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Australian Centre for International Agricultural Research

Final report

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Contents

1 Acknowledgments

We wish to acknowledge the assistance we received in preparing this report from members of the China Council for International Cooperation on Environment and Development (CCICED) Task Force on Rural Development and its Energy, Environment and Climate Change Adaptation Policy. In particular, we thank Dr Dan Dudek from the US Environmental Defense Fund for his support in completing our work. We also thank Dr Martin Parry (University of East Anglia) and Ana Iglesias (Universidad Politecnica de Madrid) for their assistance in providing data.

2 Executive summary

The aim of the project is to determine how regional agricultural commodity production and trade are likely to change over the remainder of this century as a result of climate change and income growth, with a particular focus on China. The work was undertaken as part of the work of the China Council for International Cooperation on Environment and Development (CCICED) Task Force on Rural Development and its Energy, Environment and Climate Change Adaptation Policy, of which Dr Fisher was a member.

The study uses the global general equilibrium model GTAP (Global Trade Analysis Project) to analyse the impacts of different climate stabilisation scenarios on future trade patterns for selected basic 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 mean for agricultural trade flows. The second part of the study analyses how changes to trade policy might alter the trade flows of those commodities and discusses the associated benefits of trade liberalisation to food security and welfare.

The main conclusion in this report aligns with most of the published climate change research relating to agriculture in concluding that food production will be sufficient to meet the world's needs for the remainder of this century, irrespective of the climate change scenario adopted. Productivity improvements associated with technical change (and carbon fertilisation) are likely to outweigh any negative productivity effects from climate change assuming historic rates of improvement continue.

A note of caution here is that the simulated productivity shocks do not capture possible sea level rise or effects of potential increases or changes in the patterns of crop and livestock pestilence, nor any potential threshold effects and discontinuities.

While real prices for all commodities increase under every scenario, incomes increase at a faster rate, and hence all commodities become more affordable over time relative to 2004 and hence food security from an affordability perspective increases. The Chinese are among the greatest beneficiaries of affordability improvements over time.

Trade liberalisation was implemented by progressively removing export, import and output taxes on all agricultural commodities and processing sectors. Removal of border taxes and subsidies resulted in uniform improvements in welfare across all regions under all scenarios.

The impact of removing border taxes and subsidies had 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).

Liberalisation may therefore be an appropriate strategy for partially offsetting any negative welfare impacts of climate change.

The demonstrated use of the modelling technique and databases has raised awareness of the techniques and their uses and encouraged further analysis by our Chinese collaborators. It is our assessment that this technique will make a significant contribution to trade and climate change analysis over the coming five years and also assist in promoting greater openness to trade policy reform in China.

The economic and community impacts of the project will largely depend on the broader adoption of freer trade in China.

3 Background

The majority of the published climate change research relating to food production concludes that sufficient agricultural land will be available to meet the world's food needs for the remainder of this century. The conclusion holds for a range of scenarios of climate change, agricultural productivity growth and growth in income and population. The consistent finding is that areas of arable land will increase in northern Europe, North America and parts of east Asia, and will decrease in tropical regions.

What is less clear is the way other important factors might change these conclusions. For example, over the coming half century world population is projected to grow to about 9 billion and much agricultural land will 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 biofuels and forest carbon sequestration. 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.

There may be actions that can be taken now to reduce the costs of adapting to climate change and to reduce the number of people at risk of hunger by making timely investments in infrastructure and in the development of well-functioning markets.

A first step in determining which regions are likely to require pre-emptive 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 fundamentally alter. This work investigates the ramifications for regional commodity flows by applying a range of climate change 'shocks' in a general-equilibrium model of the world economy.

The research was completed as input into the deliberations of the China Council for International Cooperation on Environment and Development (CCICED) Task Force on Rural Development and its Energy, Environment and Climate Change Adaptation Policy that reported its findings on 13 November 2009 (http://english.mep.gov.cn/international_cooperation/CCICED/201001/t20100126_184824.htm).

4 Objectives

The aim of the project is to determine 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 particular 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.

The project objectives were:

1. Actively participate in the China Council for International Cooperation on Environment and Development (CCICED) Task Force on Rural Development and its Energy, Environment and Climate Change Adaptation Policy meetings.

Undertake economic modelling and produce a report on the impacts of climate change on agricultural production and trade flows with particular reference to China.

5 Methodology

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.

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.

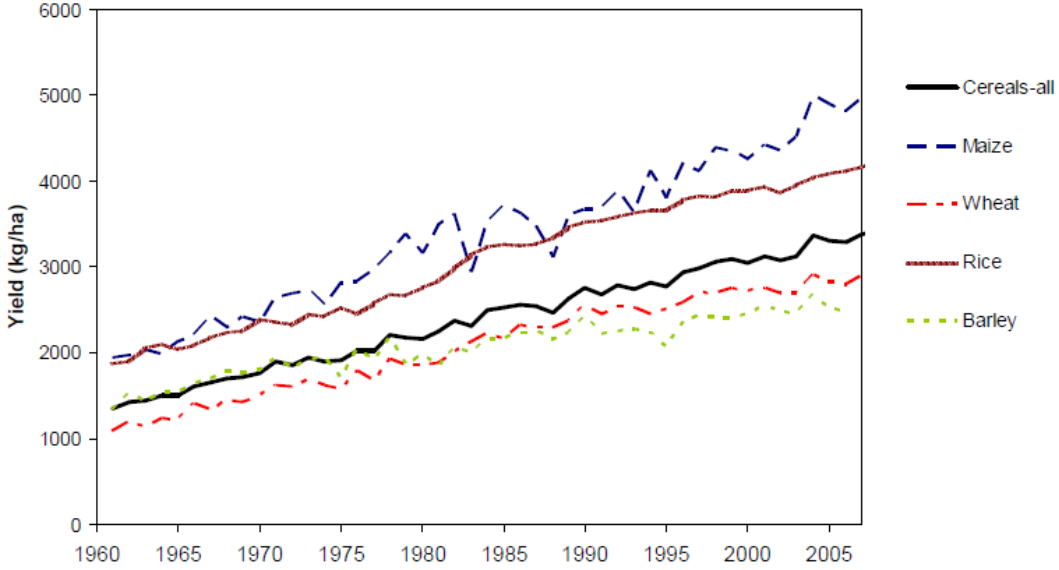
Four climate change scenarios are examined. The first corresponds to a world in which the atmospheric concentration of CO_2 has been stabilised at around 530 parts per million (ppm) by 2080 (hereafter C-B1). The second scenario is one in which stabilisation is achieved at 560 ppm by 2080 (hereafter C-B2). 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. Figure 5.1: Worldwide historic yield trends for major cereals



Source: Gallagher Biofuels Review 2008

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 5.1.

Table 5.1: 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	

5.1 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 5.2.

Table 5.2: 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

5.2 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 Concept Economics' 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 5.3 to 5.6 present the average regional GDP growth assumptions by scenario for selected timeframes.

