productivity under various climate change scenarios.

**Table 6.7: World average yield change under various climate change scenarios – $CO_2$ fertilisation effect only (percentage change from the base year)**

| Year | | A1FI | A2 | B1 | B2 |
|---|---|---|---|---|---|
| 1990s | *CO2 levels (ppm)* | 358 | 358 | 358 | 358 |
| 2020s | *CO2 levels (ppm)* | 432 | 432 | 421 | 422 |
| | wheat (%) | 4 | 4 | 3 | 3 |
| | rice (%) | 2 | 2 | 1 | 1 |
| | maize (%) | 1 | 1 | 0 | 0 |
| 2050s | *CO2 levels (ppm)* | 590 | 549 | 492 | 488 |
| | wheat (%) | 11 | 10 | 6 | 6 |
| | rice (%) | 10 | 8 | 5 | 5 |
| | maize (%) | 4 | 3 | 1 | 1 |
| 2080s | *CO2 levels (ppm)* | 810 | 709 | 527 | 561 |
| | wheat (%) | 18 | 18 | 8 | 11 |
| | rice (%) | 17 | 17 | 5 | 10 |
| | maize (%) | 8 | 7 | 2 | 4 |

Source: HadCM3

Yield changes relative to base year were supplied on a disaggregated basis for the crops under consideration for the years 2020, 2050 and 2080 under alternative SRES scenarios. From these data yearly input shocks to productivity growth were derived in GTAP to give production projections for the commodities of interest by region.

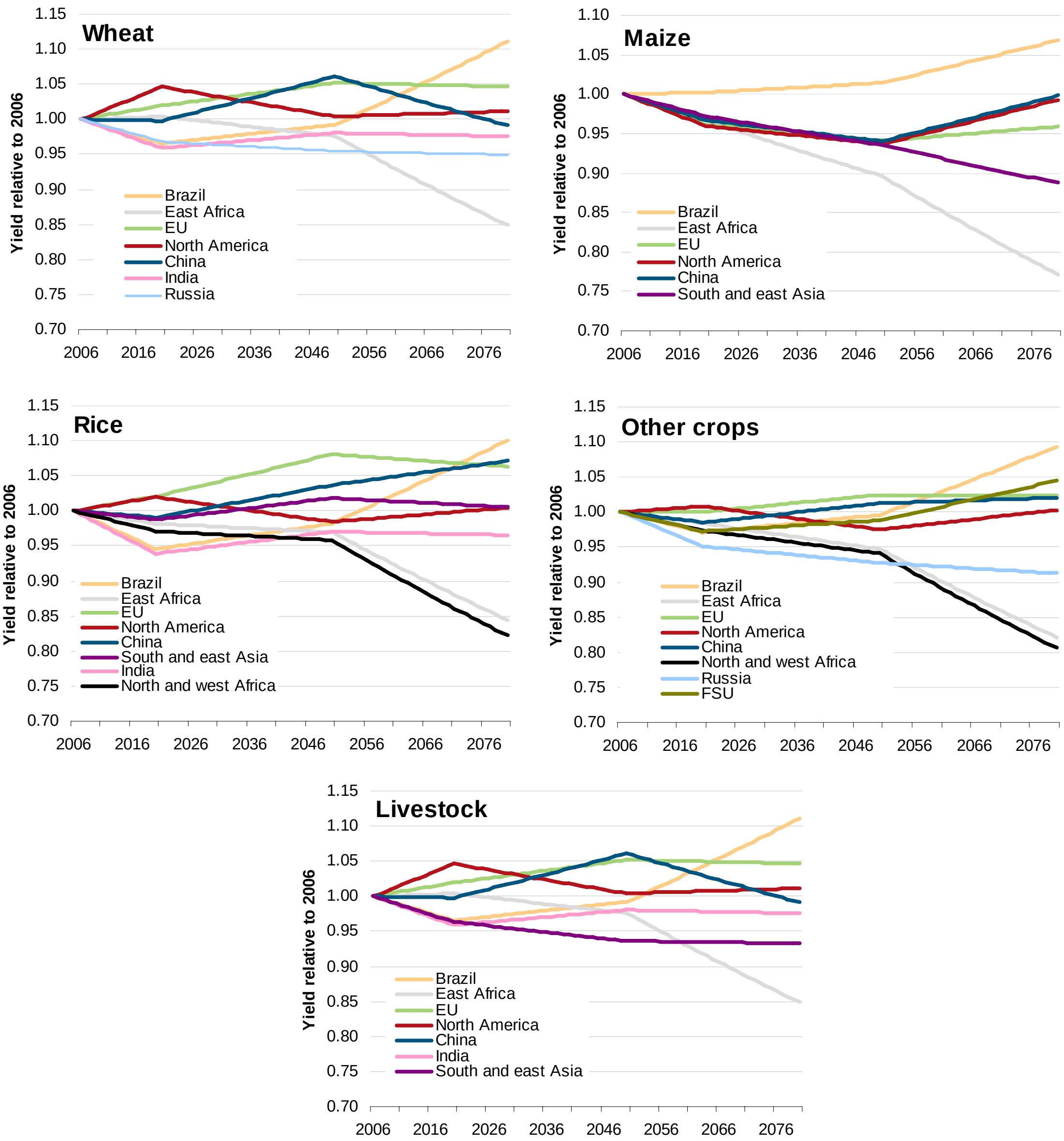
A selection of regional yield indexes for wheat, rice, maize, other crops and livestock are presented in Figures 6.2 – 6.5 under the various climate change scenarios. The numbers in the figures represent the change in crop yield (per cent) in a climate change scenario with respect to the crop yield in the base year. Given the absence of data, note that pasture productivity was shocked using the same set of yield shock projections as for wheat.

Unlike the results in Table 6.7, the changes represented in Figures 6.2 – 6.5 were derived taking into account three determinants of future crop productivity:

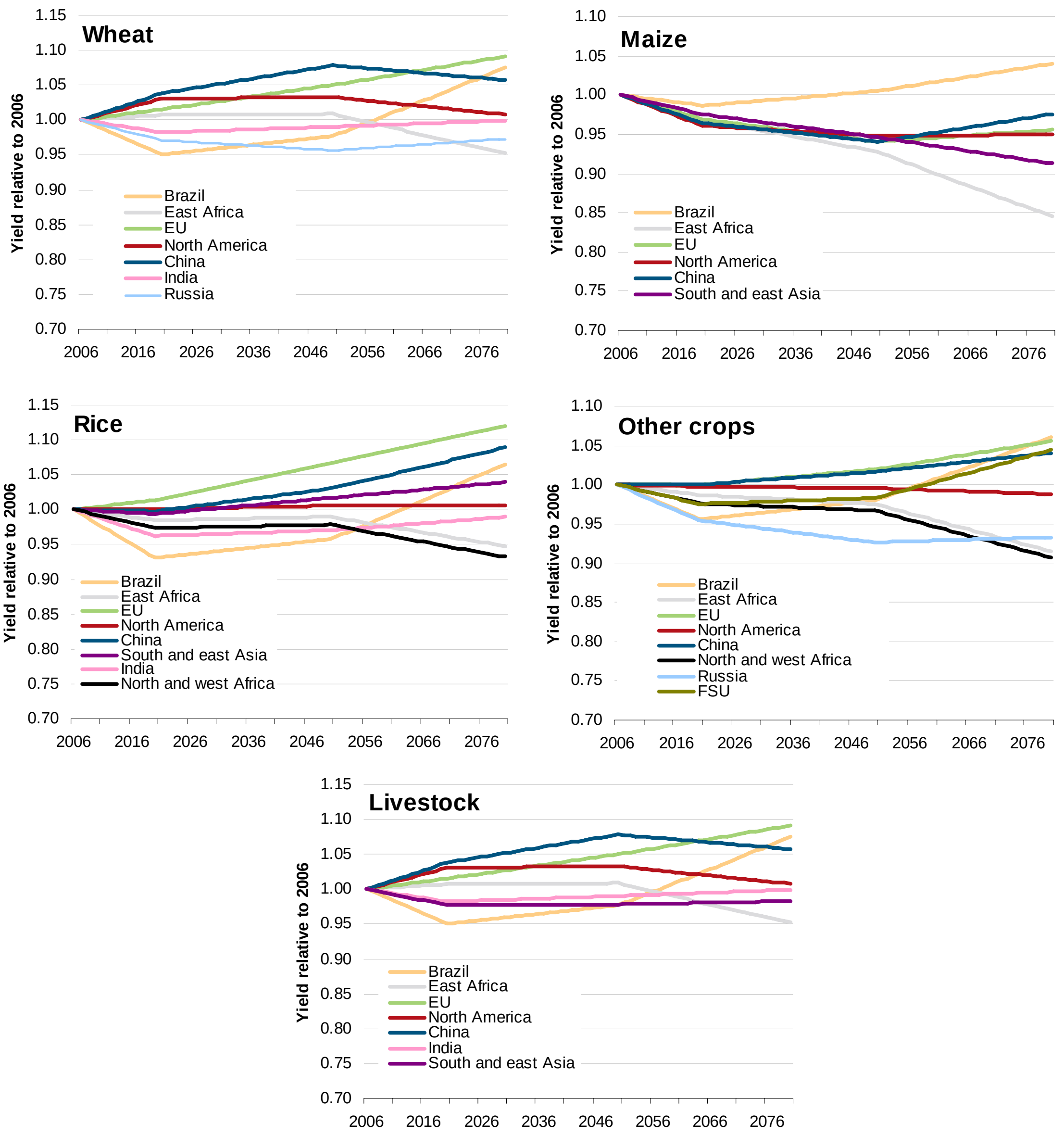
- the effects of climate variables (temperature, precipitation and solar radiation) on crop growth and development;
- the direct effect of $CO_2$ on crop productivity (defined using the potential $CO_2$ direct effect and modified by the temperature and precipitation stress in each scenario); and
- the effect of farmers' adaptation (low cost, non-policy driven) on crop productivity under the climate change scenario (defined with the conditions of each SRES scenario, the social and economic development of the region, and the magnitude of the potential impact).

All data pertaining to the effects of alternative climate change scenarios on crop yields were taken from the Hadley Centre's HadCM3 model.

**Figure 6.2: Selected regional yield indexes – C-A1**



## Figure 6.3: Selected regional yield indexes – C-A2



## Figure 6.4: Selected regional yield indexes – C-B2

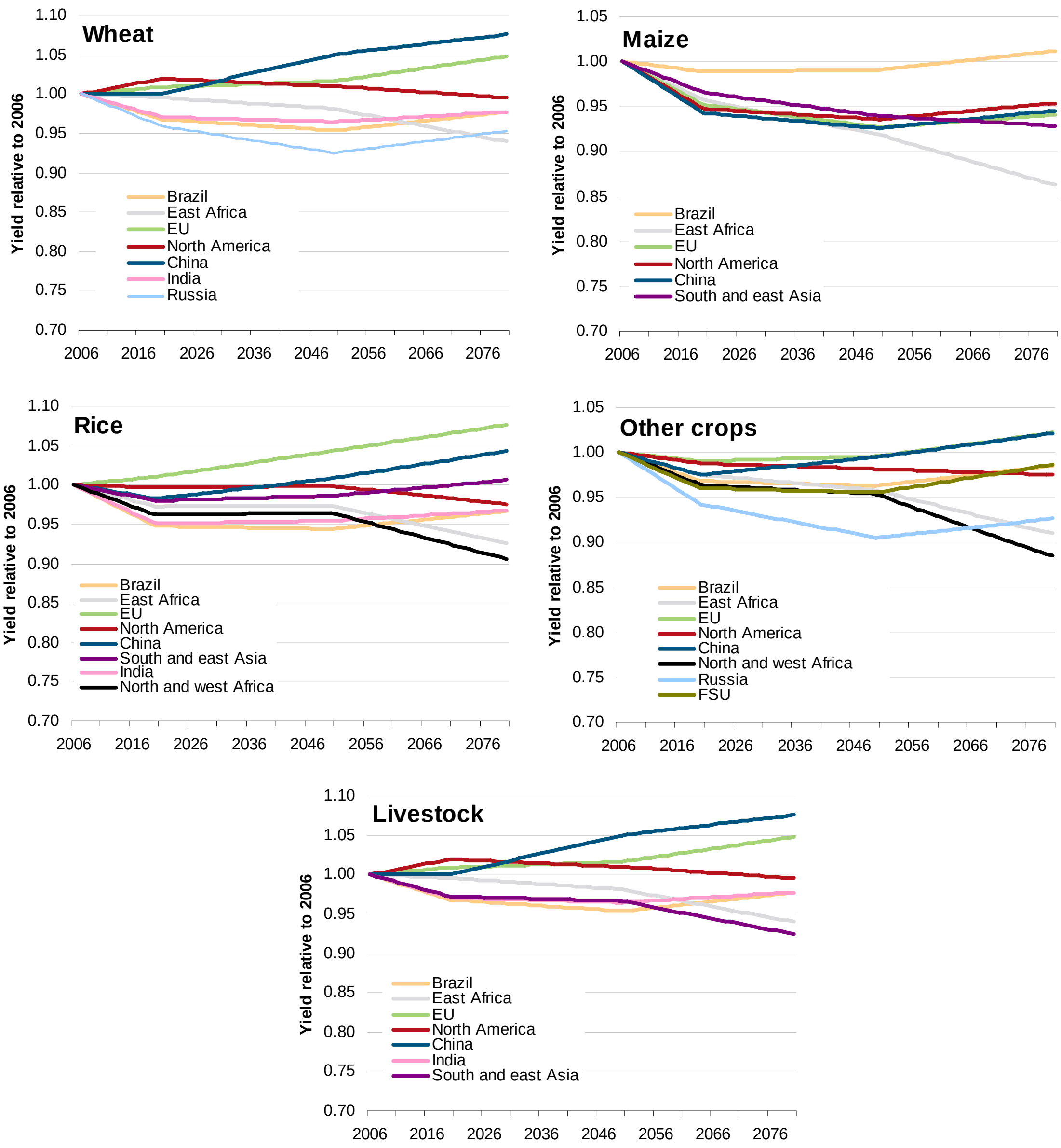
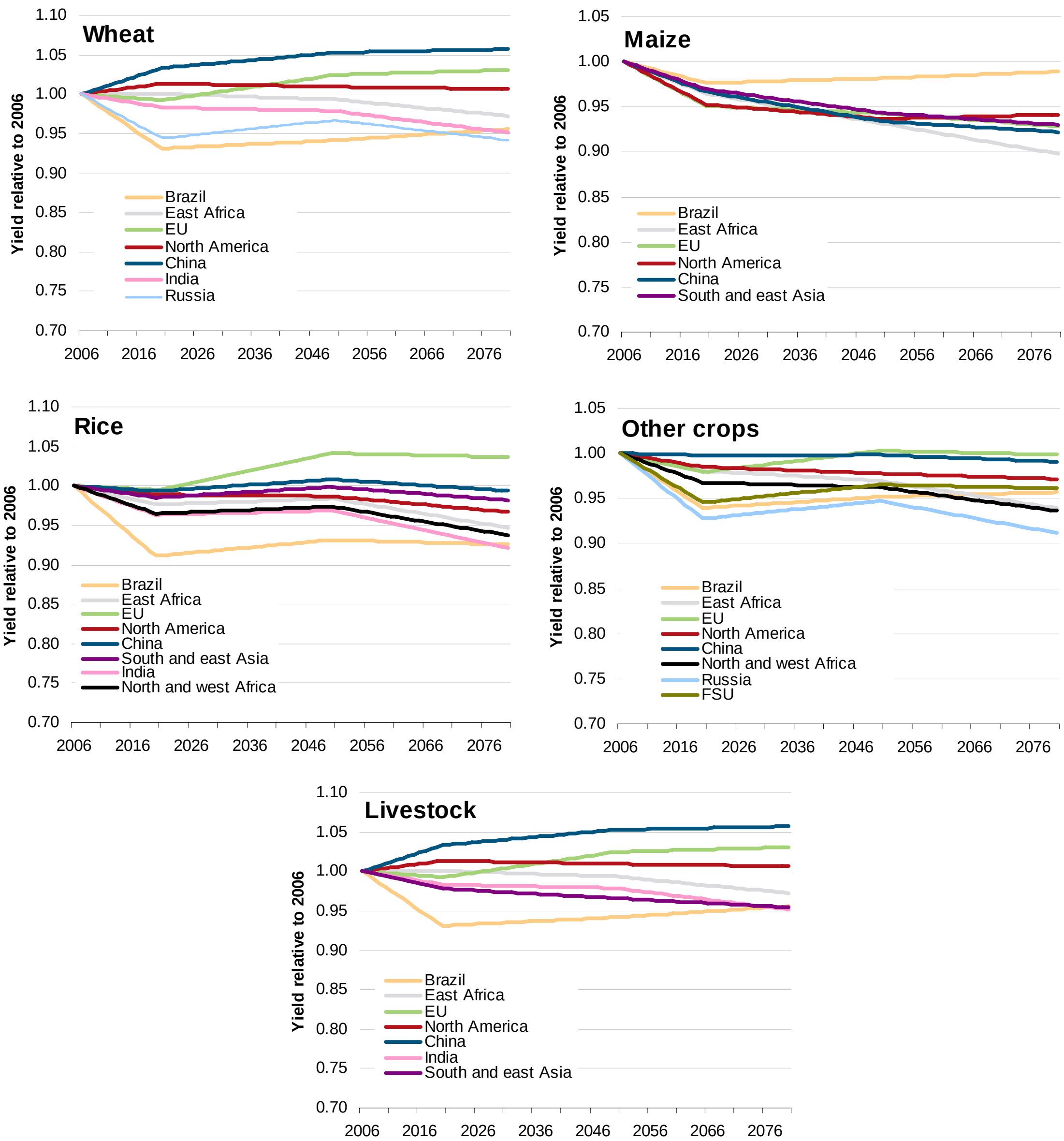


**Figure 6.5: Selected regional yield indexes – C-B1**




As depicted in the figures it is clear that crop and livestock yields are affected differentially across countries (largely spatially related differences) with changes also varying significantly depending on the stabilisation scenario under consideration. The implications of these differences for regional impacts are described in section 8 in respect of the consequences for welfare and trade.

