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Potential effects of variation in agriculture sector response to climate change: an integrated assessment

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ABSTRACT

The effects of climate change on agricultural productivity are influenced by a range of factors including changes in temperature, precipitation, humidity, and frost and carbon fertilisation. Recent literature on the sensitivity of the agriculture sector to climate change highlights the need for understanding the way climate change influences the distribution of productivity impacts. These impacts may manifest in the form of changes in food self sufficiency, export availability and import dependency and may vary across different geographic and socio-economic regions. Such effects will have considerable socio-economic implications, nationally, regionally and globally.

In this paper, we examine the potential effects of a 1⁰C warming globally by 2030 (relative to what would otherwise be) on the distribution of agricultural productivity responses in a range of key food exporting and importing countries. To carry out our analysis we use an integrated assessment modelling framework: the Global Integrated Assessment Model (GIAM). GIAM is a coupled model which consists of a global economic module – the Global Trade and Environment Model (GTEM) and a climate module – the Simple Carbon Climate Model (SCCM). The GTEM module provides the greenhouse gas emissions based on economic activities. These emissions are then fed into the SCCM module. The SCCM module converts the emissions into CO₂ concentration levels and then into changes in temperature. Changes in temperature are fed into a ‘climate change response function’ in the GIAM framework to assess the potential climate change impacts on agriculture.

The main emphasis of this paper is on sensitive regions as defined by the intersection of growing population and income and expanding demand for food. In particular, we assess the impact of climate change on export availability of key food exporting economies such as the US, Canada and Australia. Furthermore, we focus on food self sufficiency and import dependence of key emerging/developing economies such as China and Indonesia. Our results highlight considerable variation in the economic impacts induced by the climate change impacts of magnitudes from the tails of the probability distributions representing the current state of knowledge. We argue that unrestricted global trade could be a useful mediator between regions influenced differently by climate change. We reiterate that reducing the uncertainty in climate change impacts on agriculture should be a high priority for research.

1. Introduction

There is general agreement within the international scientific community that the global climate has been changing and will continue to change as a result of human activity. According to the present international scientific literature, human induced increases in the atmospheric concentration of greenhouse gases will continue to influence changes in climate across many parts of the world (IPCC 2007). Given the projected changes in key global and regional climate variables, one of the major sectors vulnerable to climate variability and change is agriculture. Changes in water availability, water quality, temperatures and pests and diseases are all likely to have an impact on agricultural productivity. In general, agricultural productivity is considerably influenced by both temperature and precipitation. According to Lobell and Burke (2008), uncertainties related to temperature represented a greater contribution to climate change impact uncertainty than those related to precipitation for most crops and regions, and in particular the sensitivity of crop yields to temperature is a critical source of uncertainty.

It is important to recognise that potential impacts of climate change are unlikely to be uniformly distributed around the world. Increasing temperatures may extend the growing season for crops in some areas but increase the demand for water by crops and decrease yields in other areas (Ecofys BV 2006). Increase in CO₂ concentration could have positive carbon fertilisation effects by increasing the rate of photosynthesis in some plants (Steffen and Canadell 2005). However, higher concentration of CO₂ could also reduce crop quality, by lowering the content of protein and trace elements (European Environment Agency 2004).

Despite an increasing amount of research and analysis on the impacts of climate variability and change on the agriculture sector, there remains considerable uncertainty as to the nature and timing of the climate impacts on agriculture (see Hertel et al 2010). This implies that potentially, there is considerable variation in agricultural sector response to climate variability and change across industries and across regions.

According to Garnaut (2011), the notion of uncertainty relating to climate change impacts refers to the fact that, while one can't be sure exactly what form the future will take, one can use the available information to assign probabilities to each possible future. One can then take a best guess of what form the future will take, although things could well turn out differently. Our ability to make this inference relies on us having a sound understanding of both the range of possible future outcomes and the likelihood of each of these outcomes. The combination of these forms the probability distribution of future outcomes (Garnaut 2011). Garnaut (2011) points out that the question of uncertainty in relation to climate change impacts relates to the dispersion of the probability distribution around the most likely or average outcome. The principles of prudent risk management dictate that the case for action is strengthened, rather than diminished, by the fact that outcomes could turn out far worse (or better) than expected (Garnaut 2011).

According to Valenzuela and Anderson (2010), given the great uncertainty associated with the magnitude - and in some cases the sign of potential agricultural productivity responses to

climate change, analytical results ideally should include confidence bounds around them or at least high and low alternatives to the median cases presented in many studies. This paper attempts to address this issue to some extent by focussing on the potential variation in agricultural response to climate change. Here, the potential medium to long term economic and trade effects of variation in agricultural sector responses to climate change are investigated within an integrated analytical framework encompassing climate-economic-biophysical interactions.