Table 5.3: 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 5.4: 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 5.5: 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 5.6: Projected average annual growth in GDP (per cent) – C-B2

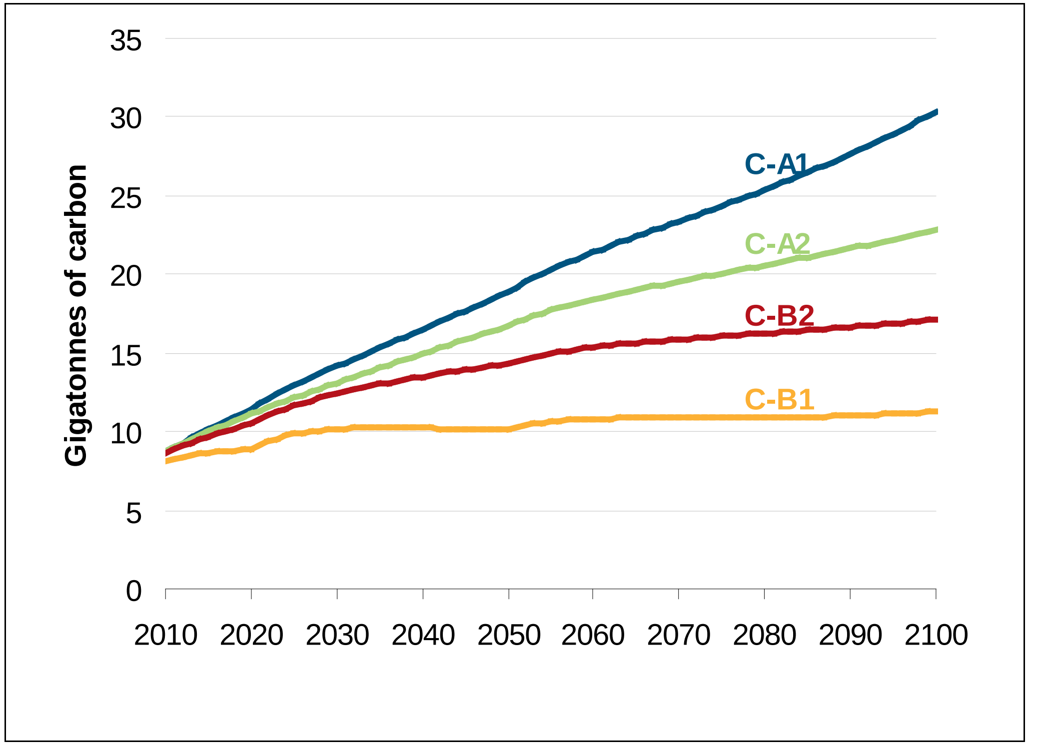
Country	2008-2020	2021-50	2051-2100
	% average per year	**% average per year**	**% average per year**
Argentina	1.38	2.01	1.81
Australia	2.84	1.60	0.65
Brazil	1.81	2.01	1.47
Central and Southern Africa	1.56	2.16	1.34
China	5.12	2.30	1.38
East Africa	1.44	1.80	1.16
EU	1.59	1.06	0.57
FSU	3.55	2.46	2.02
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

5.3 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 5.2). 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 5.2: Global CO2 emissions by scenario – Concept projections



5.4 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 5.7 summarises the CO_2 fertilisation only effects on crop productivity under various climate change scenarios.

Table 5.7: 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 5.3 – 5.6 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 5.7, the changes represented in Figures 5.3 – 5.6 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 5.3: Selected regional yield indexes – C-A1

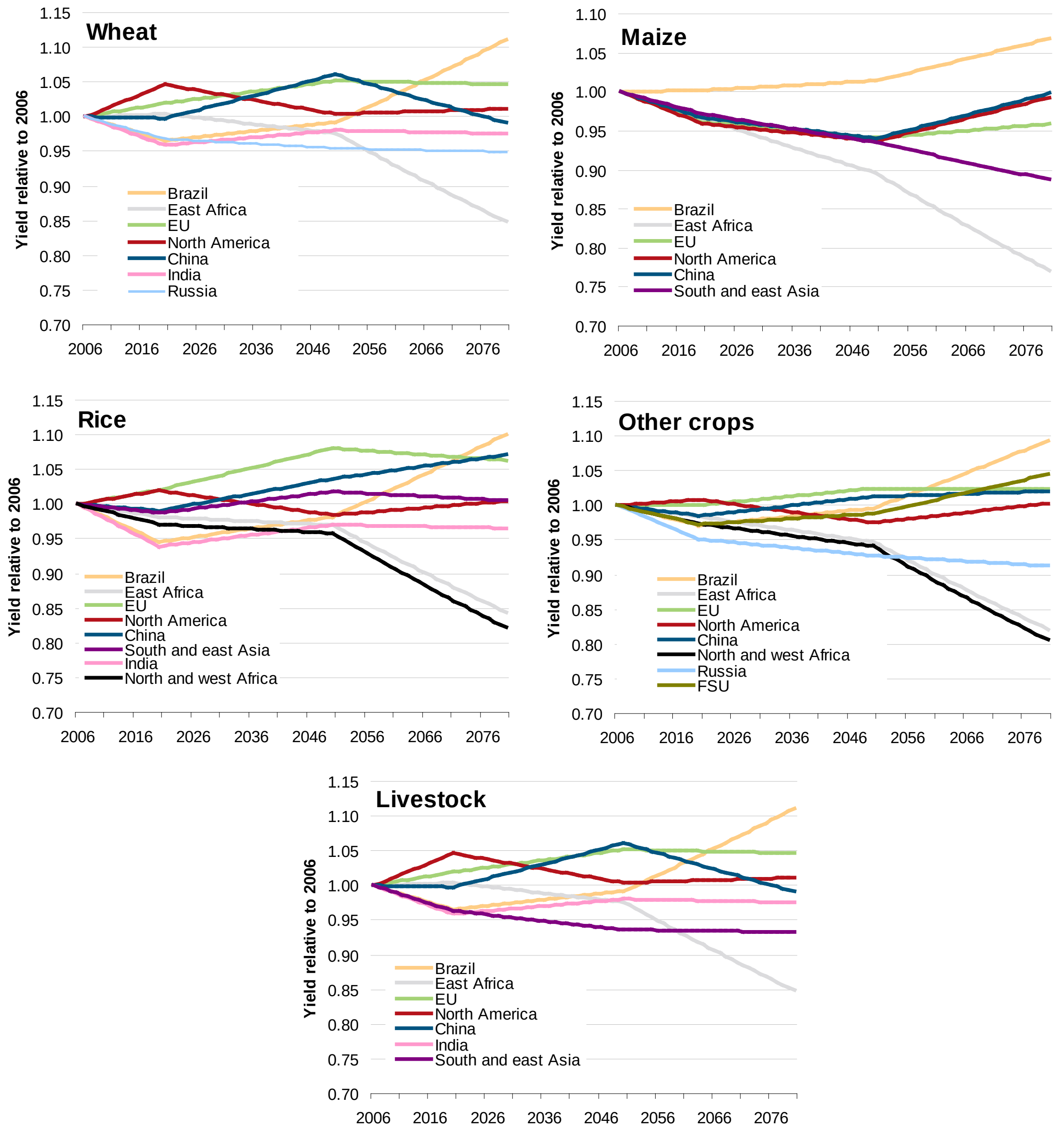
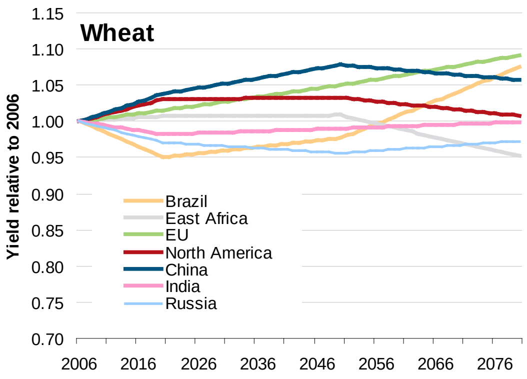
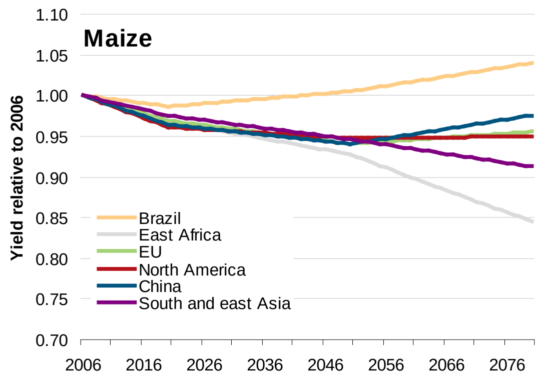
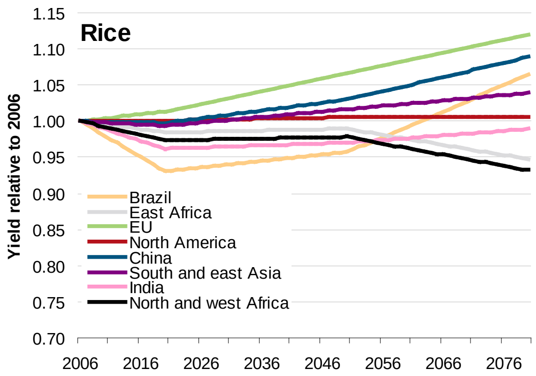
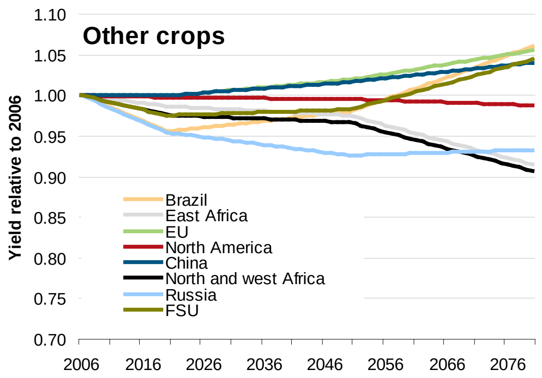