# 7 Policy Scenarios

## 7.1 Trade liberalisation

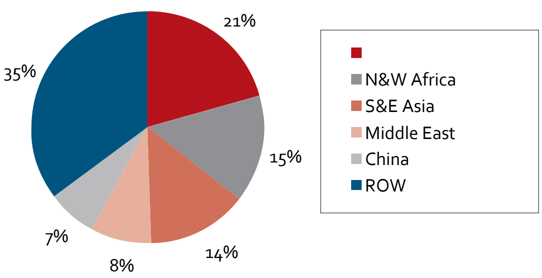
For the commodities in focus in this report namely rice, wheat, maize, other crops and meat and milk, the countries represented in Figures 7.1 to 7.12 below are the main importers and exporters. This partly determined the regional aggregation specified for modelling in this report, along with recognition of China's major trade partners.

As can be seen in these figures, China is a significant importer of wheat, maize, rice and other crops, and also a substantial exporter of maize and to a lesser extent, rice. Hence, any changes in production or consumption patterns of these commodities could have significant effects on world markets. Any impacts of climate change on United States' productivity would also be expected to materially affect world trade flows in these commodities given the prominence of the United States as a major exporter.

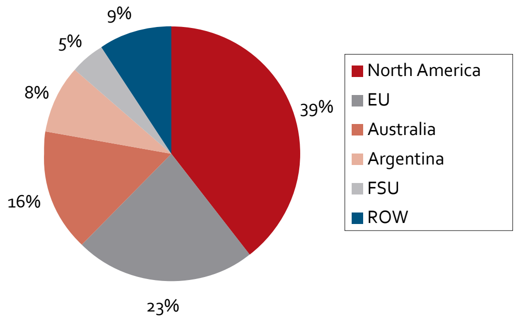
As climate change is expected to affect the world's production of grains differentially, part of the aim in this study is to assess how freer trade might act to improve the welfare of people in different regions. Another objective is to analyse how the effects of trade liberalisation might differ under alternative climate outcomes. To illustrate the effects of trade liberalisation on the flow of commodities across countries under climate change the following scenarios were examined in combination with each of the climate baselines:

1. Trade reference case – current trade restrictions and agricultural subsidies remain in place over the projection period. This trade scenario is run in conjunction with each of the climate scenarios; and
2. Trade liberalisation – current trade restrictions and agricultural subsidies are assumed to be phased out by 2020 in developed countries and in all countries by 2030.

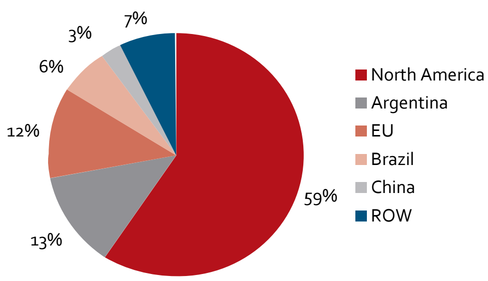
### Figure 7.1: Wheat imports, 2004



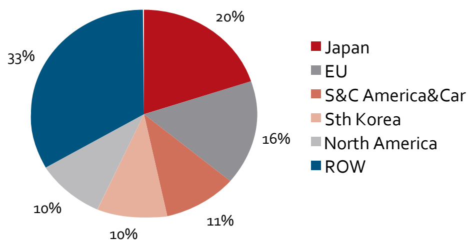

### Figure 7.2: Wheat exports, 2004



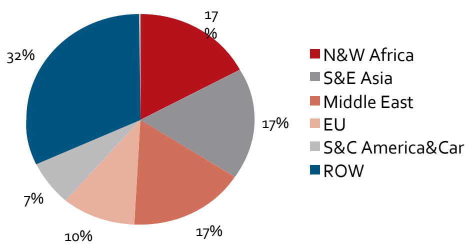

### Figure 7.3: Maize imports, 2004



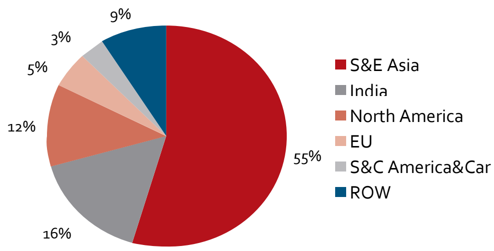

### Figure 7.4: Maize exports, 2004



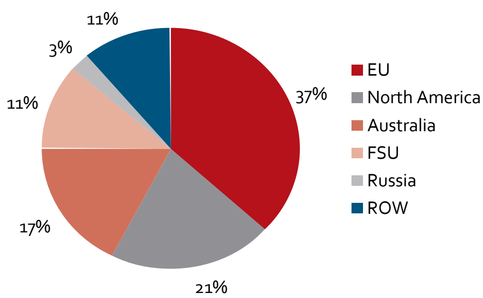

### Figure 7.5: Rice imports, 2004



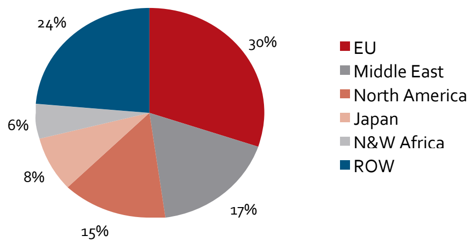

### Figure 7.6: Rice exports, 2004



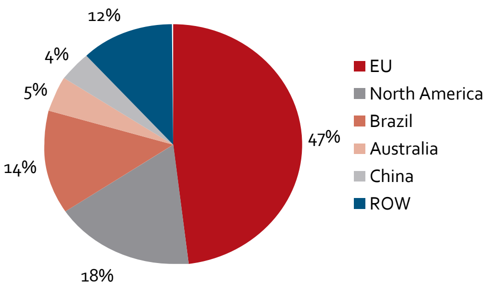

### Figure 7.7: Other crops imports, 2004



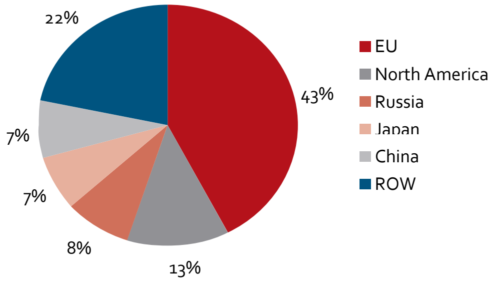

### Figure 7.8: Other crops exports, 2004



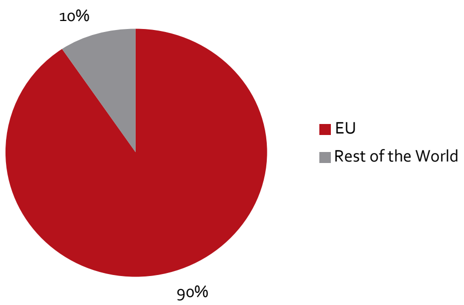
### Figure 7.9: Meat imports, 2004



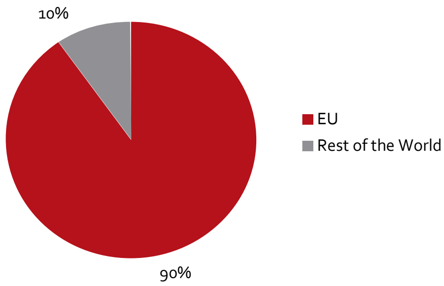

### Figure 7.10: Meat exports, 2004




### Figure 7.11: Milk imports, 2004




### Figure 7.12: Milk exports, 2004




**Data source: FAOStat 2009**

# 8 Results

In section 8.1 the impacts of climate change on the productivity of wheat, rice, maize, other crops and livestock are assessed under each scenario assuming no climate change and compared to the respective 'with climate change' scenarios assumed in the reference case. The intention is to determine the potential effects of the climate change productivity impacts alone on trade flows across the key regions of interest under given economic growth scenarios (C-A1, C-A2, C-B1, C-B2).

Once the effects of climate change and associated productivity effects on trade flows are isolated, then in section 8.2 the various scenario trade flows are compared to analyse the effects of scenarios inclusive of climate change on trade patterns. The assumption here is that given levels of economic growth will give rise to the assumed emissions levels and this in turn will result in the climate impacts modelled earlier. As such, scenarios that exclude climate impacts are not realistic and are used here only to isolate productivity effects associated with climate change from productivity effects associated with economic growth.

In section 8.3 the impacts of liberalising trade (in the presence of climate change) on agricultural commodity trade are analysed.

## 8.1 Impact of climate change on productivity and trade relative to no climate change scenario

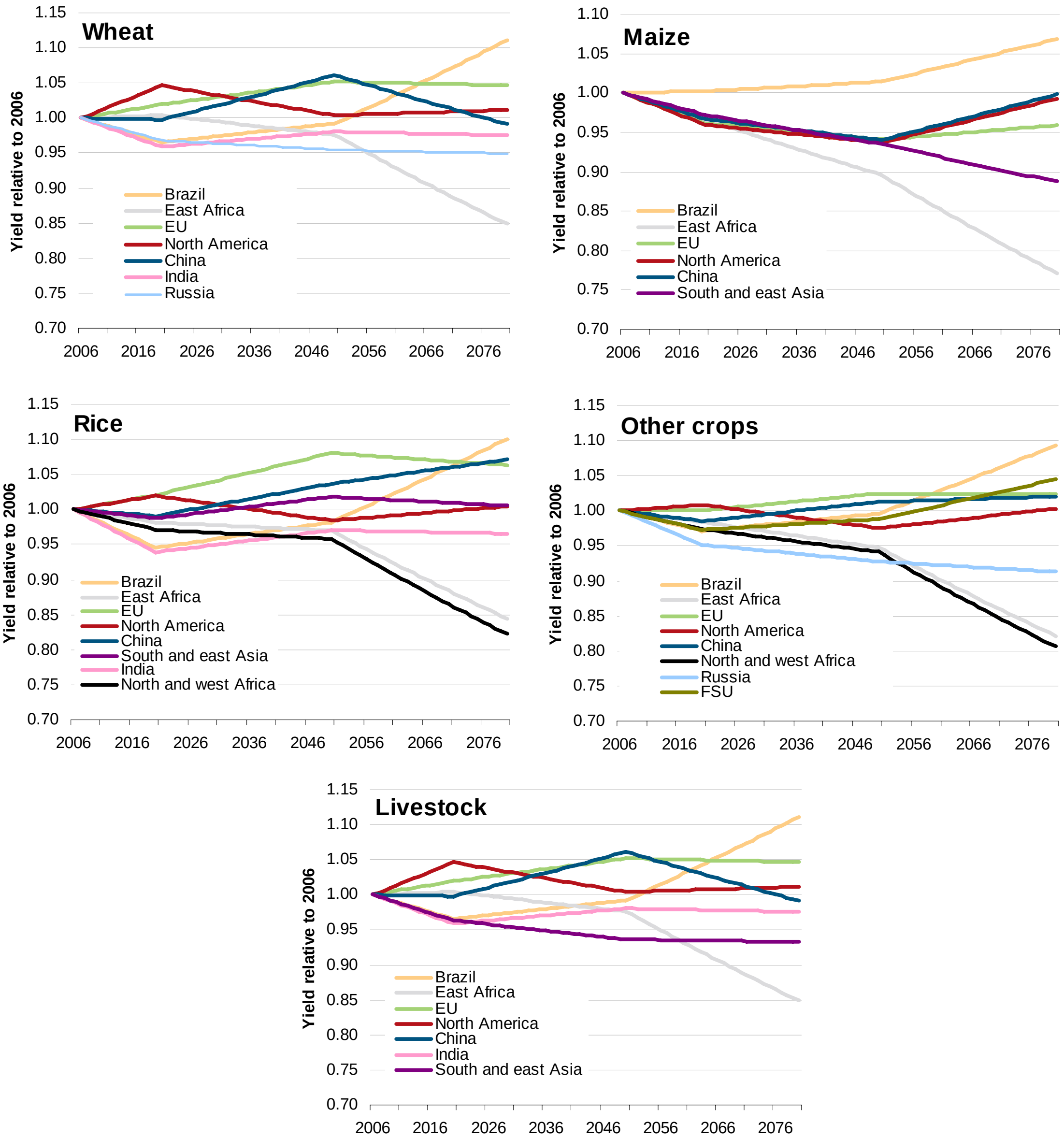
As described in section 6.4, the impact of climate change on yields over time is not insignificant and varies by region. Figure 8.1 indicates the change in yield by commodity under the assumption that climate change occurs, relative to the base year for selected regions.

Relative to historic yield changes, the potential effects of climate change on **maize** productivity are potentially quite moderate. Over the period 1996-2008, average maize productivity globally increased by around 2.4 per cent year-on-year over a twelve year timeframe or around 29.4 per cent in total (Appendix 1). The figure below indicates that even under the most severe climate change outcome (C-A1), maize productivity in the worst affected region is not projected to fall by more than 25 per cent by 2080 relative to the base year of 2004. On an average yearly basis this equates to a productivity loss of around 0.33 per cent annually. The upshot of this observation is that it may be possible for expected technical change to outweigh any negative productivity consequences associated with climate change in certain regions for this crop.

This observation also holds for **rice and wheat** productivity, since average historic yield changes for these crops were around 1 per cent year-on-year for the twelve year period 1996-2008 (see Appendix 1) while the most negative regional impact of climate change is projected to be only around 0.2 per cent per year over the period to 2080.

However, a significant note of caution in relation to this observation is that care must be taken in suggesting that there are limited impacts for agricultural productivity resulting from climate change because many of the potential impacts are not captured by the productivity effects reported in this paper from the Hadley Centre research. For example, the productivity shocks attributed here to crops and livestock do not capture the possible effects of sea level rise or the effects of potential increases or changes in the patterns of crop and livestock pestilence. They also do not capture any potential threshold effects and associated large discontinuities.

**Figure 8.1 Yield changes relative to base year – C-A1**




Examining the modeling results presented in Figure 8.2, the overall climate induced changes to regional production of agricultural commodities are for the most part moderate. These results were obtained by comparing the reference case inclusive of climate impacts with a scenario in which climate productivity effects were absent. The agricultural productivity shocks play only a relatively minor role in production outcomes compared with underlying growth related productivity - for instance even under C-B2 which is the lowest economic growth scenario, the input productivity of land into agriculture in China grows around 65 per cent from 2004 to 2100 (neglecting climate impacts), in comparison with productivity shocks associated with climate change in the order of 5 per cent. Chinese population decline is also a factor, leading to a corresponding shift in the aggregate demand curve in the latter part of the century.

Differences across scenarios are also driven in large part by different income projections, which help determine aggregate demand and consumption shares – for instance, higher income projections are typically associated with higher meat demand and lower rice demand. Taking China as an example, real private per person consumption (C-A1) grows from around US$1,040 a year in 2010 to US$2,510 by 2030 and US$10,270 a year by 2080 (see Figure 8.3). These increments have enormous implications for aggregate demand, demand composition, and technological change. Further, at these growth rates, the income elasticities of agricultural commodities are close to zero by around 2050.

The ensuing sections discuss the most significant implications of climate change and economic growth on a regional commodity by commodity basis. Results are reported both in a comparative sense across the four reference case scenarios which include the productivity related impacts of climate change, and by comparing a these reference cases with scenarios that exclude the productivity related impacts of climate change. In this way it is possible to a) compare reference cases to draw out implications of different levels of emissions concentrations and associated agricultural productivity impacts on output and trade related variables; and b) isolate the climate related aspects of the scenarios from those aspects linked to population and economic growth differences between the reference cases.

Results have been reported in all cases for China (see Figures 8.4 – 8.6) and for the top five producers of each commodity (see Appendix B). Trade flows in the commodities of interest are reported for a selection of countries with particular focus on China. Import and export data are reported from the GTAP model for relevant trading partners and major trading regions.