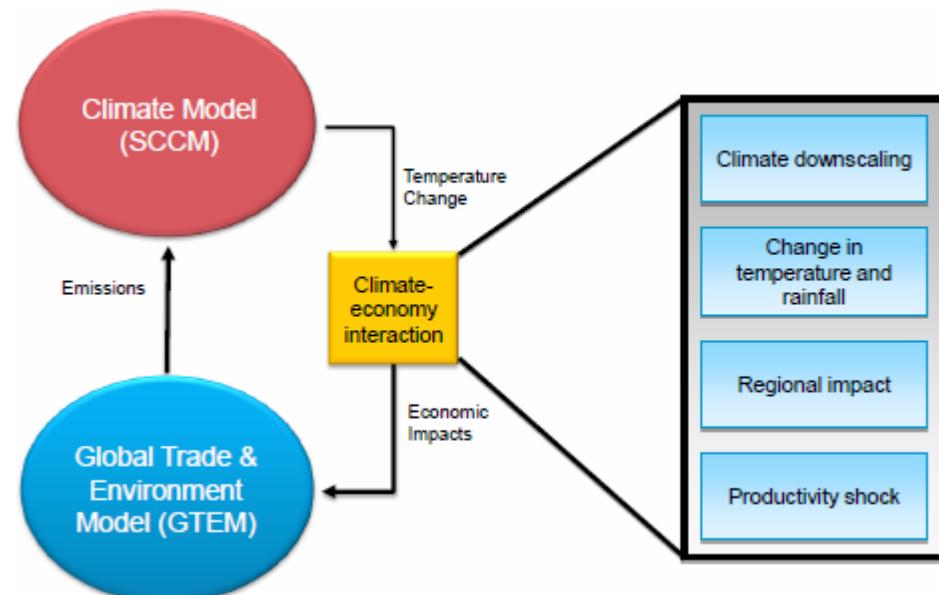
2. Analysing the effects of variation in agriculture sector response

The economic and trade implications of a variation in agricultural sector response to climate change are analysed here by undertaking the following scenarios:

- Reference case (baseline) scenario: world without climate change impacts
- Climate change scenario: impacts of a 1° C warming globally by 2030 on agricultural productivity

These scenarios are analysed using CSIRO's (Commonwealth Scientific and Industrial Research Organisation) current version of the GIAM model. A brief description of the current version of the GIAM modelling framework is provided in Box 1. Results focus on food self sufficiency, export availability and import dependency in key economies.

Box 1: GIAM analytical framework



GIAM is an integrated assessment model originally developed jointly between CSIRO and ABARE (Australian Bureau of Agricultural and Resources Economics) (see Gunasekera et al (2008), Harman et al (2008) and Garnaut (2008)). It is a coupled model of a global economic module and a climate module. The economic module of GIAM is a long run

version of global trade and environment model (GTEM) developed by ABARE, which is a dynamic, multiregional and multisectoral general equilibrium model of the global economy (Pant 2007, Gurney et al. 2009 and Clarke et al. 2009). The economic module allows projections for the major human induced factors influencing climatic conditions (such as greenhouse gas emissions) to be developed after accounting for regional and global production and consumption decisions and international trade. The economic module of GIAM used in this paper currently allows for analysis across 13 regions, 21 industries, four primary factors and six greenhouse gas emissions (see table 1).

The climate module of GIAM is a nonlinear model for global CO₂, other greenhouse gases and global temperature, commonly known as a simple carbon climate model (SCCM) (Raupach et al. 2011). This is a globally averaged or ‘box’ model of the carbon-climate system, using well established formulations. The model includes nonlinearities in the response of terrestrial carbon assimilation to CO₂, the buffering of CO₂ in the ocean mixed layer, temperature responses of land-air and ocean-air CO₂ exchanges, and the response of radiative forcing to gas concentrations (Raupach et al. 2011).

In the GIAM analytical framework, the GTEM module projects the greenhouse gas emissions based on economic activities. These emissions are then fed into the SCCM module. SCCM module converts the emissions into CO₂ concentration levels and then into changes in temperature. In the current version of the GIAM model, changes in temperature are fed into a ‘climate change response function’ (yellow box above). This response function analyses the interactions between changes in temperature and in a particular activity, (for example, agriculture sector responses to changes in temperature) based on a simple relationship developed using the individual crop sector productivity shocks provided under different scenarios (i.e. low, medium and high climate change effects). As shown in the ‘blue box panel above’, the current GIAM modelling framework can be used to undertake a range of analyses including climate downscaling impacts, regional climate impacts, impacts of changes in temperature and rainfall and productivity shocks.

Assumptions

Potential changes in key climate variables may change agricultural productivity in different regions in a non-uniform manner. As indicated earlier, there is some uncertainty about the nature and extent of these potential productivity changes. In this analysis, estimates of the potential impacts of climate change on productivity of different crops across different regions from a recent study by Hertel et al. (2010) are used.

Using a number of recently published relevant analyses of the potential responses of crop yields to climate change under different scenarios and under C fertilization, Hertel et al. (2010) have prescribed a range of productivity estimates (low, medium and high) attributable to climate change over the period 2000-30 for several key agricultural commodity groups. These estimates of changes in agricultural productivity are used in the modelling in this paper and are listed in table 2.