Wheat
Yield relative to 2006
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
India
Russia
Maize
Yield relative to 2006
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
Brazil
East Africa
EU
North America
China
South and east Asia
Rice
Yield relative to 2006
Brazil
East Africa
EU
North America
China
South and east Asia
India
North and west Africa
Other crops
Yield relative to 2006
Brazil
East Africa
EU
North America
China
North and west Africa
Russia
FSU
Livestock
Yield relative to 2006
Brazil
East Africa
EU
North America
China
India
South and east Asia

Figure 5.4: Selected regional yield indexes – C-A2


Wheat
Yield relative to 2006
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
India
Russia


Maize
Yield relative to 2006
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
South and east Asia


Rice
Yield relative to 2006
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
South and east Asia
India
North and west Africa


Other crops
Yield relative to 2006
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
North and west Africa
Russia
FSU

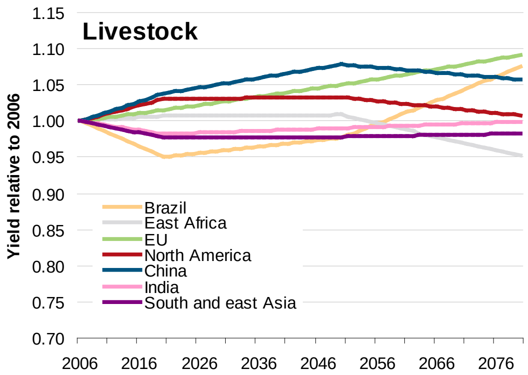

Livestock
Yield relative to 2006
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
India
South and east Asia

Figure 5.5: Selected regional yield indexes – C-B2

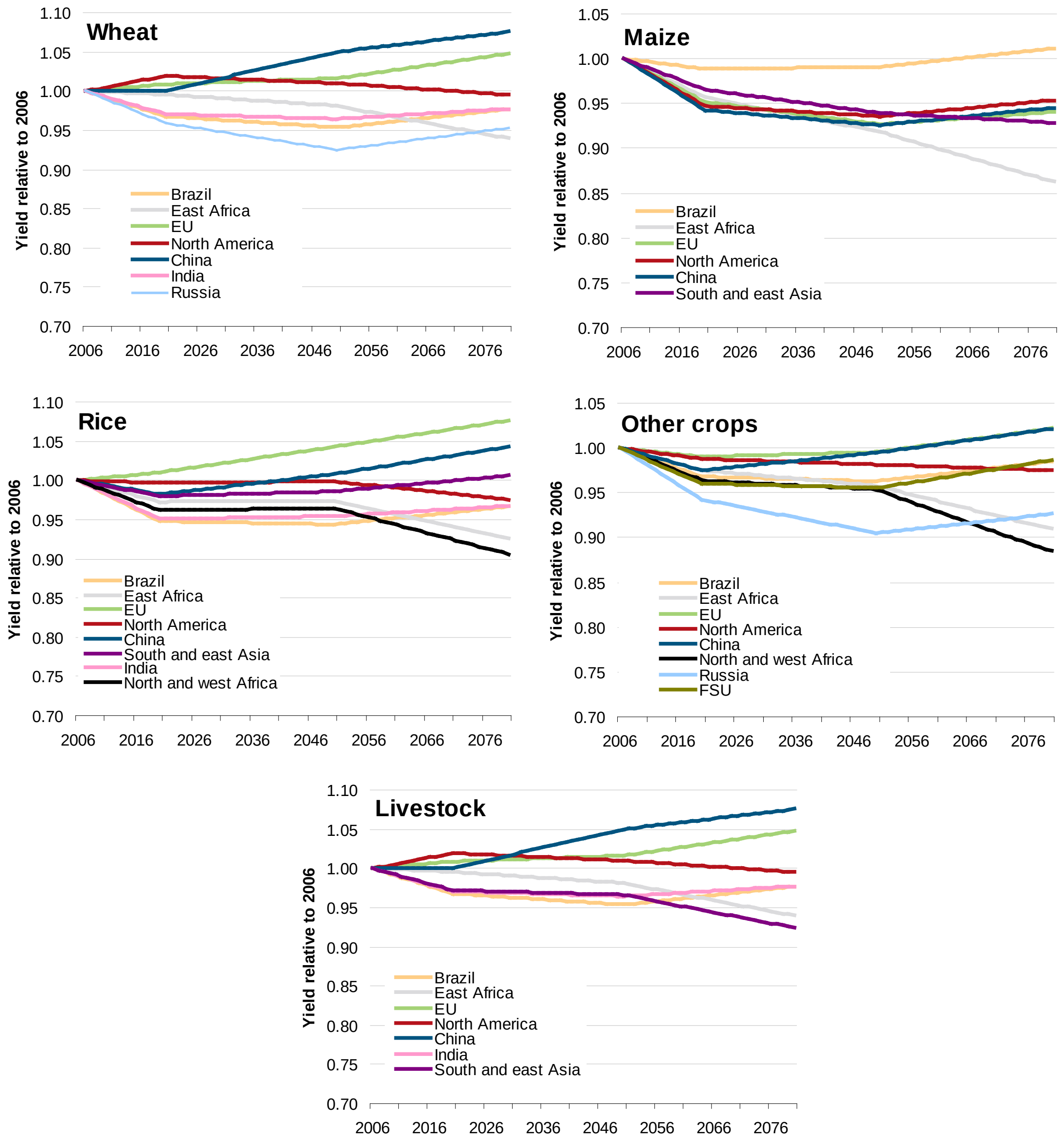
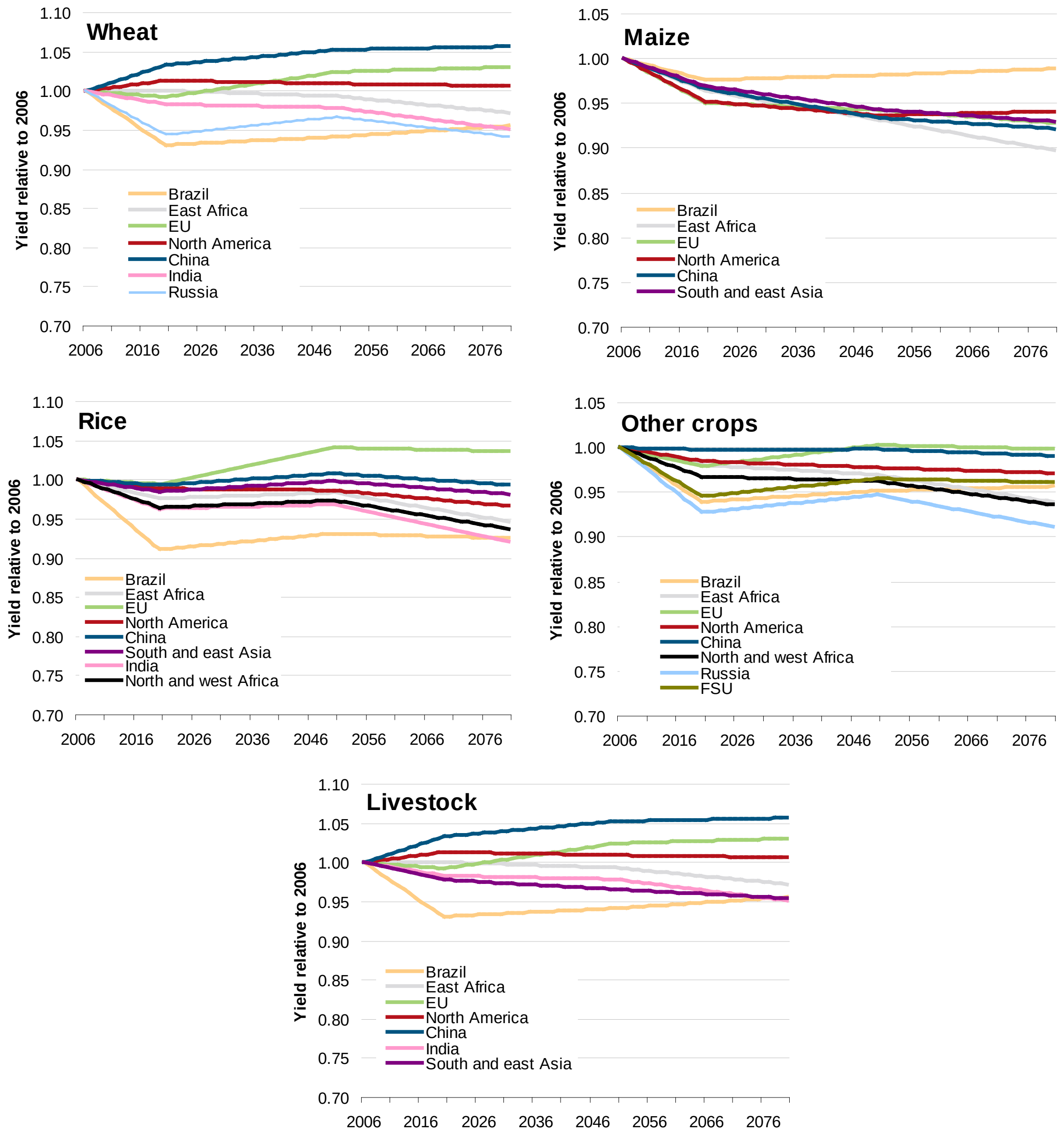