**Figure 8.2 World production impacts of climate change**

% change relative to no climate impact scenarios

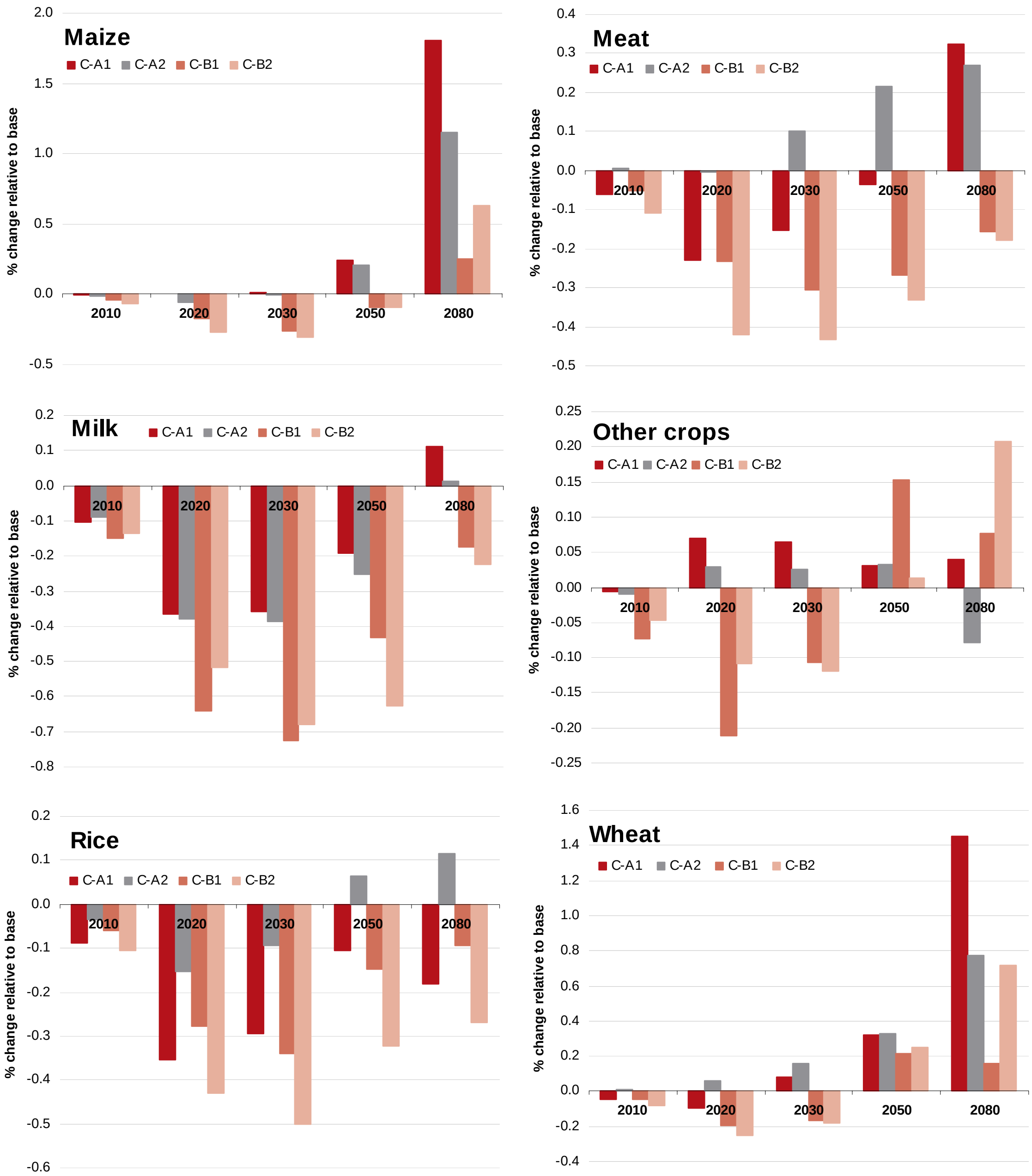
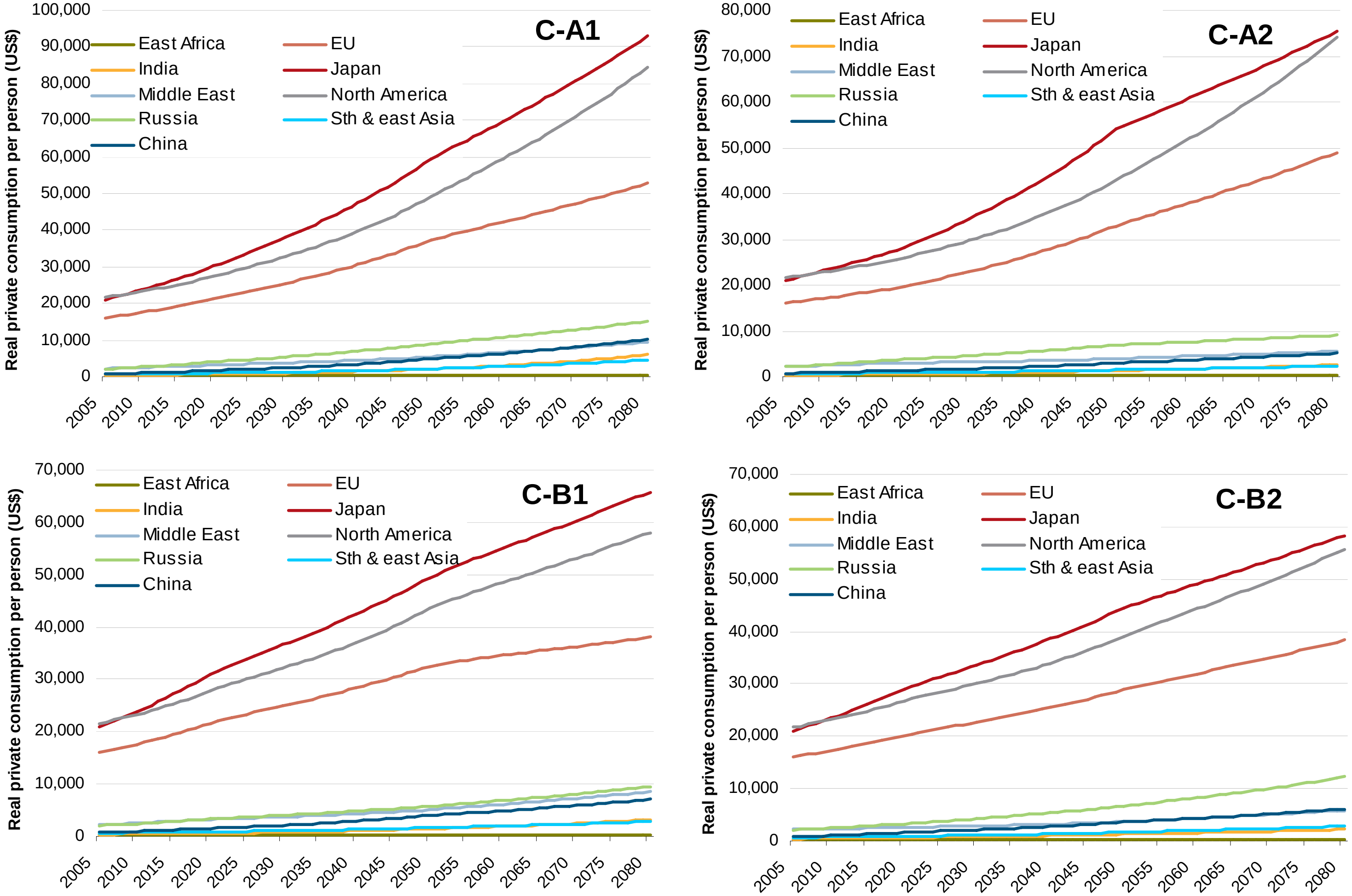


**Figure 8.3 Real private consumption per person (US$)**



### 8.1.1 Wheat

Productivity of Chinese wheat improves slightly as a result of climate change, and most significantly so around mid century. This result can be ascertained by comparing the four reference cases (inclusive of climate impacts) with their respective scenarios modelled in the absence of climate induced productivity impacts. Scenario C-A2 results in the best growing conditions for Chinese wheat production over the course of the modelling horizon (Figure 8.4), however C-B2 results in the highest level of Chinese wheat output. This result is largely explained by the fact that in C-B2, economic growth is lower and hence the degree of substitution between meat and wheat is lower as Chinese consumers demand less meat than in C-A2. China is not a wheat exporter under any scenario and its imports are highest under C-A1 and lowest under C-B2, which reflects Chinese GDP growth paths under the different scenarios. China's main sources of wheat imports are North America, which supplies around 80 per cent of Chinese wheat imports; Australia which supplies around 18 per cent; and the EU which supplies around 2 per cent. Wheat affordability in China improves over time.

Production in the EU increases by as much as 6 per cent by 2080 relative to a no climate change world under C-B1 (low growth scenario), and the EU's production profile follows a similar pattern to China's, with steady increases to 2050 followed by decline through to 2080, reflecting shrinking global population and slowing economic growth.

Wheat production in Russia declines compared to a constant climate world by as much as 4.7 per cent under C-A2. Combined with negative population growth, Russian production falls around 44 per cent between 2010 and 2080. Since wheat output varies only marginally across the various scenarios this result is more closely linked to relative productivity and population factors than climate change (recall that across scenarios population is constant while economic growth and productivity vary).

North American wheat production also suffers slightly due to climate change toward the latter part of the period in all scenarios. The exception is that North American production and exports under C-A1 improve by 2080 in response to poor growing conditions in North and West Africa. Wheat production does however grow steadily over time in all scenarios as other productivity improvements outweigh the climatic effects, and exports grow between 2.1 (C-B1) and 2.5 (C-A1) times.

Indian wheat production rises throughout the century in line with increasing population, and the slight negative implications of climate change for productivity have limited effect. India's imports remain constant in response to climate change while exports decline marginally in all scenarios in response to climate change.

### 8.1.2 Rice

Chinese rice production grows moderately over the projection horizon, peaking mid century before falling again slightly in response to population decline. Rice productivity in China is not significantly affected by climate change, however C-A2 appears to provide the best growing conditions relative to a no climate change world. Chinese exports and imports of rice remain negligible over the period to 2080. Rice affordability in China improves over time and by 2080 the price to income ratio has fallen between 80 and 90 per cent relative to 2004.

South and East Asian and Indian rice production grows over the full modeling timeframe. There is a significant difference in output between scenarios (39 Mt difference between C-A1 and C-A2 in South and East Asia), which reflects the differences in productivity effects for rice across scenarios, and relative to other agricultural commodities. In SE Asia, rice exports are highest under C-A1, reflecting the higher level of production under that scenario.

Rice production in North and West Africa grows over time albeit modestly. This growth hides a significant impact due to climate change - production in that region declines by between 1.7 and 13.2 per cent by 2080 relative to a no climate change world. The most adverse scenario for North and West African rice production is the high growth (high emissions) C-A1 scenario and the least adverse scenario is low growth C-B1 scenario.

Rice production in Brazil grows modestly over time, despite Brazilian rice yields declining due to climate change slightly for the most part of the century before recovering around 2080. This result indicates that technical improvements outweigh the climate impacts on total productivity in this sector.

Indian rice production grows strongly throughout the period to 2080 under all scenarios, which masks a small decline in productivity due to climate change for the most part of the century.

South and East Asian and particularly North American rice exports increase significantly to North and West Africa, Middle East and South and East Asia, with the largest results occurring under C-A1.

### 8.1.3 Maize

Chinese maize output is maximized under C-B1 and is lowest under C-A1, however the difference is a matter of around 14 Mt between scenarios in any given year. Chinese maize productivity is highest under C-A2, but climatic effects on Chinese maize are only marginal. China is not a maize exporter of significance however imports increase modestly compared to the base year to a total of around 12 Mt by 2080. This result is similar under all scenarios. Maize affordability in China improves dramatically over time, with a 75-85 per cent drop in the price to income ratio relative to the base year (scenarios C-A2 and C-A1 respectively).

North American production grows significantly over time under all scenarios, with an increasing share of production diverted to exports. The exception to this observation is under C-B1, where production falls 19 Mt between 2050 and 2080. While production increases most under C-B1 initially, the latter half of the century sees a reversal in this trend for North American production. This result is interesting since North American population and economic growth are positive for that period so this suggests the result is occurring as an outcome of relative differences in productivity impacts between North America and Brazil. Although North American maize productivity is higher in all scenarios than in a no climate change world for the period 2050-80, Brazilian maize productivity increases 600 per cent more than in North America in C-B1. As such, Brazil significantly increases the share of its maize production into exports, primarily into North America and other South and Central American countries, thus displacing domestic production.

Maize production in South East Asia and the EU is relatively stable over the century which masks the fact that South East Asian maize productivity falls slightly under all scenarios relative to a world in which climate change does not occur, while EU maize productivity improves slightly.

### 8.1.4 Other crops

Chinese production of other crops varies little in output terms under any scenario between 2010 and 2080.However imports increase by as much as five times over the same timeframe (in scenario C-A1) and are predominantly sourced from Brazil and North America. Chinese productivity of other crops improves slightly in the face of climate change. Affordability of other crops in China improves over time, despite real prices increasing by between 85 and 134 per cent from 2004- 2080.

Productivity of other crops does best in the EU and North America in response to climate change. In North America, around 50 per cent of production is diverted to exports by 2080. This represents an increase over current export shares of around 25 per cent, and partly reflects relative improvements in growing conditions in North America. In the EU, productivity improvements occur consistently in all scenarios as a result of climate change, although output and exports remain relatively unaffected.

Russian output falls over time primarily in response to substantial falls in productivity (as much as 3.1 to 6.3 per cent in 2050) in the face of climate change and a declining population which lowers domestic demand.

Climate change productivity effects are also detrimental for N&W Africa, particularly toward the end of the century and under the higher growth (and emissions) scenarios – for example under C-A1 productivity falls 7.5 per cent by 2080 due to the effects of climate change.

Production of other crops largely stagnates at 2010 levels for the remaining regions.

### 8.1.5 Meat

In the meat sector, Chinese productivity owing to climatic effects is slightly positively affected in all scenarios for the bulk of the reporting horizon. Meat production under scenario C-A1 is associated with the highest output which is closely linked to greater affluence and hence a higher demand for meat than in the other scenarios. The difference in production of meat in China between scenarios differs by no more than 15 Mt in any given year throughout the modeling horizon. China is not a meat exporter in any scenario, and as a direct result of climate change, it substantially reduces its imports as domestic livestock conditions improve relative to other countries (Figure 8.6). However, the overall impact of both economic growth and climate change is a substantial increase in Chinese meat imports, as the affluence effects of higher per person wealth outweigh any production cost increases – this result can be seen in table B6 which indicates that meat affordability (price to income ratio) in China improves dramatically over the course of the century under all scenarios.

North American meat production increases steadily to 2080 while the share of production to exports increases substantially from around 12 per cent in 2010 to between 30 per cent (C-B2) and 44 (C-A1) per cent in 2080. A large part of these exports are absorbed by China.

Other major exporters are the EU, Brazil and Australia. While Brazil and to a lesser extent South and East Asia increase meat production consistently in all scenarios, in Brazil, meat production is significantly higher under C-A1 and C-B1 than in the other two scenarios due to Brazilian income growth assumptions in being much higher in those scenarios.

### 8.1.6 Milk

Chinese milk output grows roughly 15 Mt to around 48 Mt by 2050 in all reference case scenarios and productivity changes due to climate are small but positive. China imports very little milk, which is partly diet related and partly owing to the fact that the specification reported here is raw milk. Processed livestock products includes processed meat and dairy and this sector benefits in China as a direct result of climate change regardless of scenario.

India, North America and the EU display the largest increases in milk production over the modeling horizon, with Indian milk production more than doubling to between 254 Mt (C-B2) and 298 Mt (C-A1) by 2080. This is despite the fact that climate related productivity in the milk sector in India and North America suffers a decline for a large part of the century. The EU is also the only real importer and exporter of milk however this reflects largely intra-EU trade. Trade in (raw) milk outside the EU is minimal.

### 8.1.7 Affordability

The key observations to draw with respect to the affordability of agricultural commodities include:

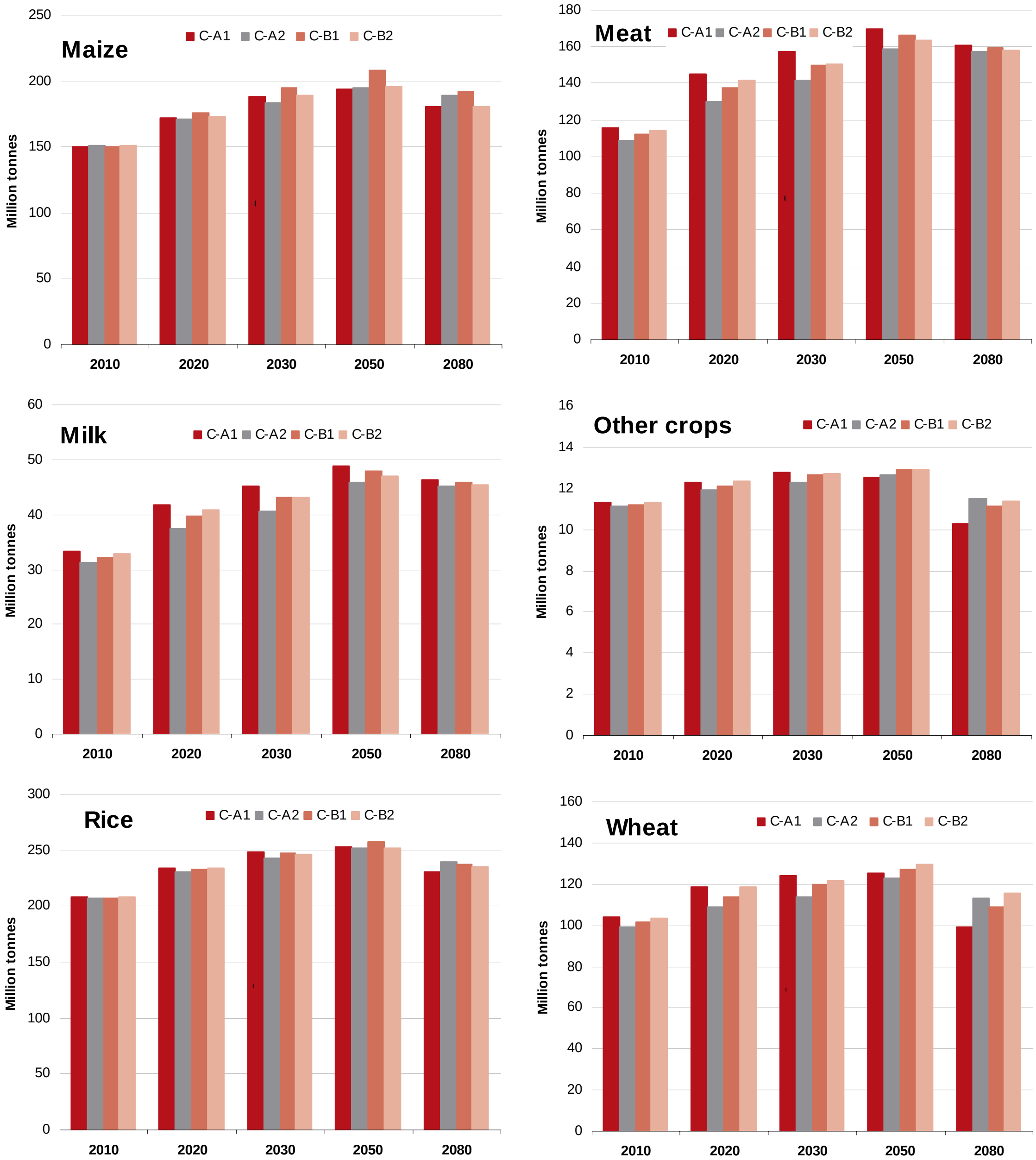
- While real prices for all commodities increase under every scenario, incomes increase at a faster rate in every case, and hence all commodities become more affordable over time relative to 2004 (see Appendix B, tables B5 and B6).
- Real prices increase fastest in China, however the rapid pace of income growth in China ensures that the Chinese are among the greatest beneficiaries of affordability improvements over the modelling horizon.
- The other regions to benefit most from improvements in affordability of agricultural commodities are Brazil, North America, and the EU.
- On a regional basis, while food is becoming more affordable relative to the base year in East Africa, this region lags all others modelled with respect to the size of the improvement in affordability. This observation holds for all scenarios considered.
- The disparity in affordability improvements between developed countries and those in Africa is a stark feature of the modelling results. The result occurs for several reasons including:

  the negative impact of climate change on productivity of most agricultural commodities produced in Africa;

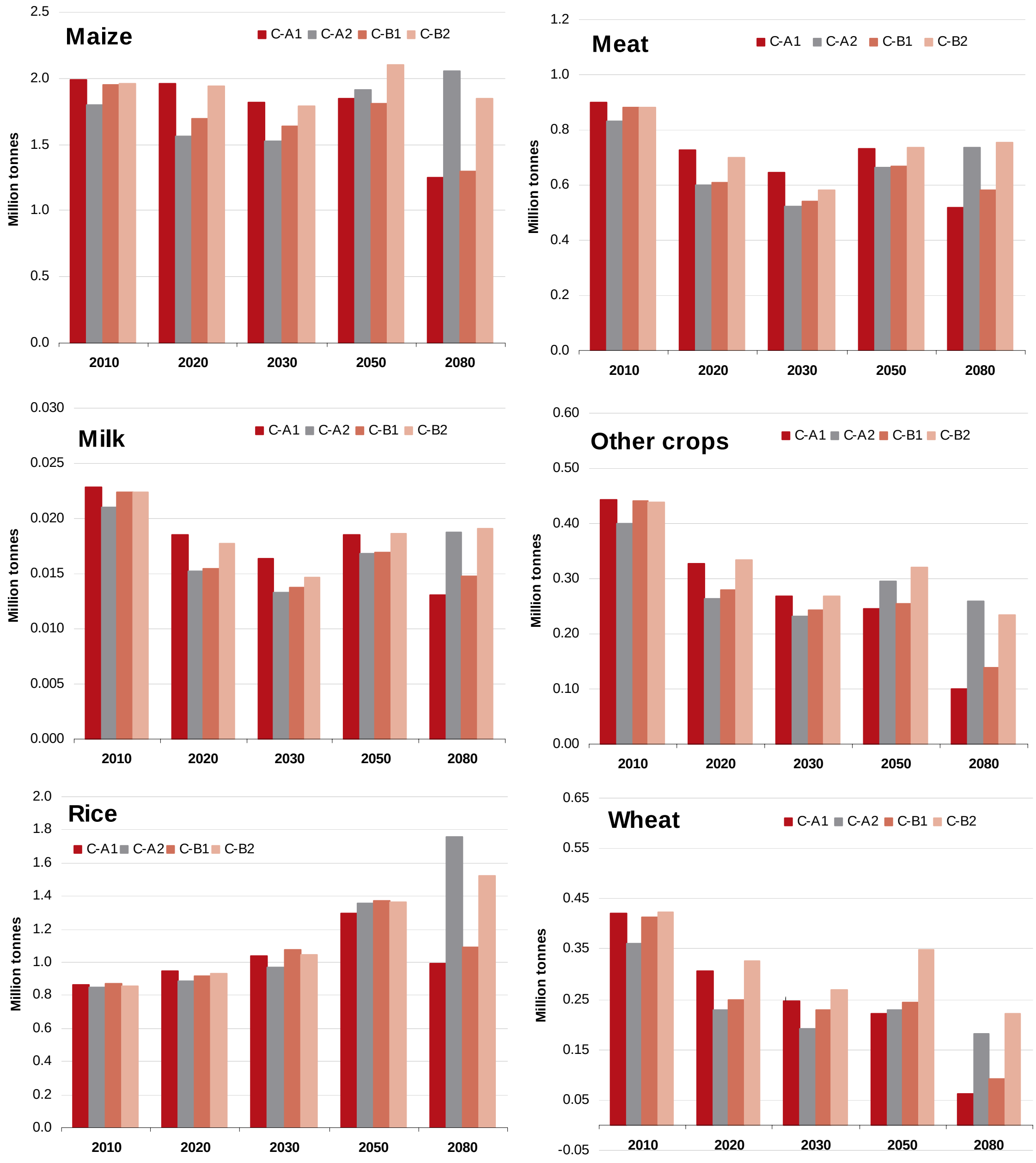
  although African productivity of some crops improves under climate change, these gains are typically less than other regions' gains and hence the relative outcome for Africa is competitively disadvantageous;

  economic growth has a much larger effect on overall affordability of commodities than the climate impacts and hence Africa's lower starting point stymies it for decades despite reasonable growth rates.

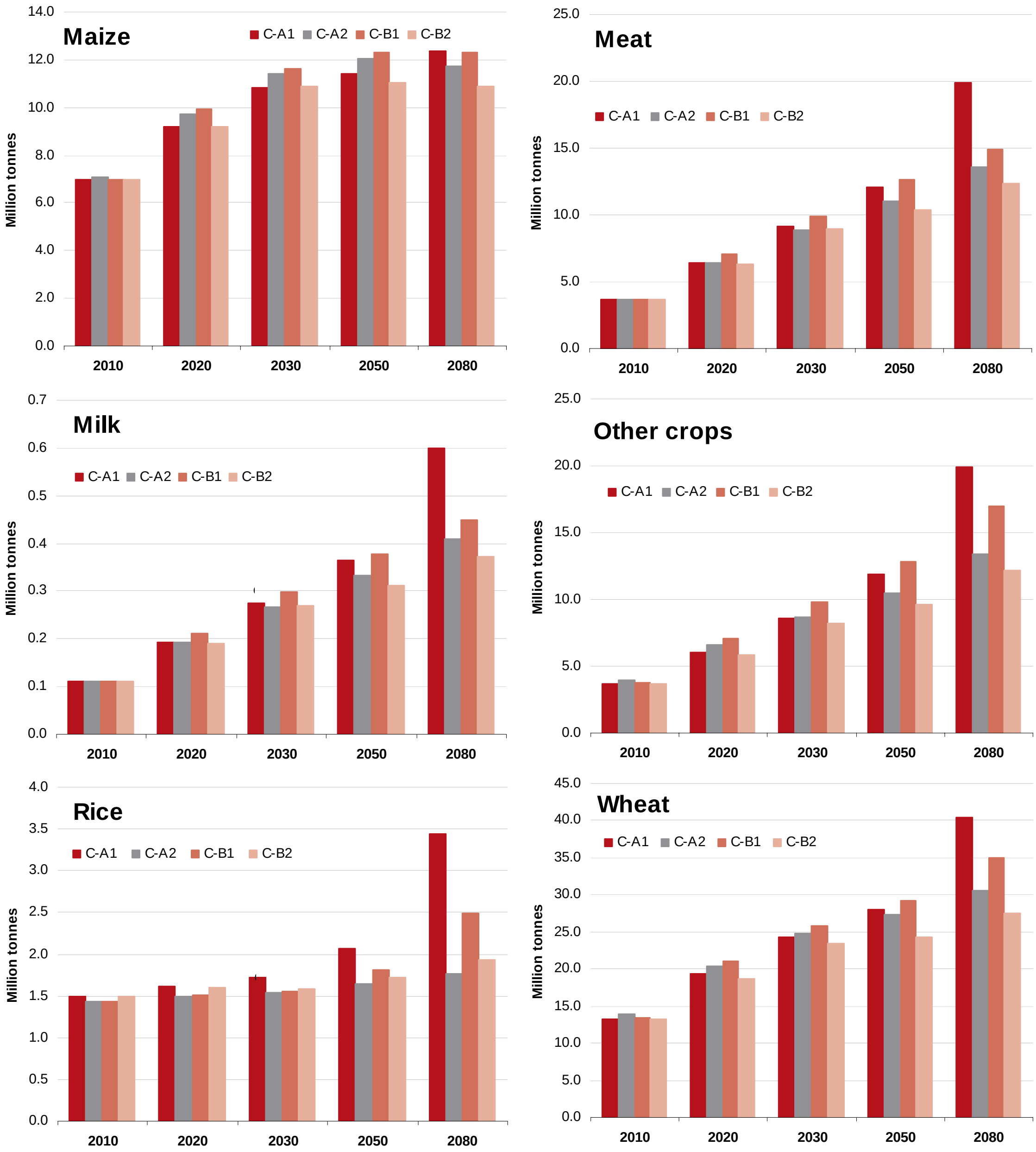
## Figure 8.4 China's production by scenario, by commodity



## Figure 8.5 China's exports by scenario, by commodity



## Figure 8.6 China's imports by scenario, by commodity



## 8.2 Trade liberalisation under climate change

To estimate the effectiveness of trade liberalisation as a tool for mitigating any negative effects of climate change, and to assess its effect on production, trade and welfare more broadly, a policy scenario whereby all countries progressively liberalise trade was designed and implemented. A comparison of the values of key variables in the policy scenario relative to their value in the base case can give an indication of the sign and magnitude of likely changes. The base case includes the effects of climate change.

Trade liberalisation was implemented by progressively removing export taxes, import taxes and output taxes on all agricultural commodities and agricultural processing sectors in the GTAP database. For developed economies, liberalisation of these sectors is assumed to be complete by 2020, and for developing economies, by 2030. The approach to implementing trade liberalisation policies used here is similar to that used in Hertel (1997).

### 8.2.1 Wheat production and trade

Under trade liberalisation, China's output of wheat is projected to be higher across all scenarios and all years, albeit by a relatively small amount, relative to the climate change base case. By 2020, China's production is 0.8 to 1.0 Mt (about 0.8 per cent) higher than it otherwise would have been, and by 2030 (when world trade is fully liberalised) China produces 1.6 to 1.9 Mt more than without liberalisation (about 1.4 per cent more). Chinese wheat exports as a result of trade liberalisation are essentially unchanged from the reference case across all scenarios, and imports are at most 1.4 Mt lower by 2080 (under C-B1). The real price of wheat is 1 to 2 per cent higher in a world of liberalised trade than under the base case.

The effect of developed economies liberalising trade by 2020 has a pronounced effect on North American wheat production. By 2050, North American wheat production is lower in a liberalised world than in the base case. North American wheat exports also decrease; under the C-A2 trade liberalisation scenario, exports are 11.2 Mt lower than they otherwise would have been.

### 8.2.2 Rice production and trade

Trade liberalisation is projected to result in very large reductions in the volume of rice produced in China relative to the reference case by the end of the forecast horizon. China's import tariffs on rice from some regions are high, so phasing these tariffs out can be expected to have a large impact on domestic production. Out to 2020, China's production is slightly higher across all scenarios but by the time all developing economies have liberalised in 2030, production falls substantially relative to the reference case. Losses occur across all scenarios, and all are in the range of 56 to 63 Mt reductions (in the case of C-A1, equivalent to 24.4 per cent reduction). China's imports of rice increase by about 30 million tonnes as domestic production falls, although exports also increase somewhat relative to the base case. It follows that China's rice consumption is projected to fall overall. The real price of rice in China is projected to be lower in 2020, 2030 and 2050 than under the base case.

The region of North and West Africa gains consistently in rice production as trade barriers are relaxed, particularly under C-B1. South and East Asia also makes gains relative to the reference case, with exports increasing by between 10.4 Mt (C-A2 scenario) to 15.3 Mt (C-A1) relative to the base case by 2080.

Rice is the only commodity for which North America's production falls relative to the reference case in a liberalised world. This is because North America imposes large tariffs on rice imports, and the removal of these is detrimental to domestic production.

### 8.2.3 Maize production and trade

China's production of maize increases immediately as border taxes and subsidies are removed. In 2020, maize production is up by 4 to 5 million tonnes (about 3 per cent) across all scenarios relative to the base case, with more gains out to 2030, at which time production is projected to be about 8 million tonnes higher than in the reference case (equivalent to 4.4 per cent). China's exports are higher by less than one million tonnes across all years and all scenarios, and imports are lower by a more or less equal amount. China's crop processing sector (of which maize is an input) is about 6.7 per cent higher under C-A1 in 2030 than it would have been in a world of artificial trade constraints.

It is not surprising that regions with increased livestock production also have increases in maize production relative to the climate change base case. For example, by 2050 North America's production of livestock is higher under a world of liberal trade policies by about 4 to 5 million tonnes for meat products and about 4 to 9 million tonnes for milk. Correspondingly, maize production in the same region is higher by a maximum of 8.3 million tonnes relative to the reference case (in the C-A2 scenario, equivalent to 1.5 per cent). Brazil, a significant livestock producer, is projected to have higher maize production in the range of 4.7 (C-B2) to 14.4 million tonnes (C-A1) in 2080. Given the initially high EU tariffs on livestock, it is perhaps not surprising that both maize and livestock production in the EU are lower under trade liberalisation scenarios.

### 8.2.4 Other crops production and trade

China's production of 'other crops' increases as the world pursues trade liberalisation policies. By 2030, production is 0.2 to 0.3 million tonnes higher than under the base case, with exports 0.1 to 0.2 million tonnes higher also. Although production in North America falls out to 2020 under all but the C-A1 scenario, by 2050 (when all trade has been liberalised for twenty years) it recovers to as much as 4.8 million tonnes in 2080 (for the C-A1 scenario). Production in other major producer regions such as FSU, Russia and North and West Africa is lower in a world of liberalised trade than in the base case. Under the C-A1 scenario, South & Central America makes gains of about 19 per cent relative to the base case by 2080.

### 8.2.5 Meat production and trade

China's production of meat products is projected to decline (relative to the reference case) across all years and under all scenarios in a world of liberalised trade. At 2050, production decreases are largest under the C-A1 scenario (1.8 million tonnes) and smallest under the C-A2 and C-B2 scenarios (1.5 million tonnes). While production is projected to decline, exports are set to be more or less the same as in the reference case. China's imports are projected to be 0.3 million tonnes higher under the C-A1 scenario.

Under free trade, Brazilian production of meat products is projected to be substantially higher than under the reference case. In 2080, production is 59.8 million tonnes higher under C-B1 than it otherwise would have been. The bulk of the increase is transformed in Brazil's livestock processing sector, which under the C-A1 scenario (for example) is twice the size in 2080 than it would otherwise have been under the reference case. So although Brazil's unprocessed meat exports fall, exports of Brazil's processed livestock sector increase substantially under a world of free trade.

### 8.2.6 Milk production and trade

Removal of trade barriers is projected to reduce China's milk production in 2030 by between 1.5 Mt (for C-B2 and C-A2 scenarios) and 1.8 Mt (C-A1) (relative to the climate change base case). Milk exports are essentially unchanged across all scenarios in all years as China is not an exporter of significance in this sector.

EU milk production is projected to be substantially lower under trade liberalisation than with trade barriers. In 2020, when all developed economies have fully liberalised, EU production is down by between 4.4 million tonnes (under C-B2) and -7.5 million tonnes (under C-A1). By 2080, production is 18.2 million tonnes lower under B1 than in the reference case. Imports are also lower, although only by a small amount.

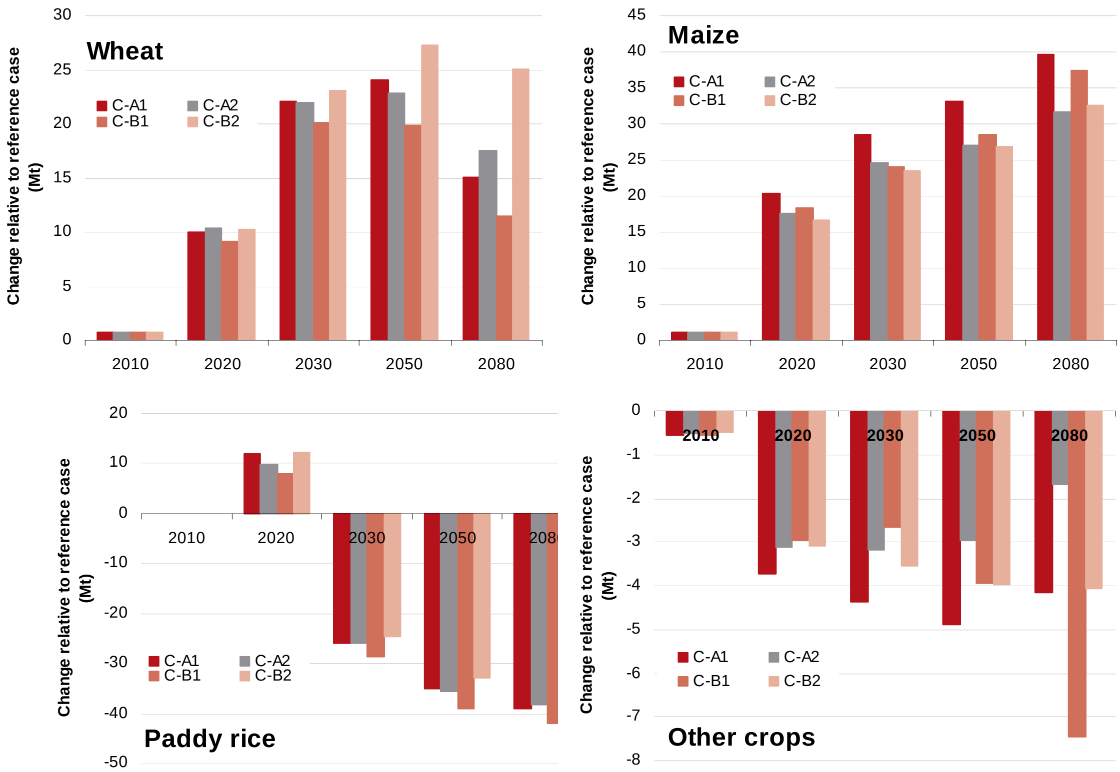
Both India's and North America's milk production stands to increase significantly.

### 8.2.7 A comparison of scenarios

Of the four climate change scenarios modelled, no single scenario consistently yields larger changes in world crop production under trade liberalisation across all commodities and all years than any other. For example, in the case of wheat production in 2020, production is highest relative to the reference case for C-A2, but by 2030 and for the years thereafter, C-B2 generates the largest increases in production (Figure 8.7). Scenario C-A1 leads to reasonably large increases relative to the reference case in 2030 and 2050, but by 2080 it is associated with an increase in wheat production only slightly more than half that of C-B2. Scenario C-B1 yields the smallest increases relative to the reference case in all reported years.

C-A1 leads to the largest increases in world maize production across all years, and, generally, C-B2 leads to the smallest increases. The effect of removing developing economy protection on paddy rice is dramatic, turning increases relative to the base case in 2020 to substantial decreases in 2030. Rice production is lower by the largest amount under C-B1 in 2030, 2050 and 2080, although under all scenarios the amounts are reasonably similar.