Wheat
Yield relative to 2006
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
India
Russia
Maize
Yield relative to 2006
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
Brazil
East Africa
EU
North America
China
South and east Asia
Rice
Yield relative to 2006
Brazil
East Africa
EU
North America
China
South and east Asia
India
North and west Africa
Other crops
Yield relative to 2006
Brazil
East Africa
EU
North America
China
North and west Africa
Russia
FSU
Livestock
Yield relative to 2006
Brazil
East Africa
EU
North America
China
India
South and east Asia

Figure 5.6: Selected regional yield indexes – C-B1


Wheat
Yield relative to 2006
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006 2016 2026 2036 2046 2056 2066 2076
Brazil
East Africa
EU
North America
China
India
Russia
Maize
Yield relative to 2006
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006 2016 2026 2036 2046 2056 2066 2076
Brazil
East Africa
EU
North America
China
South and east Asia
Rice
Yield relative to 2006
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006 2016 2026 2036 2046 2056 2066 2076
Brazil
East Africa
EU
North America
China
South and east Asia
India
North and west Africa
Other crops
Yield relative to 2006
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006 2016 2026 2036 2046 2056 2066 2076
Brazil
East Africa
EU
North America
China
North and west Africa
Russia
FSU
Livestock
Yield relative to 2006
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006 2016 2026 2036 2046 2056 2066 2076
Brazil
East Africa
EU
North America
China
India
South and east Asia

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 7 in respect of the consequences for welfare and trade.

6 Achievements against activities and outputs/milestones

Objective 1:

no.	activity	outputs/ milestones	completion date	comments
1.1	Participate in task force meetings	All full meetings of the task force attended	25 June 2009	Participation in 4 meetings in China including a regional field trip

Objective 2:

no.	activity	outputs/ milestones	completion date	comments
2.1	Develop economic model and run policy simulations	Deliver final report to Task Force by 30 September 2009	21 September 2009	The modelling work was considered by the Task force in the preparation of its final report

7 Key results and discussion

In section 7.1 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 7.2 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 7.3 the impacts of liberalising trade (in the presence of climate change) on agricultural commodity trade are analysed.

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

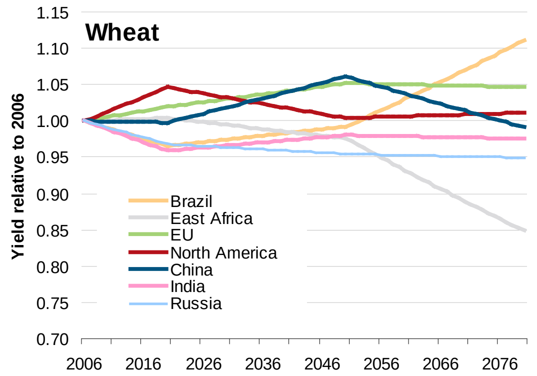
The impact of climate change on yields over time is not insignificant and varies by region. Figure 7.1 indicates the change in yield by commodity under the assumption that climate change occurs, relative to the base year for selected regions.

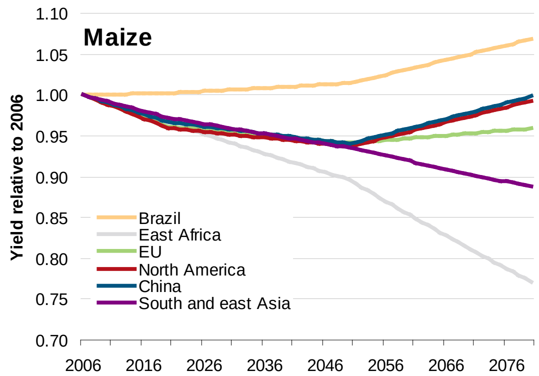
Relative to historic yield changes, the potential effects of climate change on **maize** productivity are potentially quite moderate. Over the period 1996-2008, average maize productivity globally increased by around 2.4 per cent year-on-year over a twelve-year timeframe or around 29.4 per cent in total. 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.

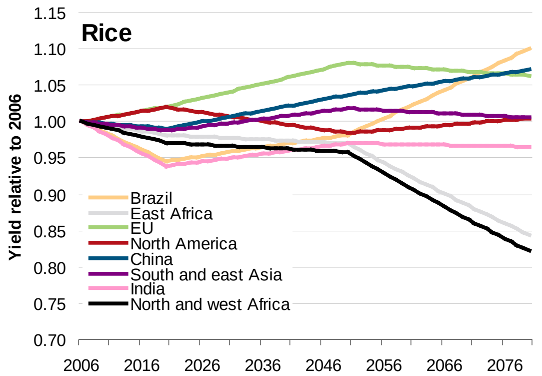
This observation also holds for **rice and wheat** productivity, since average historic yield changes for these crops were around 1 per cent year-on-year for the twelve year period 1996-2008 while the most negative regional impact of climate change is projected to be only around 0.2 per cent per year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

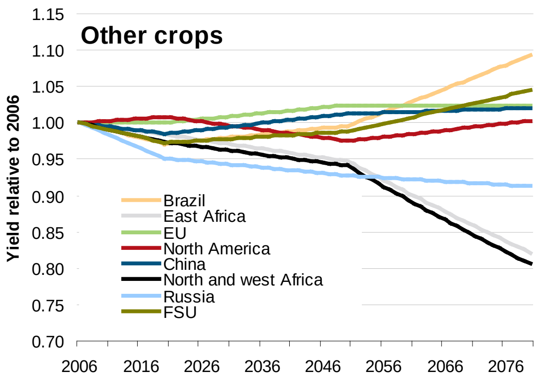
However, a significant note of caution in relation to this observation is that care must be taken in suggesting that there are limited impacts for agricultural productivity resulting from climate change because many of the potential impacts are not captured by the productivity effects reported in this 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.