**Figure 8.7 Change in world crop production relative to the reference case under a policy of trade liberalisation.**

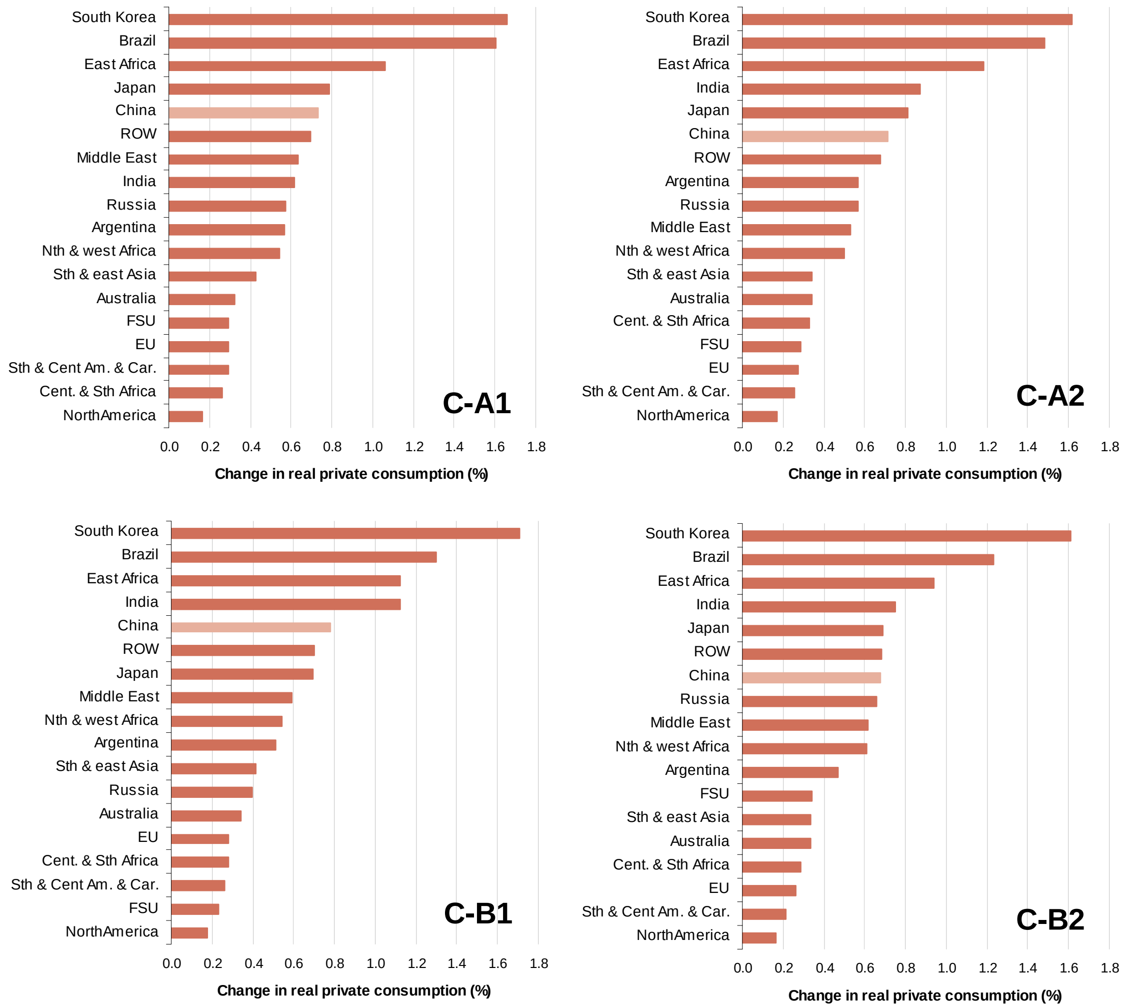



## 8.2.8 Real private consumption

Liberalising trade affects a country's welfare by changing the real price of agricultural commodities (and, to a lesser extent, all other goods and services), and by altering the structure of the country's economy. By inducing a more efficient structure of commodity production, more output can be produced for the same cost. It follows that welfare can be expected to increase relative to the reference case following trade liberalisation. Liberalisation may therefore be an appropriate strategy for partially offsetting any negative welfare impacts of climate change. In this section, real private consumption is used as a proxy for economic welfare.

Across all scenarios, South Korea, Brazil and East Africa make the most gains in terms of real private consumption relative to the reference case in a world of liberalised trade in 2050 (Figure 8.8). South Korea's consumption is between 1.61 per cent (C-B2) and 1.71 per cent (C-B1) higher. China's consumption gains from trade liberalisation are between 0.68 per cent (under C-B2) and 0.78 per cent (under C-B1). North America is projected to have the least to gain across all scenarios.

**Figure 8.8 Change in real private consumption in 2050 relative to the reference case under a policy of trade liberalisation, by region**



# 9 Conclusions

The major conclusion in this report aligns with the majority of the published climate change research relating to agriculture, in the sense that it concludes that food production will be sufficient to meet the world's needs for the remainder of this century, regardless of the climate change scenario adopted. The productivity improvements associated with technical change over time are highly likely to outweigh any negative productivity effects associated with climate change assuming historic rates of improvement continue into the future.

A major caveat to this conclusion is that the yield shocks utilised in this research from the Hadley Centre do not include possible threshold effects associated with climate change, changes in pestilence, changes in sea levels or fresh water supply (other than precipitation) that could potentially have enormous and uncertain consequences for agricultural production around the globe.

Other key conclusions from this research include the following.

- The impacts of climate change and trade liberalisation will not be uniform across the globe since land productivity for agricultural production will improve in some regions and decline in others. The regions generally most beneficially affected by climate change across all agricultural produce include China, the EU, North America and Brazil. The regions worst affected as a result of climate change include East Africa, Central and Southern Africa, North and West Africa, Middle East, and Russia. India and South and East Asia are typically affected negatively but only marginally. This result has important implications for the distribution of global wealth in the future, particularly considering it is generally the poorest regions that will be most negatively affected by climate change. Moreover, the regions affected in Africa in particular are more dependent on agricultural activities as a primary source of income and for subsistence living than many other regions.
- Although the productivity effects of climate change for a given crop may be positive in a region, this does not necessarily result in production shifting to that region. If other regions have a relatively greater improvement in productivity, production shifts to those regions preferentially so long as the necessary inputs are abundant and competitively priced.
- Processed meat and dairy sectors improve production performance most under climate change in China, Australia, FSU and ROW. The regional sectors that suffer most in response to climate impacts are East Africa, North and West Africa, Middle East, Central and Southern Africa, Russia and South and East Asia.
- Processed food sectors in East Africa, North and West Africa, Middle East and Russia perform worst under climate change, while China, FSU, Brazil and Australia perform marginally better in the face of climate effects.
- Differences between climate scenarios (C-A1, C-A2, C-B1, C-B2) are typically modest with respect to production, however there is a discernible 'jump' in output effects under scenario C-A1 relative to the other scenarios. This is likely to reflect the non-linear nature of climate change impacts as emissions concentrations increase.

- Removal of border taxes and subsidies results in a uniform improvement in welfare across all regions and under all scenarios. Liberalisation may therefore be an appropriate strategy for partially offsetting any negative welfare impacts of climate change.
- The impact of removing border taxes and subsidies has a universally positive outcome for Chinese welfare, with real private consumption increasing by around 0.7- 0.8 per cent by 2050 under all scenarios (relative to no liberalisation). Removal of border taxes/subsidies results in higher Chinese domestic production in all commodities except rice and livestock. Exports of rice increase significantly under a liberalised trade world in China by as much as 14 Mt in 2030. Chinese maize exports increase modestly and all other agricultural commodity exports from China are largely unaffected by the trade policy. Imports of rice are also the most affected commodity as a result of the trade policy - Chinese rice imports are projected to increase (relative to the reference case) by around 30 Mt by 2030 and as much as 36 Mt (C-B1) by 2080 as a result of trade liberalisation. Chinese wheat and maize imports fall slightly. Real prices of all agricultural commodities rise modestly in China as a result of trade liberalisation however income improvements are sufficient to offset these increases to ensure Chinese welfare improves.

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# APPENDIX AHISTORIC YIELD CHANGES BY CROP FOR SELECTED REGIONS

| WHEAT | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Australia | 0.211 | -0.150 | 0.040 | 0.048 | -0.092 | 0.157 | -0.570 | 1.205 | -0.183 | 0.236 | -0.546 | 0.152 | 0.0423 |
| Canada | 0.082 | -0.124 | 0.060 | 0.152 | -0.059 | -0.204 | -0.058 | 0.231 | 0.170 | 0.037 | -0.047 | -0.110 | 0.0108 |
| France | 0.096 | -0.071 | 0.148 | -0.048 | -0.017 | -0.070 | 0.125 | -0.161 | 0.213 | -0.078 | -0.035 | -0.072 | 0.0025 |
| USA | 0.013 | 0.090 | 0.093 | -0.011 | -0.016 | -0.044 | -0.128 | 0.261 | -0.023 | -0.027 | -0.075 | 0.035 | 0.0140 |
| World | 0.028 | 0.051 | -0.005 | 0.021 | -0.013 | 0.011 | -0.022 | 0.003 | 0.082 | -0.022 | 0.001 | -0.009 | 0.0105 |
| **RICE** | **1995-96** | **1996-97** | **1997-98** | **1998-99** | **1999-2000** | **2000-01** | **2001-02** | **2002-03** | **2003-04** | **2004-05** | **2005-06** | **2006-07** | **average** |
| India | 0.046 | 0.008 | 0.012 | 0.034 | -0.043 | 0.094 | -0.160 | 0.192 | -0.046 | 0.060 | 0.013 | 0.034 | 0.0203 |
| Thailand | -0.003 | -0.013 | 0.036 | -0.017 | 0.078 | 0.003 | -0.004 | 0.017 | 0.077 | 0.037 | -0.016 | 0.032 | 0.0190 |
| USA | 0.089 | -0.036 | -0.040 | 0.036 | 0.070 | 0.034 | 0.013 | 0.014 | 0.048 | -0.050 | 0.040 | 0.047 | 0.0219 |
| Viet Nam | 0.021 | 0.029 | 0.021 | 0.036 | 0.034 | 0.010 | 0.071 | 0.011 | 0.047 | 0.007 | 0.001 | 0.018 | 0.0255 |
| World | 0.034 | 0.009 | 0.000 | 0.020 | -0.002 | 0.013 | -0.022 | 0.021 | 0.026 | 0.012 | 0.009 | 0.028 | 0.0123 |
| **MAIZE** | **1995-96** | **1996-97** | **1997-98** | **1998-99** | **1999-2000** | **2000-01** | **2001-02** | **2002-03** | **2003-04** | **2004-05** | **2005-06** | **2006-07** | **average** |
| Argentina | -0.107 | 0.128 | 0.334 | -0.116 | 0.012 | 0.004 | 0.114 | 0.065 | -0.013 | 0.151 | -0.198 | 0.299 | 0.0561 |
| Brazil | 0.037 | -0.027 | 0.066 | -0.013 | -0.005 | 0.240 | -0.101 | 0.219 | -0.097 | -0.097 | 0.113 | 0.119 | 0.0377 |
| France | 0.086 | 0.081 | -0.067 | 0.059 | 0.014 | -0.057 | 0.048 | -0.207 | 0.263 | -0.082 | 0.040 | 0.105 | 0.0237 |
| USA | 0.120 | -0.003 | 0.061 | -0.005 | 0.023 | 0.010 | -0.064 | 0.100 | 0.128 | -0.077 | 0.008 | 0.011 | 0.0258 |
| World | 0.109 | -0.016 | 0.070 | -0.002 | -0.023 | 0.035 | -0.016 | 0.012 | 0.109 | -0.021 | -0.014 | 0.051 | 0.0244 |

Source: FAO Stat

# APPENDIX B BASELINE RESULTS

**Table B1. Regional production by commodity under alternative climate scenarios – baselines**

| Million tonnes | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Wheat | EU | 168 | 168 | 169 | 169 | 197 | 198 | 209 | 202 | 235 | 241 | 253 | 241 | 273 | 302 | 286 | 280 | 257 | 296 | 206 | 259 |
| | China | 104 | 99 | 102 | 103 | 119 | 109 | 114 | 118 | 124 | 114 | 120 | 122 | 125 | 123 | 127 | 130 | 99 | 113 | 109 | 116 |
| | North America | 107 | 108 | 106 | 108 | 135 | 130 | 134 | 133 | 155 | 149 | 152 | 150 | 193 | 187 | 192 | 182 | 253 | 241 | 211 | 222 |
| | India | 84 | 82 | 81 | 84 | 101 | 96 | 93 | 100 | 118 | 108 | 106 | 110 | 152 | 135 | 145 | 138 | 158 | 144 | 173 | 146 |
| | Russia | 36 | 35 | 38 | 35 | 32 | 32 | 35 | 31 | 29 | 29 | 34 | 29 | 26 | 26 | 31 | 26 | 20 | 22 | 24 | 22 |
| Rice | S &E Asia | 249 | 245 | 244 | 248 | 281 | 274 | 272 | 280 | 309 | 298 | 294 | 302 | 366 | 344 | 340 | 351 | 412 | 373 | 385 | 383 |
| | China | 208 | 207 | 207 | 208 | 234 | 231 | 233 | 234 | 249 | 243 | 248 | 246 | 253 | 252 | 257 | 252 | 231 | 240 | 238 | 235 |
| | India | 146 | 144 | 143 | 145 | 174 | 170 | 166 | 172 | 201 | 191 | 187 | 192 | 248 | 234 | 245 | 234 | 256 | 245 | 259 | 241 |
| | N&W Africa | 17 | 17 | 17 | 16 | 22 | 22 | 23 | 20 | 26 | 26 | 28 | 25 | 32 | 31 | 34 | 30 | 31 | 31 | 41 | 34 |
| | Brazil | 15 | 15 | 15 | 15 | 17 | 17 | 17 | 16 | 20 | 19 | 19 | 18 | 23 | 22 | 22 | 21 | 23 | 22 | 23 | 21 |
| Maize | North America | 372 | 370 | 374 | 372 | 431 | 425 | 438 | 431 | 481 | 477 | 489 | 479 | 536 | 549 | 545 | 538 | 553 | 571 | 535 | 552 |
| | China | 150 | 151 | 150 | 151 | 172 | 171 | 176 | 173 | 189 | 183 | 195 | 189 | 194 | 194 | 208 | 196 | 181 | 189 | 192 | 180 |
| | EU | 77 | 77 | 77 | 77 | 84 | 83 | 85 | 84 | 89 | 89 | 91 | 89 | 91 | 94 | 92 | 91 | 84 | 87 | 80 | 83 |
| | Brazil | 47 | 47 | 46 | 46 | 58 | 56 | 57 | 52 | 68 | 63 | 66 | 58 | 85 | 73 | 82 | 69 | 111 | 89 | 118 | 85 |
| | S&E Asia | 37 | 36 | 36 | 37 | 42 | 40 | 40 | 42 | 46 | 44 | 43 | 46 | 54 | 51 | 50 | 53 | 61 | 54 | 56 | 57 |
| Other crops | EU | 108 | 109 | 109 | 109 | 117 | 119 | 121 | 121 | 126 | 130 | 133 | 131 | 124 | 136 | 129 | 133 | 106 | 117 | 99 | 112 |
| | North America | 52 | 52 | 52 | 52 | 63 | 61 | 65 | 64 | 74 | 73 | 75 | 73 | 97 | 97 | 97 | 92 | 128 | 125 | 103 | 108 |
| | N&W Africa | 34 | 34 | 34 | 33 | 40 | 40 | 41 | 37 | 45 | 44 | 46 | 42 | 54 | 50 | 54 | 50 | 61 | 55 | 66 | 58 |
| | Russia | 23 | 23 | 25 | 23 | 21 | 21 | 22 | 20 | 19 | 20 | 22 | 20 | 17 | 18 | 20 | 18 | 13 | 15 | 15 | 15 |
| | FSU | 25 | 25 | 24 | 25 | 28 | 28 | 26 | 28 | 30 | 29 | 27 | 29 | 30 | 30 | 26 | 31 | 29 | 28 | 26 | 29 |
| | China | 11 | 11 | 11 | 11 | 12 | 12 | 12 | 12 | 13 | 12 | 13 | 13 | 13 | 13 | 13 | 13 | 10 | 12 | 11 | 11 |

**Table B1 continued. Regional production by commodity under alternative climate scenarios - baselines**

| Million tonnes | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Meat | China | 115 | 109 | 112 | 114 | 145 | 130 | 138 | 142 | 157 | 142 | 150 | 150 | 170 | 159 | 167 | 164 | 161 | 157 | 160 | 158 |
| | North America | 66 | 65 | 66 | 66 | 81 | 77 | 82 | 80 | 94 | 90 | 94 | 91 | 112 | 111 | 113 | 109 | 123 | 124 | 115 | 118 |
| | EU | 56 | 55 | 56 | 55 | 63 | 61 | 64 | 62 | 69 | 68 | 70 | 68 | 73 | 74 | 73 | 71 | 68 | 70 | 63 | 67 |
| | Brazil | 25 | 25 | 25 | 24 | 31 | 29 | 30 | 27 | 37 | 33 | 34 | 29 | 48 | 38 | 45 | 36 | 71 | 49 | 83 | 46 |
| | S&E Asia | 25 | 24 | 23 | 25 | 32 | 28 | 28 | 31 | 37 | 33 | 33 | 36 | 49 | 42 | 43 | 46 | 58 | 49 | 53 | 52 |
| Milk | EU | 168 | 166 | 169 | 167 | 190 | 184 | 194 | 188 | 208 | 204 | 212 | 204 | 219 | 223 | 220 | 215 | 204 | 212 | 191 | 201 |
| | North America | 109 | 108 | 109 | 109 | 133 | 127 | 134 | 132 | 155 | 148 | 155 | 150 | 185 | 183 | 186 | 179 | 204 | 204 | 189 | 194 |
| | India | 114 | 109 | 108 | 112 | 157 | 142 | 139 | 150 | 194 | 173 | 172 | 176 | 261 | 235 | 245 | 232 | 298 | 264 | 279 | 254 |
| | S&E Asia | 46 | 44 | 44 | 46 | 59 | 53 | 53 | 58 | 70 | 61 | 62 | 67 | 91 | 79 | 81 | 85 | 109 | 91 | 98 | 97 |
| | ROW | 43 | 42 | 41 | 39 | 54 | 53 | 51 | 44 | 66 | 60 | 60 | 53 | 83 | 74 | 75 | 69 | 94 | 81 | 94 | 85 |
| | China | 33 | 31 | 32 | 33 | 42 | 37 | 40 | 41 | 45 | 41 | 43 | 43 | 49 | 46 | 48 | 47 | 46 | 45 | 46 | 45 |

**Table B2 Major exporters by commodity under alternative scenarios – baselines**

| Million tonnes | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Wheat | North America | 60 | 61 | 60 | 61 | 77 | 74 | 77 | 77 | 90 | 86 | 87 | 86 | 114 | 110 | 113 | 106 | 155 | 146 | 126 | 133 |
| | EU | 35 | 36 | 36 | 36 | 51 | 52 | 58 | 55 | 74 | 80 | 86 | 80 | 103 | 124 | 113 | 109 | 100 | 128 | 64 | 102 |
| | Australia | 22 | 22 | 22 | 22 | 26 | 26 | 27 | 27 | 28 | 28 | 27 | 27 | 34 | 35 | 31 | 31 | 45 | 39 | 38 | 37 |
| | Argentina | 10 | 10 | 10 | 9 | 11 | 10 | 10 | 9 | 12 | 11 | 11 | 9 | 16 | 12 | 14 | 10 | 22 | 14 | 28 | 18 |
| | FSU | 8 | 8 | 7 | 8 | 12 | 12 | 8 | 11 | 13 | 13 | 9 | 13 | 15 | 13 | 9 | 16 | 14 | 11 | 9 | 15 |
| | China | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rice | Sth & east Asia | 16 | 15 | 15 | 16 | 16 | 14 | 13 | 15 | 15 | 13 | 12 | 14 | 19 | 14 | 13 | 16 | 28 | 16 | 18 | 20 |
| | India | 5.8 | 6 | 6 | 6 | 7 | 8 | 7 | 7 | 8 | 9 | 7 | 9 | 6 | 9 | 10 | 9 | 2 | 5 | 7 | 7 |
| | North America | 5 | 5 | 5 | 5 | 8 | 8 | 9 | 8 | 11 | 11 | 13 | 11 | 16 | 18 | 20 | 16 | 21 | 26 | 20 | 20 |
| | EU | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 6 | 6 | 5 | 6 | 7 | 4 | 5 |
| | Sth & Cent. America & Car. | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 4 | 3 | 4 | 2 | 7 | 5 | 11 | 5 |
| | China | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 |
| Maize | North America | 59 | 59 | 59 | 59 | 71 | 71 | 73 | 72 | 82 | 82 | 83 | 82 | 99 | 102 | 100 | 97 | 116 | 120 | 100 | 107 |
| | Argentina | 12 | 12 | 12 | 11 | 14 | 13 | 14 | 11 | 16 | 14 | 16 | 13 | 24 | 18 | 22 | 17 | 36 | 26 | 36 | 26 |
| | EU | 11 | 11 | 11 | 11 | 13 | 13 | 13 | 13 | 14 | 15 | 15 | 15 | 16 | 17 | 16 | 16 | 15 | 16 | 13 | 15 |
| | Brazil | 6 | 6 | 6 | 6 | 8 | 8 | 8 | 7 | 10 | 9 | 10 | 8 | 14 | 11 | 14 | 10 | 22 | 16 | 23 | 15 |
| | China | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 2 |

**Table B2 continued. Major exporters by commodity under alternative scenarios – baselines**

| Million tonnes | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Other crops | EU | 18 | 18 | 18 | 18 | 21 | 22 | 23 | 23 | 24 | 27 | 28 | 28 | 25 | 31 | 27 | 30 | 19 | 24 | 16 | 22 |
| | North America | 12 | 12 | 12 | 12 | 17 | 16 | 18 | 18 | 24 | 23 | 24 | 23 | 39 | 38 | 39 | 34 | 64 | 61 | 43 | 46 |
| | Australia | 10 | 10 | 10 | 10 | 13 | 14 | 16 | 14 | 16 | 18 | 19 | 17 | 21 | 24 | 21 | 20 | 27 | 28 | 24 | 23 |
| | FSU | 6 | 6 | 5 | 6 | 7 | 8 | 6 | 7 | 8 | 8 | 6 | 8 | 8 | 8 | 5 | 9 | 6 | 7 | 4 | 7 |
| | Russia | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | China | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Meat | EU | 18 | 18 | 18 | 18 | 24 | 24 | 25 | 24 | 29 | 30 | 32 | 30 | 35 | 37 | 37 | 35 | 36 | 38 | 31 | 34 |
| | North America | 8 | 8 | 8 | 8 | 13 | 12 | 14 | 13 | 19 | 17 | 19 | 18 | 30 | 28 | 31 | 25 | 54 | 45 | 39 | 36 |
| | Brazil | 5 | 5 | 5 | 4 | 6 | 5 | 5 | 4 | 6 | 5 | 5 | 4 | 9 | 6 | 7 | 5 | 15 | 10 | 15 | 9 |
| | Australia | 2 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 8 | 8 | 8 | 7 | 13 | 12 | 11 | 10 |
| | China | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Milk | EU | 5.9 | 5.9 | 5.9 | 5.9 | 7.6 | 7.6 | 8.1 | 7.7 | 9.5 | 9.7 | 10.4 | 9.6 | 11.2 | 12.0 | 11.9 | 11.2 | 11.6 | 12.2 | 9.8 | 11.0 |
| | FSU | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 |
| | Sth & Cent. America & Car. | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 | 0.2 | 0.1 | 0.4 | 0.3 | 0.5 | 0.3 |
| | ROW | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.3 |
| | Australia | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.4 | 0.4 | 0.4 | 0.3 |
| | China | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

### Table B3 Major importers by commodity under alternative scenarios – baselines

| Million tonnes | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Wheat | EU | 25 | 25 | 25 | 25 | 27 | 26 | 27 | 27 | 29 | 28 | 29 | 28 | 30 | 29 | 29 | 29 | 28 | 28 | 28 | 27 |
| | Nth & west Africa | 21 | 21 | 21 | 21 | 29 | 28 | 29 | 30 | 40 | 39 | 39 | 39 | 66 | 67 | 63 | 63 | 89 | 90 | 68 | 80 |
| | S&E Asia | 20 | 20 | 20 | 20 | 27 | 26 | 27 | 26 | 33 | 31 | 32 | 31 | 41 | 41 | 42 | 39 | 43 | 47 | 46 | 44 |
| | Middle East | 13 | 13 | 13 | 13 | 22 | 20 | 20 | 21 | 32 | 29 | 29 | 28 | 53 | 47 | 50 | 44 | 75 | 65 | 74 | 63 |
| | China | 13 | 14 | 13 | 13 | 19 | 20 | 21 | 19 | 24 | 25 | 26 | 23 | 28 | 27 | 29 | 24 | 40 | 31 | 35 | 27 |
| Rice | Nth & west Africa | 5 | 5 | 5 | 5 | 7 | 6 | 6 | 6 | 8 | 7 | 7 | 8 | 12 | 11 | 11 | 11 | 18 | 16 | 14 | 15 |
| | Sth & east Asia | 6 | 6 | 7 | 6 | 9 | 10 | 10 | 9 | 12 | 13 | 14 | 13 | 16 | 19 | 21 | 17 | 17 | 22 | 20 | 18 |
| | Middle East | 6 | 6 | 6 | 6 | 8 | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 13 | 12 | 13 | 12 | 17 | 15 | 17 | 15 |
| | EU | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Sth & Cent. America & Car. | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 4 | 3 | 3 | 2 | 3 |
| | China | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Maize | Japan | 18 | 18 | 18 | 18 | 20 | 20 | 20 | 20 | 21 | 21 | 21 | 21 | 20 | 20 | 20 | 20 | 18 | 18 | 18 | 18 |
| | EU | 14 | 14 | 14 | 14 | 15 | 15 | 15 | 15 | 16 | 15 | 16 | 15 | 16 | 16 | 16 | 16 | 15 | 15 | 15 | 15 |
| | Sth & Cent. America & Car. | 10 | 10 | 10 | 10 | 12 | 12 | 12 | 13 | 14 | 14 | 14 | 15 | 16 | 17 | 15 | 17 | 17 | 18 | 15 | 16 |
| | South Korea | 10 | 10 | 10 | 10 | 12 | 11 | 11 | 12 | 13 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 11 | 11 | 11 | 11 |
| | North America | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 | 11 | 11 | 12 | 11 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| | China | 7 | 7 | 7 | 7 | 9 | 10 | 10 | 9 | 11 | 11 | 12 | 11 | 11 | 12 | 12 | 11 | 12 | 12 | 12 | 11 |

**Table B3 continued. Major importers by commodity under alternative scenarios - baselines**

| Million tonnes | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Other crops | EU | 12 | 12 | 12 | 12 | 13 | 12 | 13 | 12 | 13 | 12 | 13 | 12 | 13 | 12 | 13 | 12 | 14 | 13 | 14 | 13 |
| | Middle East | 9 | 9 | 9 | 9 | 15 | 14 | 14 | 14 | 23 | 21 | 21 | 19 | 41 | 37 | 39 | 33 | 68 | 58 | 62 | 53 |
| | North America | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 7 |
| | Japan | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 4 | 4 | 4 | 4 |
| | Nth & west Africa | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 6 | 5 | 6 | 5 | 11 | 11 | 10 | 10 | 18 | 19 | 12 | 15 |
| | China | 4 | 4 | 4 | 4 | 6 | 7 | 7 | 6 | 9 | 9 | 10 | 8 | 12 | 10 | 13 | 10 | 20 | 13 | 17 | 12 |
| Meat | EU | 13 | 13 | 13 | 13 | 14 | 13 | 14 | 13 | 15 | 14 | 15 | 14 | 16 | 15 | 15 | 15 | 15 | 15 | 15 | 14 |
| | North America | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Russia | 5 | 5 | 4 | 5 | 9 | 8 | 7 | 8 | 11 | 10 | 7 | 10 | 12 | 12 | 8 | 11 | 11 | 10 | 8 | 10 |
| | Japan | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | China | 4 | 4 | 4 | 4 | 6 | 6 | 7 | 6 | 9 | 9 | 10 | 9 | 12 | 11 | 13 | 10 | 20 | 14 | 15 | 12 |
| Milk | EU | 6.2 | 6.1 | 6.2 | 6.1 | 6.8 | 6.5 | 6.8 | 6.5 | 7.2 | 6.8 | 7.1 | 6.8 | 7.6 | 7.4 | 7.4 | 7.2 | 7.4 | 7.3 | 7.1 | 7.0 |
| | ROW | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| | S&E Asia | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.3 | 0.2 | 0.4 | 0.4 | 0.4 | 0.3 | 0.6 | 0.7 | 0.7 | 0.5 | 0.6 | 0.9 | 0.7 | 0.7 |
| | North America | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | China | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.4 | 0.3 | 0.6 | 0.4 | 0.4 | 0.4 |

## Table B4 Regional Real Private Consumption under alternative scenarios - baseline

| US$ billion | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Argentina | 117 | 115 | 117 | 108 | 163 | 152 | 165 | 133 | 218 | 186 | 218 | 167 | 367 | 269 | 344 | 244 | 697 | 414 | 624 | 392 |
| Australia | 453 | 449 | 453 | 451 | 608 | 579 | 616 | 592 | 758 | 709 | 751 | 709 | 1147 | 1060 | 1042 | 968 | 1837 | 1468 | 1364 | 1202 |
| Brazil | 440 | 429 | 438 | 401 | 630 | 579 | 633 | 495 | 829 | 695 | 824 | 614 | 1383 | 989 | 1302 | 885 | 2613 | 1507 | 2379 | 1312 |
| Sth & Cent. America & Car. | 206 | 205 | 205 | 194 | 268 | 259 | 268 | 229 | 345 | 311 | 343 | 285 | 557 | 448 | 530 | 421 | 950 | 667 | 883 | 619 |
| China | 1413 | 1284 | 1341 | 1387 | 2511 | 1919 | 2216 | 2354 | 3595 | 2541 | 3123 | 3115 | 6850 | 4201 | 5622 | 5047 | 13054 | 6565 | 8981 | 7723 |
| East Africa | 85 | 85 | 85 | 82 | 101 | 99 | 102 | 90 | 122 | 112 | 123 | 106 | 172 | 144 | 169 | 141 | 257 | 194 | 252 | 191 |
| EU | 8635 | 8413 | 8660 | 8496 | 10436 | 9551 | 10646 | 9886 | 12492 | 11245 | 12213 | 11125 | 17526 | 15513 | 15291 | 13575 | 22372 | 20784 | 16141 | 16278 |
| FSU | 133 | 129 | 120 | 128 | 192 | 175 | 151 | 173 | 238 | 200 | 171 | 216 | 356 | 264 | 208 | 321 | 483 | 272 | 278 | 539 |
| India | 584 | 550 | 540 | 567 | 955 | 799 | 782 | 874 | 1459 | 1108 | 1136 | 1176 | 3382 | 2157 | 2380 | 2097 | 9173 | 3920 | 4796 | 3325 |
| Japan | 3049 | 2971 | 3064 | 3014 | 3824 | 3496 | 3921 | 3662 | 4654 | 4227 | 4485 | 4120 | 6659 | 6059 | 5542 | 4989 | 9122 | 7394 | 6467 | 5728 |
| Middle East | 546 | 537 | 545 | 503 | 837 | 783 | 844 | 671 | 1133 | 964 | 1124 | 861 | 1998 | 1450 | 1874 | 1341 | 3952 | 2303 | 3552 | 2432 |
| North America | 10679 | 10489 | 10686 | 10630 | 13696 | 12794 | 13890 | 13358 | 17494 | 15852 | 17166 | 16054 | 28303 | 24701 | 25102 | 22551 | 49788 | 43698 | 34296 | 32906 |
| Nth & west Africa | 282 | 279 | 281 | 266 | 381 | 362 | 382 | 324 | 493 | 434 | 488 | 403 | 808 | 626 | 761 | 601 | 1457 | 951 | 1337 | 967 |
| Sth & Cent. America & Car. | 590 | 575 | 589 | 538 | 852 | 780 | 859 | 664 | 1154 | 952 | 1149 | 840 | 2061 | 1416 | 1934 | 1272 | 4185 | 2314 | 3786 | 2107 |
| ROW | 856 | 839 | 822 | 773 | 1212 | 1127 | 1110 | 925 | 1636 | 1369 | 1388 | 1160 | 2905 | 2026 | 2042 | 1728 | 5664 | 3140 | 3552 | 2781 |
| Russia | 376 | 365 | 341 | 345 | 545 | 495 | 440 | 438 | 677 | 578 | 507 | 534 | 1006 | 777 | 644 | 750 | 1381 | 827 | 869 | 1114 |
| S&E Asia | 810 | 768 | 765 | 807 | 1212 | 1035 | 1059 | 1185 | 1698 | 1345 | 1435 | 1548 | 3253 | 2255 | 2515 | 2555 | 7132 | 3610 | 4399 | 3986 |
| South Korea | 440 | 422 | 420 | 435 | 634 | 558 | 572 | 605 | 813 | 685 | 719 | 729 | 1247 | 978 | 1016 | 976 | 1821 | 1176 | 1320 | 1167 |

**Table B5 Real prices**

| % change relative to 2004 | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Wheat | Brazil | 0 | 2 | 0 | 5 | 0 | 7 | 4 | 12 | 4 | 15 | 14 | 18 | -1 | 12 | 5 | 14 | -11 | -2 | -19 | -6 |
| | East Africa | 5 | 6 | 6 | 6 | 13 | 15 | 16 | 15 | 20 | 23 | 27 | 25 | 20 | 25 | 25 | 28 | 18 | 16 | 19 | 20 |
| | EU | 1 | 3 | 1 | 2 | 1 | 5 | 3 | 4 | 1 | 5 | 8 | 7 | -1 | 1 | 3 | 3 | 4 | 1 | 3 | -1 |
| | North America | 7 | 10 | 8 | 9 | 14 | 22 | 20 | 19 | 23 | 32 | 36 | 34 | 21 | 30 | 29 | 30 | 22 | 24 | 15 | 17 |
| | China | 13 | 17 | 14 | 15 | 26 | 35 | 33 | 29 | 40 | 46 | 52 | 49 | 43 | 43 | 48 | 43 | 72 | 45 | 50 | 41 |
| Rice | Brazil | 0 | 2 | 1 | 4 | -1 | 4 | 2 | 9 | -1 | 7 | 5 | 11 | -9 | 3 | -6 | 4 | -22 | -12 | -29 | -15 |
| | East Africa | 3 | 4 | 4 | 4 | 8 | 8 | 9 | 8 | 12 | 11 | 14 | 11 | 15 | 14 | 16 | 14 | 17 | 15 | 20 | 17 |
| | EU | -1 | 0 | -1 | 0 | -2 | 0 | -2 | -2 | -3 | -2 | -2 | -2 | -6 | -5 | -5 | -5 | -5 | -6 | -3 | -7 |
| | North America | 3 | 4 | 3 | 3 | 5 | 9 | 7 | 7 | 9 | 13 | 14 | 13 | 9 | 13 | 11 | 11 | 8 | 11 | 4 | 5 |
| | China | 7 | 8 | 7 | 7 | 15 | 17 | 18 | 15 | 23 | 23 | 28 | 25 | 29 | 27 | 32 | 27 | 47 | 29 | 35 | 26 |
| Maize | Brazil | 0 | 3 | 1 | 6 | 0 | 8 | 4 | 15 | 3 | 17 | 14 | 23 | -4 | 14 | 1 | 14 | -15 | -6 | -24 | -11 |
| | East Africa | 5 | 6 | 5 | 6 | 17 | 18 | 19 | 18 | 37 | 36 | 43 | 35 | 104 | 88 | 102 | 80 | 190 | 169 | 140 | 141 |
| | EU | 1 | 4 | 2 | 3 | 2 | 7 | 3 | 5 | 2 | 6 | 9 | 9 | 0 | 2 | 3 | 3 | 5 | 2 | 4 | -1 |
| | North America | 8 | 10 | 9 | 9 | 17 | 26 | 23 | 23 | 26 | 37 | 42 | 40 | 22 | 34 | 31 | 33 | 19 | 22 | 15 | 15 |
| | China | 19 | 27 | 22 | 22 | 40 | 61 | 57 | 47 | 64 | 84 | 93 | 82 | 67 | 78 | 83 | 71 | 100 | 70 | 80 | 63 |
| Other crops | Brazil | 1 | 4 | 2 | 6 | 2 | 10 | 7 | 17 | 5 | 21 | 19 | 26 | -2 | 17 | 5 | 17 | -14 | -5 | -23 | -9 |
| | East Africa | 6 | 7 | 7 | 7 | 18 | 20 | 22 | 20 | 35 | 35 | 43 | 36 | 79 | 70 | 81 | 66 | 130 | 112 | 107 | 104 |
| | EU | 2 | 4 | 3 | 3 | 4 | 8 | 6 | 7 | 6 | 9 | 13 | 11 | 9 | 9 | 10 | 9 | 19 | 15 | 12 | 8 |
| | North America | 5 | 10 | 7 | 8 | 9 | 20 | 15 | 15 | 12 | 24 | 28 | 26 | 0 | 11 | 9 | 12 | -9 | -6 | -7 | -8 |
| | China | 23 | 30 | 25 | 26 | 49 | 64 | 62 | 54 | 73 | 85 | 97 | 88 | 84 | 82 | 93 | 82 | 134 | 85 | 102 | 83 |
| Livestock | Brazil | 1 | 4 | 2 | 6 | 3 | 11 | 8 | 17 | 7 | 21 | 20 | 26 | -1 | 18 | 7 | 19 | -13 | -4 | -21 | -8 |
| | East Africa | 5 | 5 | 5 | 5 | 15 | 15 | 17 | 16 | 31 | 29 | 37 | 31 | 73 | 62 | 75 | 62 | 155 | 116 | 120 | 109 |
| | EU | 1 | 3 | 2 | 2 | 2 | 6 | 4 | 4 | 3 | 6 | 9 | 8 | 4 | 4 | 6 | 4 | 11 | 7 | 8 | 3 |
| | North America | 2 | 5 | 3 | 3 | 1 | 9 | 4 | 4 | 0 | 9 | 10 | 10 | -12 | -5 | -7 | -3 | -23 | -20 | -19 | -20 |
| | China | 22 | 26 | 23 | 23 | 46 | 57 | 58 | 50 | 67 | 78 | 90 | 82 | 70 | 74 | 83 | 71 | 107 | 73 | 83 | 67 |