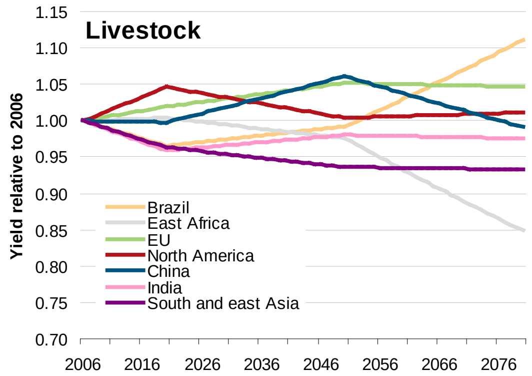
Figure 7.1 Yield changes relative to base year – C-A1


Wheat
Yield relative to 2006
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
India
Russia


Maize
Yield relative to 2006
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
South and east Asia


Rice
Yield relative to 2006
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
South and east Asia
India
North and west Africa


Other crops
Yield relative to 2006
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
North and west Africa
Russia
FSU

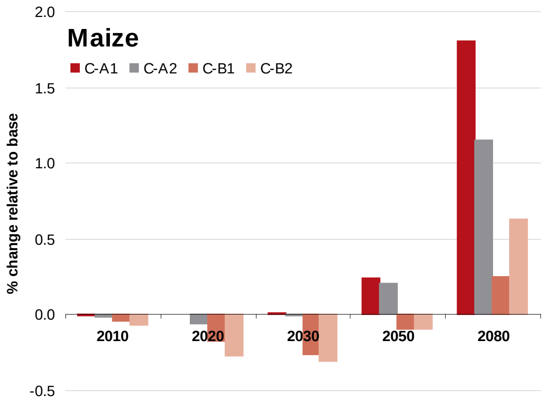

Livestock
Yield relative to 2006
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
2006
2016
2026
2036
2046
2056
2066
2076
Brazil
East Africa
EU
North America
China
India
South and east Asia

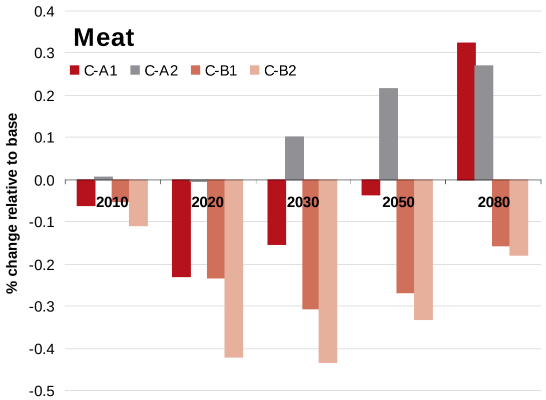
Examining the modeling results presented in Figure 7.2, the overall climate induced changes to regional production of agricultural commodities are for the most part moderate. These results were obtained by comparing the reference case inclusive of climate impacts with a scenario in which climate productivity 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.

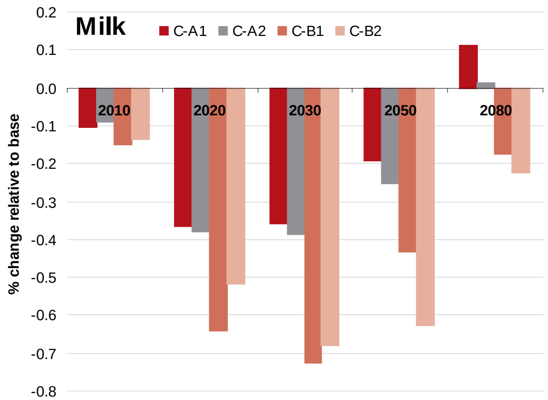
Differences across scenarios are also driven in large part by different income projections, which help determine aggregate demand and consumption shares – for instance, higher income projections are typically associated with higher meat demand and lower rice demand. Taking China as an example, real private 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 7.3). 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.

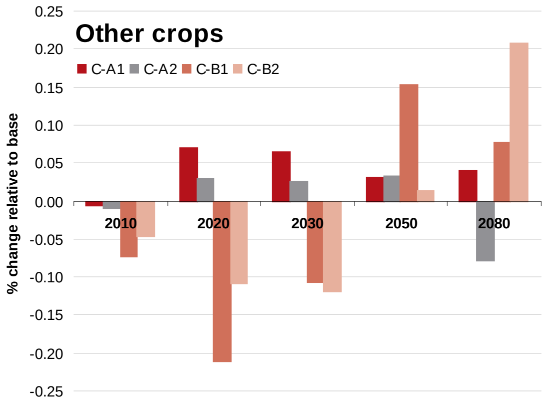
The ensuing sections discuss the most significant implications of climate change and economic growth on a regional commodity by commodity basis. Results are reported both in a comparative sense across the four reference case scenarios which include the productivity related impacts of climate change, 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.

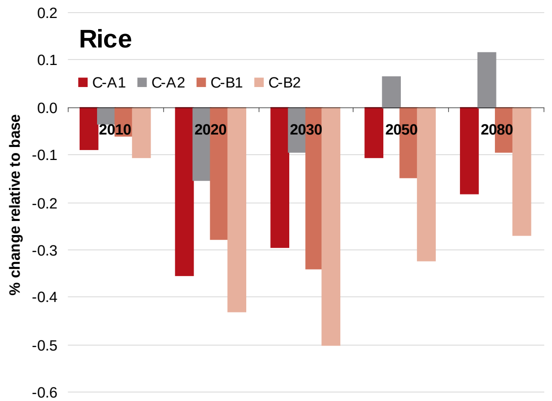
Results have been reported in all cases for China (see Figures 7.4 – 7.6) and for the top five producers of each commodity. Trade flows in the commodities of interest are reported for a selection of countries with particular focus on China. Import and export data are reported from the GTAP model for relevant trading partners and major trading regions.


Maize
C-A1 C-A2 C-B1 C-B2
% change relative to base
2.0
1.5
1.0
0.5
0.0
-0.5
2010
2020
2030
2050
2080


Meat
C-A1 C-A2 C-B1 C-B2
% change relative to base
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
2010
2020
2030
2050
2080


Milk
C-A1 C-A2 C-B1 C-B2
% change relative to base
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
2010
2020
2030
2050
2080


Other crops
C-A1 C-A2 C-B1 C-B2
% change relative to base
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
2010
2020
2030
2050
2080


Rice
C-A1 C-A2 C-B1 C-B2
% change relative to base
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
2010
2020
2030
2050
2080