## Table B6 Price-Income ratio

| % change relative to 2004 | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| | Brazil | -22 | -18 | -21 | -10 | -45 | -36 | -44 | -22 | -57 | -43 | -53 | -34 | -75 | -61 | -72 | -56 | -88 | -78 | -88 | -75 |
| | East Africa | -3 | -3 | -3 | 1 | -13 | -10 | -11 | -1 | -23 | -14 | -19 | -9 | -46 | -32 | -42 | -30 | -64 | -53 | -63 | -51 |
| Wheat | EU | -10 | -6 | -10 | -8 | -26 | -15 | -26 | -19 | -38 | -28 | -32 | -26 | -56 | -50 | -48 | -42 | -64 | -63 | -51 | -53 |
| | North America | -7 | -3 | -6 | -5 | -23 | -11 | -20 | -17 | -35 | -23 | -27 | -23 | -60 | -51 | -53 | -47 | -77 | -74 | -69 | -67 |
| | China | -23 | -12 | -18 | -21 | -52 | -32 | -42 | -47 | -63 | -45 | -53 | -54 | -80 | -67 | -75 | -73 | -87 | -79 | -84 | -82 |
| | Brazil | -22 | -18 | -21 | -11 | -46 | -38 | -45 | -24 | -59 | -47 | -56 | -38 | -77 | -64 | -75 | -60 | -90 | -80 | -90 | -78 |
| | East Africa | -5 | -5 | -5 | -1 | -17 | -15 | -16 | -7 | -28 | -22 | -28 | -19 | -48 | -38 | -46 | -37 | -64 | -54 | -63 | -52 |
| Rice | EU | -12 | -8 | -12 | -10 | -28 | -20 | -29 | -23 | -41 | -33 | -38 | -32 | -59 | -53 | -52 | -46 | -67 | -65 | -54 | -56 |
| | North America | -11 | -8 | -11 | -10 | -29 | -21 | -29 | -26 | -42 | -34 | -39 | -35 | -64 | -57 | -59 | -54 | -80 | -77 | -72 | -71 |
| | China | -28 | -19 | -23 | -26 | -56 | -42 | -49 | -53 | -67 | -54 | -61 | -61 | -82 | -71 | -77 | -76 | -89 | -81 | -86 | -84 |
| | Brazil | -21 | -17 | -21 | -9 | -45 | -36 | -43 | -20 | -57 | -42 | -52 | -31 | -76 | -60 | -73 | -56 | -89 | -79 | -89 | -77 |
| | East Africa | -3 | -3 | -3 | 1 | -10 | -7 | -9 | 1 | -12 | -5 | -9 | -1 | -8 | 2 | -7 | -1 | -12 | 8 | -26 | -2 |
| Maize | EU | -10 | -5 | -10 | -7 | -25 | -14 | -25 | -18 | -37 | -28 | -31 | -25 | -56 | -50 | -48 | -42 | -64 | -62 | -51 | -53 |
| | North America | -7 | -3 | -6 | -5 | -21 | -9 | -18 | -15 | -33 | -20 | -23 | -19 | -60 | -50 | -52 | -45 | -78 | -74 | -69 | -68 |
| | China | -19 | -5 | -13 | -15 | -46 | -20 | -32 | -40 | -56 | -30 | -41 | -44 | -77 | -59 | -69 | -67 | -85 | -75 | -81 | -80 |
| | Brazil | -21 | -17 | -20 | -9 | -44 | -35 | -42 | -18 | -56 | -40 | -50 | -29 | -76 | -59 | -72 | -55 | -89 | -78 | -89 | -76 |
| | East Africa | -3 | -2 | -2 | 2 | -9 | -6 | -7 | 3 | -13 | -6 | -9 | -1 | -19 | -8 | -17 | -9 | -30 | -15 | -36 | -17 |
| Other crops | EU | -9 | -5 | -9 | -7 | -23 | -13 | -23 | -17 | -35 | -26 | -29 | -23 | -52 | -46 | -45 | -39 | -59 | -58 | -47 | -49 |
| | North America | -9 | -3 | -7 | -6 | -26 | -13 | -23 | -21 | -41 | -27 | -31 | -27 | -67 | -58 | -60 | -54 | -83 | -80 | -75 | -74 |
| | China | -16 | -3 | -10 | -13 | -43 | -18 | -30 | -37 | -54 | -30 | -39 | -42 | -74 | -58 | -67 | -65 | -83 | -73 | -78 | -77 |
| | Brazil | -21 | -17 | -19 | -9 | -44 | -34 | -41 | -18 | -56 | -40 | -50 | -29 | -75 | -59 | -72 | -54 | -89 | -78 | -89 | -76 |
| | East Africa | -4 | -4 | -3 | 0 | -11 | -9 | -10 | -1 | -16 | -10 | -13 | -4 | -22 | -12 | -19 | -11 | -23 | -13 | -32 | -15 |
| Livestock | EU | -10 | -6 | -10 | -7 | -25 | -15 | -25 | -19 | -36 | -28 | -31 | -26 | -55 | -48 | -47 | -41 | -62 | -60 | -49 | -52 |
| | North America | -12 | -7 | -11 | -10 | -32 | -21 | -31 | -28 | -47 | -36 | -41 | -37 | -71 | -64 | -66 | -60 | -86 | -83 | -78 | -77 |
| | China | -17 | -5 | -12 | -14 | -44 | -21 | -32 | -39 | -55 | -33 | -41 | -44 | -76 | -60 | -69 | -67 | -85 | -75 | -80 | -79 |

# APPENDIX C TRADE LIBERALISATION RESULTS

**Table C1 Regional production by commodity**

| Change relative to ref case Million tonnes | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Wheat | EU | 3.0 | 4.1 | 7.0 | 5.3 | 19.4 | 18.8 | 21.8 | 17.4 | 28.9 | 26.9 | 31.0 | 21.7 | 33.6 | 33.5 | 21.9 | 23.4 |
| | China | 1.0 | 0.8 | 1.0 | 1.0 | 1.7 | 1.6 | 1.9 | 1.7 | 1.4 | 1.3 | 1.8 | 1.4 | 0.5 | 0.6 | 1.7 | 0.6 |
| | North America | 6.2 | 5.3 | 5.1 | 5.2 | 1.2 | 0.8 | 0.7 | 0.6 | -4.4 | -5.9 | -5.1 | -5.3 | -9.3 | -13.3 | -0.5 | -11.1 |
| | India | -1.4 | -0.9 | -0.4 | -1.4 | -3.0 | -1.3 | -0.3 | -1.7 | -6.3 | -2.2 | -4.3 | -3.9 | -4.8 | -2.6 | -13.9 | -5.3 |
| | Russia | 0.2 | 0.3 | 0.3 | 0.3 | 0.5 | 0.7 | 0.9 | 0.9 | 0.1 | 0.4 | 0.4 | 0.7 | -0.4 | 0.0 | -0.4 | -0.2 |
| Rice | Sth & east Asia | 10.7 | 9.5 | 7.8 | 10.9 | 6.2 | 4.4 | 2.1 | 5.2 | 3.9 | 0.1 | -1.8 | 2.4 | 6.3 | -2.3 | -0.2 | 1.8 |
| | China | 5.2 | 3.7 | 1.7 | 5.7 | -60.7 | -58.9 | -62.8 | -56.4 | -70.7 | -66.1 | -73.1 | -63.7 | -82.6 | -68.2 | -84.2 | -67.8 |
| | India | 1.7 | 1.9 | 2.0 | 1.7 | 4.6 | 5.7 | 6.0 | 5.5 | 2.5 | 4.7 | 4.4 | 4.9 | -1.1 | 1.5 | 0.8 | 2.3 |
| | Nth & west Africa | 1.2 | 1.3 | 1.6 | 1.0 | 22.0 | 21.1 | 22.8 | 19.7 | 19.1 | 16.5 | 20.3 | 16.9 | 15.7 | 12.2 | 23.7 | 15.4 |
| | Brazil | -0.6 | -0.5 | -0.5 | -0.6 | -0.7 | -0.6 | -0.6 | -0.6 | -0.7 | -0.7 | -0.6 | -0.7 | -0.5 | -0.7 | -0.7 | -0.8 |
| Maize | North America | 4.8 | 4.4 | 4.6 | 5.2 | 8.1 | 7.7 | 6.8 | 7.8 | 8.4 | 8.3 | 7.9 | 8.5 | 6.8 | 8.3 | 3.9 | 8.1 |
| | China | 4.9 | 4.3 | 4.6 | 4.9 | 8.2 | 7.5 | 7.7 | 7.9 | 8.3 | 8.2 | 8.3 | 8.6 | 6.2 | 7.8 | 7.1 | 7.8 |
| | EU | -2.0 | -1.7 | -1.8 | -1.6 | -1.6 | -1.2 | -1.1 | -1.1 | -1.7 | -0.8 | -1.3 | -1.0 | -2.5 | -1.3 | -3.2 | -1.7 |
| | Brazil | 8.0 | 6.2 | 6.8 | 4.7 | 6.4 | 4.1 | 4.4 | 3.3 | 6.9 | 2.7 | 4.2 | 2.5 | 14.4 | 4.8 | 13.1 | 4.7 |
| | Sth & east Asia | 0.6 | 0.6 | 0.6 | 0.6 | 1.3 | 1.3 | 1.3 | 1.3 | 1.5 | 1.5 | 1.5 | 1.5 | 1.7 | 1.6 | 1.4 | 1.7 |
| Other crops | EU | -3.5 | -2.7 | -2.9 | -2.5 | -2.1 | -0.9 | -0.9 | -1.0 | -2.9 | -0.6 | -1.8 | -0.9 | -4.3 | -2.2 | -5.4 | -2.6 |
| | North America | -0.2 | -0.4 | -0.3 | -0.4 | 0.1 | -0.3 | -0.2 | -0.5 | 1.7 | 0.8 | 0.8 | 0.3 | 4.8 | 4.3 | 1.5 | 2.6 |
| | Nth & west Africa | 0.1 | 0.2 | 0.2 | 0.2 | -0.5 | -0.4 | -0.4 | -0.4 | -0.7 | -0.6 | -0.7 | -0.6 | -0.8 | -0.6 | -1.1 | -0.7 |
| | Russia | -0.4 | -0.4 | -0.4 | -0.3 | -0.7 | -0.6 | -0.7 | -0.6 | -0.9 | -0.7 | -0.8 | -0.8 | -1.0 | -0.8 | -1.0 | -1.1 |
| | FSU | -0.6 | -0.5 | -0.4 | -0.5 | -1.1 | -0.9 | -0.6 | -1.0 | -1.2 | -0.9 | -0.6 | -1.2 | -1.2 | -0.8 | -0.8 | -1.2 |
| | China | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 |

**Table C1 continued. Regional production by commodity**

| Change relative to ref case Million tonnes | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Meat | China | -0.8 | -0.8 | -0.8 | -0.8 | -1.2 | -1.0 | -1.1 | -1.1 | -1.8 | -1.5 | -1.7 | -1.5 | -2.4 | -2.0 | -1.7 | -2.0 |
| | North America | 2.5 | 1.9 | 2.3 | 2.5 | 3.4 | 2.9 | 2.9 | 3.2 | 4.5 | 4.5 | 4.5 | 4.6 | 4.2 | 5.2 | 2.6 | 4.5 |
| | EU | -2.5 | -1.9 | -2.0 | -1.7 | -2.5 | -1.7 | -1.6 | -1.5 | -3.4 | -2.0 | -2.9 | -2.1 | -5.3 | -3.3 | -6.0 | -3.7 |
| | Brazil | 17.6 | 13.5 | 15.0 | 10.4 | 19.6 | 13.1 | 14.6 | 10.0 | 28.4 | 14.6 | 22.4 | 13.0 | 58.0 | 28.7 | 59.8 | 27.7 |
| | S&E Asia | -0.1 | -0.1 | 0.0 | -0.1 | -0.1 | 0.0 | 0.0 | 0.0 | -0.1 | 0.1 | 0.1 | 0.0 | -0.3 | 0.0 | -0.1 | -0.1 |
| Milk | EU | -7.4 | -5.8 | -6.2 | -5.2 | -7.5 | -5.2 | -4.7 | -4.4 | -10.4 | -5.9 | -8.8 | -6.4 | -16.1 | -9.9 | -18.2 | -11.1 |
| | North America | 4.0 | 3.2 | 3.9 | 4.2 | 5.6 | 4.8 | 4.8 | 5.3 | 7.4 | 7.4 | 7.4 | 7.5 | 7.0 | 8.6 | 4.3 | 7.4 |
| | India | 7.0 | 7.6 | 6.0 | 8.3 | 8.2 | 9.2 | 6.5 | 10.2 | 6.2 | 8.3 | 7.3 | 10.8 | 1.6 | 4.7 | 3.4 | 7.7 |
| | S&E Asia | -0.2 | -0.1 | -0.1 | -0.1 | -0.1 | 0.0 | 0.1 | 0.0 | -0.2 | 0.1 | 0.2 | 0.0 | -0.6 | 0.1 | -0.2 | -0.2 |
| | ROW | 1.5 | 1.4 | 1.2 | 0.7 | 1.8 | 1.4 | 1.0 | 0.5 | 4.5 | 2.6 | 2.1 | 2.1 | 4.1 | 4.2 | 3.7 | 6.5 |
| | China | -0.8 | -0.8 | -0.8 | -0.8 | -1.2 | -1.0 | -1.1 | -1.1 | -1.8 | -1.5 | -1.7 | -1.5 | -2.4 | -2.0 | -1.7 | -2.0 |

**Table C.2 Exports by commodity**

| Change relative to ref case Million tonnes | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Wheat | North America | 3.6 | 3.0 | 2.8 | 2.9 | -0.4 | -0.6 | -0.8 | -0.8 | -4.6 | -5.7 | -5.1 | -5.1 | -8.4 | -11.2 | -1.9 | -9.4 |
| | EU | 8.9 | 9.1 | 11.0 | 9.9 | 21.3 | 19.8 | 21.9 | 18.8 | 29.2 | 26.1 | 29.9 | 22.7 | 34.7 | 32.4 | 26.0 | 25.4 |
| | Australia | -0.4 | -0.5 | -0.7 | -0.6 | -0.6 | -0.8 | -0.8 | -0.8 | -0.7 | -1.3 | -0.8 | -1.0 | -1.7 | -2.0 | 0.5 | -1.5 |
| | Argentina | 0.3 | 0.1 | 0.2 | 0.2 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 0.2 | 1.6 | -0.3 |
| | FSU | 5.8 | 5.8 | 3.9 | 5.2 | 12.0 | 11.3 | 8.4 | 12.3 | 13.9 | 12.4 | 8.7 | 17.0 | 13.1 | 11.5 | 8.8 | 19.0 |
| | China | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rice | S&E Asia | 9.7 | 8.9 | 8.1 | 9.8 | 11.3 | 10.2 | 9.2 | 10.7 | 12.2 | 9.9 | 9.3 | 11.1 | 15.3 | 10.4 | 11.3 | 12.1 |
| | India | 1.8 | 2.0 | 2.0 | 1.8 | 4.5 | 5.4 | 5.1 | 5.1 | 3.3 | 4.9 | 5.3 | 5.1 | 0.8 | 2.6 | 2.9 | 3.2 |
| | North America | 8.7 | 8.8 | 9.7 | 8.4 | 17.0 | 16.4 | 17.4 | 16.2 | 21.9 | 21.4 | 22.4 | 19.6 | 29.1 | 27.7 | 23.4 | 22.6 |
| | EU | -1.3 | -1.3 | -1.3 | -1.3 | -1.1 | -1.0 | -0.9 | -1.0 | -0.7 | -0.5 | -0.5 | -0.6 | -0.4 | -0.1 | -0.7 | -0.5 |
| | Sth & Cent. America & Car. | 0.9 | 0.9 | 1.0 | 0.6 | 2.4 | 1.9 | 2.3 | 1.5 | 4.5 | 3.0 | 4.8 | 2.6 | 8.0 | 5.1 | 12.3 | 5.5 |
| | China | 13.0 | 12.4 | 12.3 | 12.9 | 14.4 | 14.0 | 14.1 | 14.4 | 12.3 | 12.4 | 12.5 | 13.2 | 7.8 | 10.6 | 9.3 | 11.1 |
| Maize | North America | 0.4 | 0.7 | 0.4 | 0.5 | 1.5 | 1.8 | 1.4 | 1.5 | 0.7 | 0.5 | 0.4 | 0.5 | 0.3 | 0.0 | 0.1 | 0.5 |
| | Argentina | 0.7 | 0.6 | 0.7 | 0.6 | 0.3 | 0.3 | 0.4 | 0.5 | 0.0 | 0.0 | 0.1 | 0.3 | 0.7 | -0.3 | 0.6 | -0.4 |
| | EU | -0.2 | -0.1 | -0.1 | -0.1 | 0.2 | 0.3 | 0.3 | 0.2 | 0.4 | 0.6 | 0.6 | 0.5 | 0.4 | 0.6 | 0.1 | 0.4 |
| | Brazil | -1.4 | -1.1 | -1.2 | -1.0 | -2.7 | -2.0 | -2.3 | -1.6 | -4.6 | -3.1 | -4.3 | -2.7 | -7.8 | -5.7 | -8.1 | -5.4 |
| | China | 0.5 | 0.4 | 0.4 | 0.5 | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.5 | 0.6 | 0.4 | 0.6 | 0.4 | 0.5 |