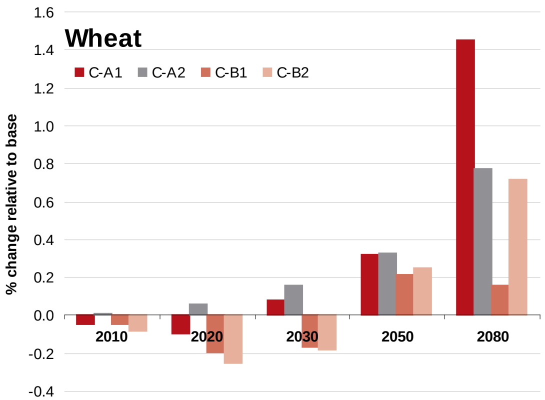
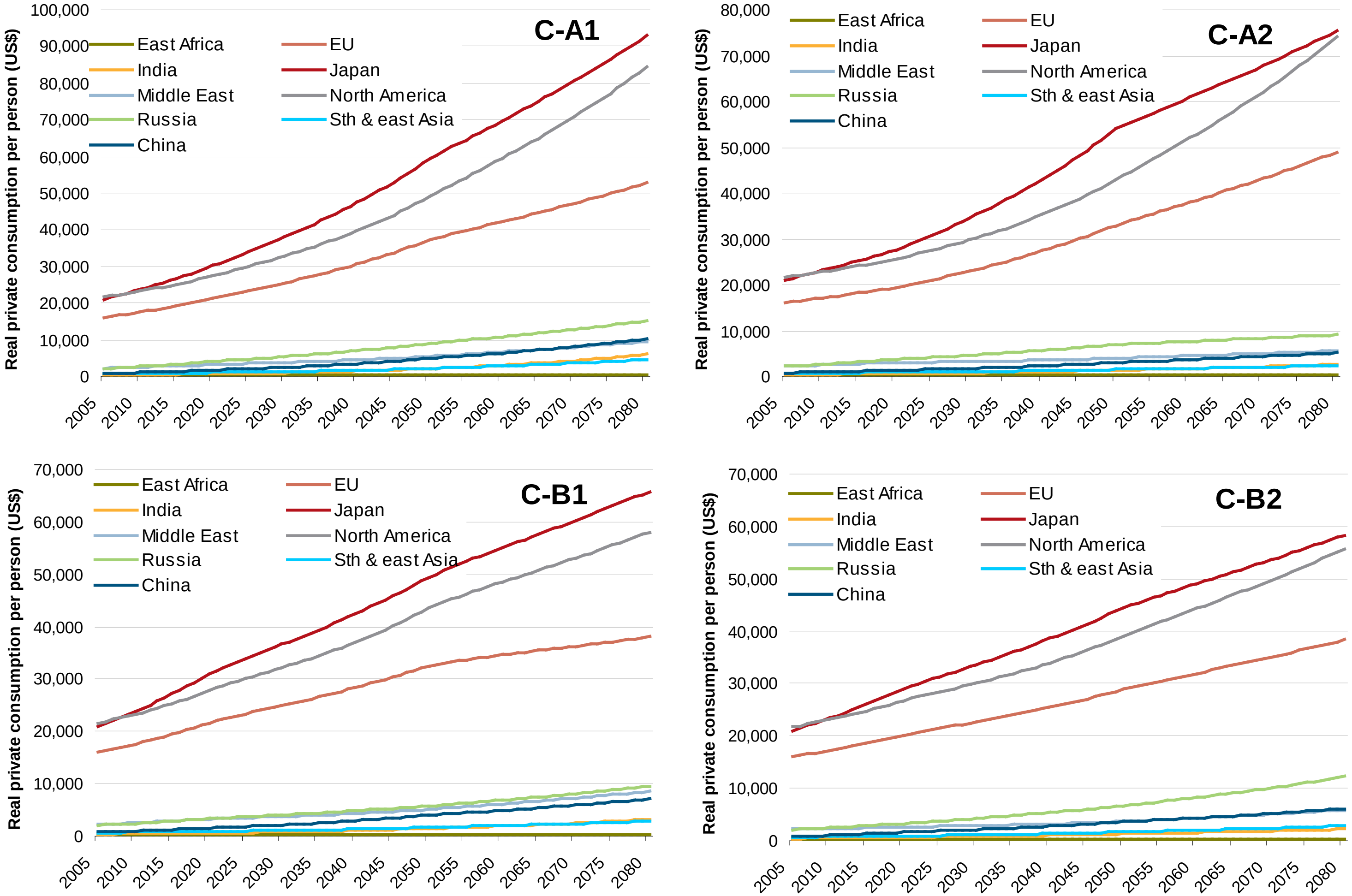

Wheat
C-A1 C-A2 C-B1 C-B2
% change relative to base
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
2010
2020
2030
2050
2080

Figure 7.3 Real private consumption per person (US$)



7.1.1 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.

7.1.2 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.

7.1.3 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.

7.1.4 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 that 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.

7.1.5 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 7.6). 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.

7.1.6 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.

7.1.7 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.
- 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 7.4 China's production by scenario, by commodity

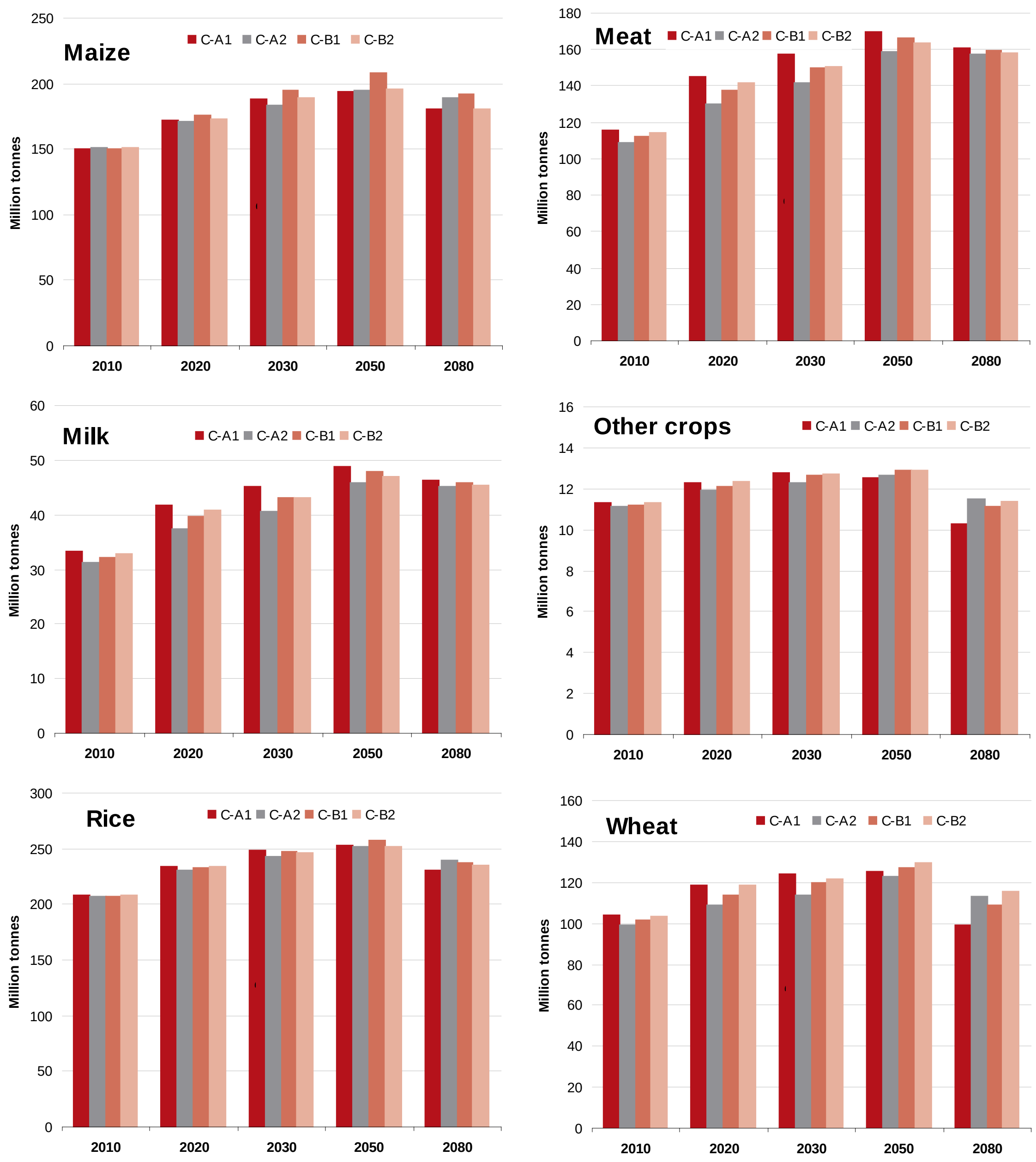


Figure 7.5 China's exports by scenario, by commodity

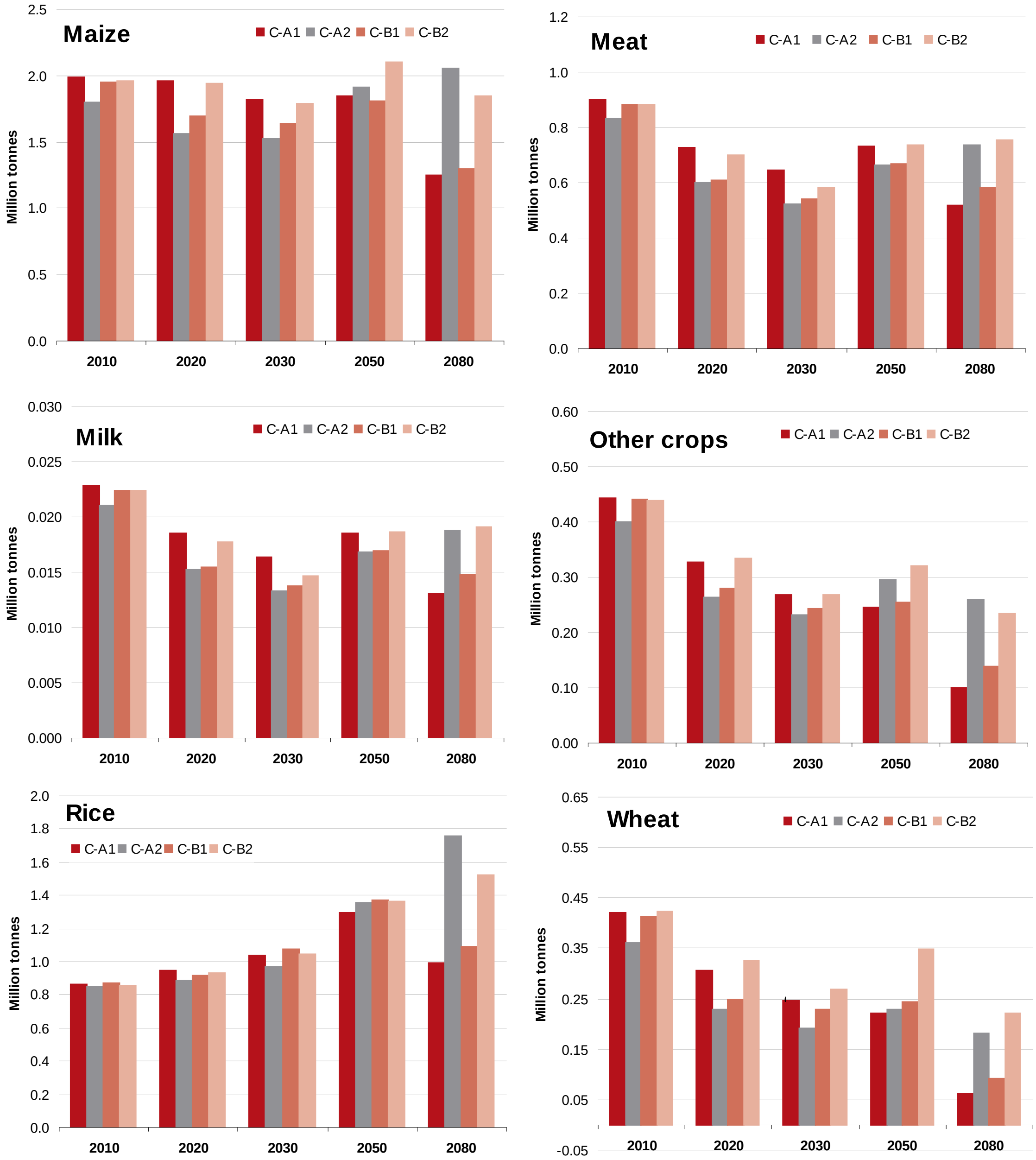
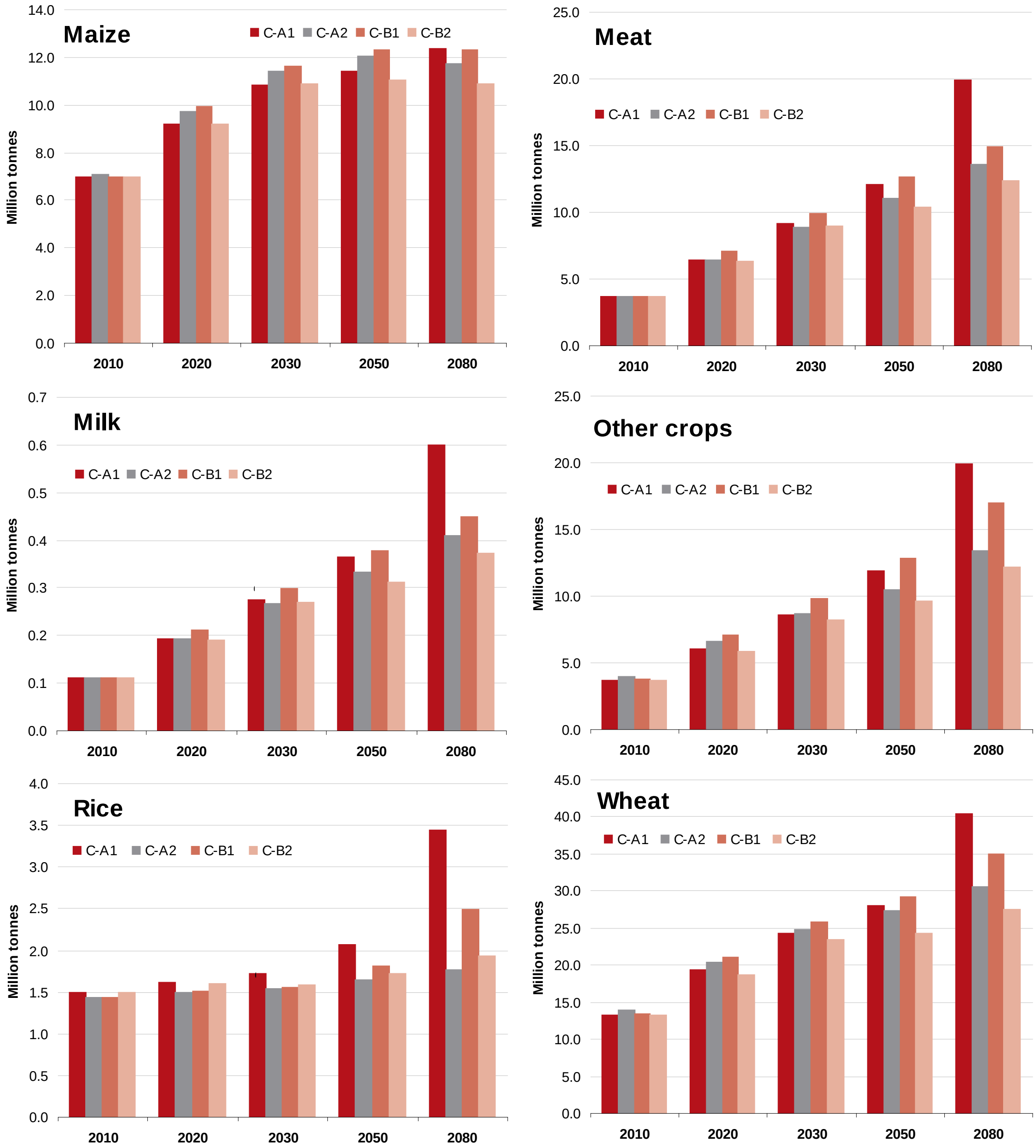

Maize
C-A1 C-A2 C-B1 C-B2
Million tonnes
0.0
0.5
1.0
1.5
2.0
2.5
2010 2020 2030 2050 2080
Meat
C-A1 C-A2 C-B1 C-B2
Million tonnes
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2010 2020 2030 2050 2080
Milk
C-A1 C-A2 C-B1 C-B2
Million tonnes
0.000
0.005
0.010
0.015
0.020
0.025
0.030
2010 2020 2030 2050 2080
Other crops
C-A1 C-A2 C-B1 C-B2
Million tonnes
0.00
0.10
0.20
0.30
0.40
0.50
0.60
2010 2020 2030 2050 2080
Rice
C-A1 C-A2 C-B1 C-B2
Million tonnes
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2010 2020 2030 2050 2080
Wheat
C-A1 C-A2 C-B1 C-B2
Million tonnes
-0.05
0.05
0.15
0.25
0.35
0.45
0.55
0.65
2010 2020 2030 2050 2080

Figure 7.6 China's imports by scenario, by commodity



7.2 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).