**Table C2 continued. Exports by commodity**

| Change relative to ref case Million tonnes | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Other crops | EU | -0.5 | -0.1 | -0.2 | -0.2 | 0.8 | 1.3 | 1.5 | 1.2 | 0.9 | 1.8 | 1.5 | 1.6 | 0.6 | 1.2 | 0.1 | 1.0 | -0.5 | -0.1 | -0.2 | -0.2 |
| | North America | 0.0 | -0.1 | -0.1 | -0.1 | 0.3 | 0.1 | 0.2 | -0.1 | 1.6 | 0.9 | 0.9 | 0.5 | 4.3 | 3.7 | 1.6 | 2.3 | 0.0 | -0.1 | -0.1 | -0.1 |
| | Australia | -0.3 | -0.5 | -0.5 | -0.5 | 0.1 | -0.1 | -0.1 | -0.2 | 0.7 | 0.3 | 0.2 | 0.1 | 2.0 | 1.1 | 0.9 | 1.0 | -0.3 | -0.5 | -0.5 | -0.5 |
| | FSU | 0.4 | 0.4 | 0.5 | 0.4 | 0.6 | 0.8 | 1.0 | 0.8 | 0.6 | 1.0 | 1.1 | 0.7 | 0.6 | 1.1 | 0.8 | 0.6 | 0.4 | 0.4 | 0.5 | 0.4 |
| | Russia | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.2 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 |
| | China | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Meat | EU | 0.7 | 0.9 | 0.9 | 0.9 | 1.1 | 1.3 | 1.6 | 1.4 | 0.8 | 1.2 | 1.3 | 1.2 | 0.2 | 0.3 | 0.0 | 0.4 | 0.7 | 0.9 | 0.9 | 0.9 |
| | North America | 0.1 | 0.0 | 0.0 | 0.0 | -0.3 | -0.4 | -0.6 | -0.5 | -0.6 | -0.8 | -1.2 | -0.7 | -0.8 | -1.3 | -1.1 | -0.8 | 0.1 | 0.0 | 0.0 | 0.0 |
| | Brazil | -2.6 | -2.2 | -2.3 | -1.9 | -3.3 | -2.5 | -2.7 | -2.0 | -4.6 | -2.9 | -3.9 | -2.6 | -7.0 | -5.0 | -7.5 | -4.8 | -2.6 | -2.2 | -2.3 | -1.9 |
| | Australia | -0.2 | -0.2 | -0.2 | -0.2 | -0.3 | -0.3 | -0.4 | -0.3 | -0.4 | -0.5 | -0.5 | -0.4 | -0.4 | -0.7 | -0.6 | -0.5 | -0.2 | -0.2 | -0.2 | -0.2 |
| | China | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Milk | EU | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.4 | 0.4 | 0.4 | 0.1 | 0.1 | 0.0 | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 |
| | FSU | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sth & Cent. America & Car. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | ROW | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.3 | 0.3 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Australia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | China | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

## Table C3 Imports by commodity

| Change relative to ref case Mt | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Wheat | EU | 3.3 | 3.0 | 2.6 | 3.0 | 2.5 | 2.2 | 2.0 | 2.4 | 2.5 | 1.9 | 2.0 | 2.4 | 3.4 | 2.6 | 3.9 | 3.2 |
| | Nth & West Africa | 1.8 | 1.9 | 2.1 | 1.7 | 6.3 | 6.0 | 6.4 | 5.9 | 5.9 | 4.6 | 5.8 | 5.5 | 5.8 | 2.9 | 8.7 | 5.4 |
| | S&E Asia | 0.4 | 0.4 | 0.4 | 0.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 1.9 | 1.5 | 1.9 | 3.0 | 2.4 | 0.8 | 2.3 |
| | Middle East | -1.6 | -1.3 | -1.3 | -1.5 | -2.7 | -2.2 | -2.1 | -2.1 | -4.4 | -3.5 | -3.9 | -3.1 | -6.8 | -5.4 | -6.7 | -4.4 |
| | China | -0.6 | -0.6 | -0.7 | -0.6 | -1.0 | -1.0 | -1.2 | -1.0 | -1.1 | -1.0 | -1.3 | -0.9 | -1.1 | -0.8 | -1.4 | -0.7 |
| Rice | Nth & west Africa | 1.3 | 1.3 | 1.3 | 1.3 | 5.2 | 5.2 | 4.9 | 5.2 | 5.2 | 5.1 | 5.4 | 5.6 | 4.3 | 3.7 | 5.1 | 4.9 |
| | S&E Asia | 3.3 | 3.4 | 3.6 | 3.3 | 8.6 | 8.8 | 9.6 | 8.8 | 11.2 | 12.1 | 13.1 | 11.4 | 11.9 | 14.5 | 12.8 | 12.6 |
| | Middle East | 0.1 | 0.0 | 0.1 | 0.0 | 0.3 | 0.2 | 0.3 | 0.2 | 0.6 | 0.4 | 0.5 | 0.3 | 1.1 | 0.8 | 1.3 | 0.8 |
| | EU | 2.2 | 2.0 | 1.9 | 2.1 | 1.8 | 1.6 | 1.4 | 1.6 | 1.5 | 1.2 | 1.3 | 1.4 | 1.4 | 1.0 | 1.9 | 1.4 |
| | Sth & Cent. America & Car. | 0.6 | 0.5 | 0.5 | 0.6 | 1.1 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.0 | 1.2 | 0.8 | 1.2 |
| | China | 4.4 | 4.4 | 4.9 | 4.2 | 29.5 | 28.3 | 30.0 | 28.1 | 31.9 | 29.6 | 32.8 | 29.9 | 34.4 | 29.4 | 36.2 | 30.5 |
| Maize | Japan | 1.3 | 1.5 | 1.3 | 1.4 | 1.3 | 1.5 | 1.3 | 1.4 | 1.2 | 1.5 | 1.2 | 1.3 | 1.1 | 1.3 | 1.1 | 1.2 |
| | EU | 0.3 | 0.3 | 0.2 | 0.3 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.0 | 0.1 | 0.1 | 0.2 | 0.1 | 0.3 | 0.2 |
| | Sth & Cent. America & Car. | 0.5 | 0.4 | 0.4 | 0.4 | 1.0 | 0.9 | 0.9 | 0.8 | 1.3 | 1.1 | 1.2 | 1.0 | 1.3 | 1.5 | 1.3 | 1.4 |
| | South Korea | 2.4 | 2.8 | 2.6 | 2.5 | 3.0 | 3.3 | 3.2 | 3.2 | 2.8 | 3.1 | 2.9 | 3.0 | 2.5 | 2.7 | 2.6 | 2.5 |
| | North America | 1.0 | 0.9 | 1.0 | 1.0 | 1.2 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.4 | 1.4 | 1.3 | 1.4 | 1.2 | 1.3 |
| | China | -0.5 | -0.5 | -0.5 | -0.5 | -0.4 | -0.4 | -0.5 | -0.4 | -0.5 | -0.5 | -0.6 | -0.5 | -0.5 | -0.4 | -0.4 | -0.4 |

**Table C.3 continued. Imports by commodity**

| Change relative to ref case Mt | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Other crops | EU | 0.6 | 0.5 | 0.5 | 0.4 | 0.6 | 0.4 | 0.5 | 0.4 | 1.0 | 0.5 | 0.9 | 0.5 | 1.6 | 1.1 | 2.0 | 1.2 | 0.6 | 0.5 | 0.5 | 0.4 |
| | Middle East | -0.2 | -0.1 | -0.1 | -0.1 | -0.4 | -0.2 | -0.2 | -0.1 | -1.8 | -1.4 | -1.5 | -1.0 | -3.5 | -3.2 | -3.0 | -2.7 | -0.2 | -0.1 | -0.1 | -0.1 |
| | North America | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 |
| | Japan | 0.0 | -0.1 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 | -0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 | 0.0 | 0.0 |
| | N&W Africa | 0.4 | 0.4 | 0.4 | 0.4 | 1.4 | 1.4 | 1.5 | 1.4 | 1.8 | 1.9 | 1.9 | 1.9 | 1.6 | 1.5 | 2.0 | 1.8 | 0.4 | 0.4 | 0.4 | 0.4 |
| | China | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.2 | -0.2 | -0.1 | -0.3 | 0.0 | -0.4 | -0.3 | -0.5 | -0.2 | 0.0 | 0.0 | 0.0 | 0.1 |
| Meat | EU | -0.8 | -0.7 | -0.7 | -0.6 | -0.8 | -0.6 | -0.6 | -0.5 | -1.1 | -0.6 | -0.9 | -0.7 | -1.6 | -0.9 | -1.9 | -1.1 | -0.8 | -0.7 | -0.7 | -0.6 |
| | North America | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.3 | 0.4 | 0.3 | 0.2 | 0.3 | 0.3 |
| | Russia | 0.1 | 0.0 | 0.0 | 0.0 | -0.2 | -0.2 | -0.1 | -0.2 | 0.0 | -0.3 | -0.1 | -0.2 | 0.4 | -0.1 | 0.3 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 |
| | Japan | -0.1 | -0.1 | -0.1 | -0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.2 | 0.1 | 0.1 | 0.1 | -0.1 | -0.1 | -0.1 | -0.1 |
| | China | 0.2 | 0.3 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.6 | 0.2 | 0.4 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 |
| Milk | EU | -0.4 | -0.3 | -0.4 | -0.3 | -0.4 | -0.3 | -0.3 | -0.2 | -0.5 | -0.3 | -0.5 | -0.3 | -0.8 | -0.4 | -0.9 | -0.5 | -0.4 | -0.3 | -0.4 | -0.3 |
| | ROW | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | S&E Asia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | North America | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | China | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table C4 Regional real private consumption**

| % change relative to ref case | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Argentina | 0.2 | 0.3 | 0.2 | 0.2 | 0.4 | 0.4 | 0.4 | 0.3 | 0.6 | 0.6 | 0.5 | 0.5 | 0.7 | 0.8 | 0.6 | 0.6 |
| Australia | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.5 | 0.4 | 0.5 |
| Brazil | 0.6 | 0.6 | 0.5 | 0.4 | 1.0 | 0.9 | 0.8 | 0.8 | 1.6 | 1.5 | 1.3 | 1.2 | 2.2 | 2.3 | 1.8 | 2.0 |
| Sth & Cent. America & Car. | 0.1 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.3 | 0.2 |
| China | 0.3 | 0.3 | 0.3 | 0.3 | 0.6 | 0.7 | 0.6 | 0.6 | 0.7 | 0.7 | 0.8 | 0.7 | 0.9 | 0.8 | 1.0 | 0.8 |
| East Africa | 0.7 | 0.8 | 0.8 | 0.7 | 0.8 | 1.0 | 1.0 | 0.9 | 1.1 | 1.2 | 1.1 | 0.9 | 0.9 | 1.1 | 1.0 | 1.0 |
| EU | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.3 |
| FSU | 0.1 | 0.1 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.2 | 0.3 | 0.4 | 0.3 | 0.3 | 0.5 |
| India | 0.3 | 0.4 | 0.5 | 0.4 | 0.5 | 0.7 | 1.0 | 0.7 | 0.6 | 0.9 | 1.1 | 0.7 | 0.7 | 1.1 | 1.3 | 0.9 |
| Japan | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 0.8 | 0.8 | 0.6 | 0.6 |
| Middle East | 0.3 | 0.3 | 0.3 | 0.4 | 0.6 | 0.6 | 0.6 | 0.7 | 0.6 | 0.5 | 0.6 | 0.6 | 0.9 | 0.5 | 0.8 | 0.8 |
| North America | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 |
| Nth & west Africa | 0.3 | 0.3 | 0.3 | 0.4 | 0.6 | 0.7 | 0.6 | 0.7 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.2 | 0.6 | 0.5 |
| Sth & Cent. America & Car. | 0.2 | 0.2 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.4 | 0.3 | 0.3 |
| ROW | 0.4 | 0.4 | 0.4 | 0.4 | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.9 | 0.8 |
| Russia | 0.3 | 0.4 | 0.3 | 0.4 | 0.6 | 0.6 | 0.5 | 0.7 | 0.6 | 0.6 | 0.4 | 0.7 | 0.5 | 0.3 | 0.3 | 0.7 |
| S&E Asia | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.4 | 0.3 | 0.7 | 0.4 | 0.6 | 0.4 |
| South Korea | 1.8 | 2.0 | 2.0 | 1.9 | 1.7 | 1.9 | 1.9 | 1.8 | 1.7 | 1.6 | 1.7 | 1.6 | 1.7 | 1.3 | 1.7 | 1.4 |

**Table C5  Real prices**

| % change relative to ref case | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Wheat | Brazil | 8 | 8 | 8 | 7 | 12 | 11 | 11 | 10 | 12 | 10 | 12 | 10 | 12 | 10 | 13 | 11 | 8 | 8 | 8 | 7 |
| | East Africa | 0 | 0 | 0 | 0 | -2 | -3 | -3 | -3 | -3 | -4 | -3 | -4 | -1 | -2 | -1 | -2 | 0 | 0 | 0 | 0 |
| | EU | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | North America | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 2 | 4 | 4 | 4 | 4 |
| | China | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Rice | Brazil | 5.9 | 5.2 | 5.5 | 5.0 | 6.5 | 5.7 | 5.8 | 5.0 | 6.2 | 5.3 | 6.0 | 5.1 | 4.7 | 4.9 | 4.8 | 5.4 | 5.9 | 5.2 | 5.5 | 5.0 |
| | East Africa | 0.8 | 0.8 | 0.7 | 0.7 | -0.1 | 0.0 | -0.3 | -0.1 | -0.8 | -0.9 | -0.8 | -0.8 | -0.2 | -0.2 | -0.4 | -0.5 | 0.8 | 0.8 | 0.7 | 0.7 |
| | EU | -1.6 | -1.7 | -1.5 | -1.7 | -1.3 | -1.3 | -1.2 | -1.4 | -1.0 | -0.9 | -1.0 | -1.1 | -0.9 | -0.8 | -1.3 | -1.0 | -1.6 | -1.7 | -1.5 | -1.7 |
| | North America | 8.1 | 8.6 | 8.9 | 8.3 | 11.5 | 12.0 | 12.8 | 12.1 | 11.3 | 12.0 | 12.4 | 11.9 | 10.5 | 10.6 | 10.6 | 10.5 | 8.1 | 8.6 | 8.9 | 8.3 |
| | China | 1.0 | 1.0 | 0.8 | 1.0 | -3.3 | -3.7 | -4.1 | -3.4 | -2.8 | -3.4 | -3.7 | -3.1 | -2.7 | -2.7 | -3.6 | -2.4 | 1.0 | 1.0 | 0.8 | 1.0 |
| Maize | Brazil | 13 | 12 | 13 | 13 | 15 | 14 | 14 | 13 | 14 | 13 | 14 | 12 | 9 | 11 | 9 | 11 | 13 | 12 | 13 | 13 |
| | East Africa | 4 | 4 | 5 | 5 | 5 | 6 | 6 | 6 | 2 | 3 | 3 | 3 | -1 | 0 | 0 | 1 | 4 | 4 | 5 | 5 |
| | EU | -1 | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 |
| | North America | 12 | 12 | 12 | 12 | 13 | 14 | 14 | 14 | 13 | 14 | 14 | 14 | 11 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | China | 2 | 3 | 2 | 2 | 2 | 3 | 3 | 3 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 2 |

**Table C.5 continued. Real prices**

| % change relative to 2004 | | 2010 | | | | 2020 | | | | 2030 | | | | 2050 | | | | 2080 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 | C-A1 | C-A2 | C-B1 | C-B2 |
| Other crops | Brazil | 9 | 9 | 10 | 9 | 11 | 11 | 11 | 10 | 10 | 10 | 11 | 10 | 7 | 8 | 7 | 9 | 9 | 9 | 10 | 9 |
| | East Africa | 7 | 7 | 7 | 7 | 8 | 9 | 8 | 9 | 3 | 5 | 3 | 5 | -1 | 0 | 0 | 1 | 7 | 7 | 7 | 7 |
| | EU | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 2 | 2 | 2 |
| | North America | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | China | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| Livestock | Brazil | 22 | 21 | 22 | 21 | 26 | 25 | 26 | 21 | 25 | 23 | 27 | 22 | 17 | 20 | 18 | 22 | 22 | 21 | 22 | 21 |
| | East Africa | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 3 | 0 | 1 | 0 | 1 | -2 | -1 | -1 | -1 | 3 | 3 | 3 | 3 |
| | EU | -1 | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | -1 | -1 | -1 | -1 |
| | North America | 2 | 2 | 2 | 2 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | China | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 | 0 | 0 | 0 |