7.2.1 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.

7.2.2 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.

7.2.3 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.

7.2.4 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.

7.2.5 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.

7.2.6 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.

7.2.7 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 7.7). 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.

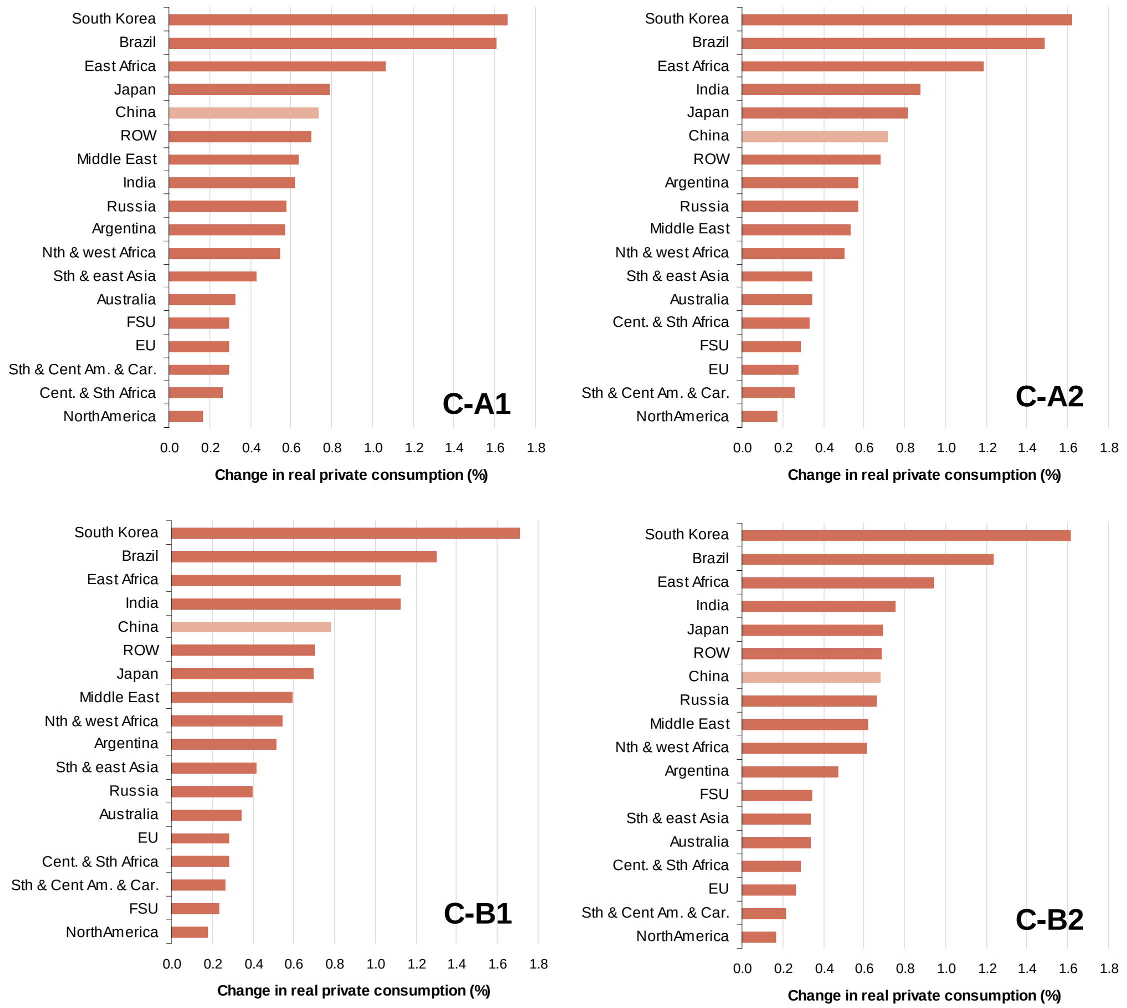
Figure 7.7 Change in world crop production relative to the reference case under a policy of trade liberalisation.

7.2.8 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 7.8). 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 7.8 Change in real private consumption in 2050 relative to the reference case under a policy of trade liberalisation, by region



8 Impacts

8.1 Scientific impacts – now and in 5 years

Removal of border taxes and subsidies would result 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.

These results were demonstrated using a computable general equilibrium model and the GTAP database together with a range of inputs from physical climate models. The discussion and demonstrated use of the modelling technique and the databases raised awareness of the techniques and their uses and encouraged further analysis by our Chinese collaborators.

CGE modelling is already being undertaken in China to assist in policy development and it is our assessment that this technique will make a significant contribution to trade and climate change analysis over the coming five years and also assist in promoting greater openness to trade policy reform in China.

8.2 Capacity impacts – now and in 5 years

There were no direct training components in this project. However, as mentioned in section 8.1 we believe that the demonstrated use of the model developed and the modelling technique will aid in the broader adoption of such techniques in future in China.

8.3 Community impacts – now and in 5 years

The community impacts of the project largely depend on the broader adoption of freer trade in China. Freer trade will raise total welfare in China. On a micro-level, the Taskforce was concerned to reduce impediments to the introduction of more energy efficient appliances, to encourage the adoption of improved technology (such as precision agriculture and better fertiliser management) and to directly enhance the health and wellbeing of householders by encouraging reductions of particulate emissions (especially inside private dwellings).

Taskforce members (including Dr Fisher) met with stakeholders as part of the process in better understanding financial and other constraints that influence the adoption of new technology. The Taskforce recommendations for improvements in Chinese policy settings reflected the insights gained in the field.

To a large extent the final community impacts depend heavily on future government policy with respect to energy efficiency targets, and other regulations and the adoption of market based instruments. It is our assessment that the probability has increased that market based policy instruments will become more prevalent in China in the coming decade.

8.3.1 Economic impacts

As mentioned in section 8.3 we are convinced that open discussion of the merits of market based policy instruments and freer trade will lead to the broader adoption of such policies in China in the future. During the Taskforce's deliberations there was constructive debate among Chinese academic participants and policy makers about the merits of economic policy instruments and their place in China.

The economic modelling demonstrated that Chinese welfare could be enhanced by freer trade and that the agricultural adjustments arising as a consequence could be smoothed to some extent in a world of freer trade compared to a world with trade restrictions. This message was well received by policy makers and our view is that the dissemination of this message is an important part of promoting the adoption of welfare enhancing trade policy in China.

8.3.2 Social impacts

As noted in the introduction to section 8.3 the Taskforce was concerned to understand and make policy recommendations on climate and energy policy that would enhance the welfare of rural people including recommendations on better fertiliser use, policy settings to encourage the adoption of improved stoves and other household appliances and policies designed to increase both the availability and use of electricity in rural areas (to replace the direct burning by households of coal and straw). Over the longer term the activities of the Taskforce will have an influence on policy settings that enhance the welfare of rural people.

Through the work that has identified potential changes in regional trade flows of basic commodities, it is also hoped that this will lay the foundation for future work that investigates whether any infrastructure or institutional changes in developing regions are required to deal with changes in commodity flows that will occur as a result of freer trade.

8.3.3 Environmental impacts

See comments in section 8.3.2

8.4 Communication and dissemination activities

As already mentioned the Taskforce met with stakeholders in rural China and interacted with policy makers. The Taskforce's recommendations were forwarded to CCICED for incorporation it its policy recommendations to government.

BAEconomics' report on the impact of climate change of agricultural trade is available at www.baeconomics.com.au and a summary will be published on the ACIAR website.

9 Conclusions and recommendations

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.

9.1 Conclusions

Other key conclusions from this research include the following.

1. 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.
2. 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.
3. 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.
4. 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.
5. 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.

9.2 Recommendations

Removal of border taxes and subsidies would result 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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10.2 List of publications produced by project

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