According to Hertel et al. (2010), the medium level productivity situation reflects a ‘central case’ estimate. The low productivity estimate situation reflects a world with a rapid temperature change, high sensitivity of crops to warming, and a CO₂ fertilisation effect at the lower end of the published estimates. The high productivity estimate situation depicts a world with relatively slow warming, low sensitivity of crops to climate change, and high CO₂ fertilisation. Hertel et al (2010) highlight that these productivity estimates are intended to

capture a range of plausible outcomes, and can be thought of as the 5th and 95th percentile values in a distribution of potential yield impacts.

Table 1: Regional, industry, factor and greenhouse emissions coverage in GIAM

Regions	Industries	Primary factors	Greenhouse gases
United States	Coal	Capital	Carbon dioxide
EU 25	Oil	Land	Methane
China	Gas	Labor	Nitrous oxide
Former Soviet Union	Petroleum and coal products	Natural resources	Hydrofluorocarbons
Japan	Electricity		Perfluorocarbons
India	Iron and steel		Sulfur hexafluoride
Canada	Nonferrous metals		
Australia	Chemicals, rubber, plastics		
Indonesia	Other mining		
South Africa	Non-metallic minerals		
Other Asia	Manufacturing		
OPEC	Water transport		
Rest of World	Air transport		
	Other transport		
	Wheat		
	Rice		
	Coarse grains		
	Other crops		
	Fishing, forestry		
	Processed food		
	Services		

Table 2: Assumed productivity changes (%) attributable to climate change over 2000-30 (calibrated against 1⁰C increase)

Region (crop)	Low	Medium	High
US (wheat)	-10	2	14
EU 25 (wheat)	-5	7	19
China (rice)	-12	0	12
FSU (wheat)	-5	7	19
Japan (rice)	2	9	16
India (rice)	-15	-5	4
Canada (wheat)	-5	7	19
Australia (wheat)	-5	7	19
Indonesia (rice)	0	7	14
South Africa (coarse grains)	-42	-25	-8
Other Asia (rice)	-10	-3	4
OPEC	0	0	0
ROW (coarse grains)	-22	-10	2

Source: Hertel et al (2010)

Simulation analysis

Based on the estimates of climate change impacts on agriculture provided in Hertel et al. (2010), the effects of potential changes in productivity in a selected group of crops in different regions are simulated up to the year 2050 using the GIAM model. In particular, the ‘climate-economy response function’ in GIAM is employed to analyse the agricultural sector responses to changes in temperature. The ‘climate-economy response function’ is based on a simple relationship developed using the individual crops sector productivity shocks provided under different scenarios (low, medium and high climate change effects) by Hertel et al. (2010) calibrated to 1°C change.

CSIRO’s current version of the GIAM framework allows ensemble projections where a ranges of parameter values for input factors that are defined with some uncertainty, can be input to GIAM and probability distribution functions of outputs estimated, rather than the model output being just single deterministic predictions. In particular, the GIAM modelling simulations carried out in this study involved undertaking over 100 model runs/simulations randomly selected so that they cut across different regions, different crops and the different levels of shocks to productivity (high, medium and low - see Table 2). The projection period in GIAM simulations was 2005-2050.

The GIAM model simulations carried out here are then used to estimate the resulting changes in production and trade in relevant crops in a selected group of countries. These estimates provided the basis for calculating self sufficiency, export availability and import dependency for several key food importing and exporting regions.

3. Discussion of simulation results

Climate change impacts on agriculture are likely to be influenced by the extent to which changes in key climate variables influence changes in agricultural productivity, crop yields, and agricultural production costs. These in turn lead to changes in competitiveness and hence changes in overall output levels. On the demand side, the likely magnitude of the changes in demand for agricultural commodities can vary depending on the degree of demand responsiveness to changes in incomes and prices in different regions for the various farm products.

As indicated earlier, the focus of the analysis in this paper is on self sufficiency (domestic production/domestic consumption), export availability (exports/domestic consumption) and import dependency (imports/domestic consumption) with respect to wheat and rice, the two key food commodities that have received the most attention because of price surges during 2007-08 (Martin and Anderson 2012, forthcoming) in several major food exporting advanced economies (US, Canada and Australia) and food importing developing countries (China and Indonesia). The simulation results are discussed below.

Based on the simulation results using the GIAM, the estimated wheat self sufficiency and export availability ratios for the US, Canada and Australia are illustrated in Figures 1 to 3

(the dotted line in the figures represent the reference case or the baseline, and the shaded areas depict the quartiles of impacts of policy shocks). Given that the US, Canada and Australia are major producers and exporters of wheat, any changes in wheat sector productivity is likely to have implications for wheat self sufficiency ratio and export availability ratio in these countries.

The modelling results shown in Figures 1 to 3 demonstrate uncertainty in changes in wheat self sufficiency and export availability due to variation in wheat sector productivity driven by uncertainty in climate change impacts. This is reflected in deviations between the reference case and the policy scenarios. For example, in 2050, the estimated percentage change in US wheat self sufficiency relative to the reference case level can vary from a 8% increase to a 16% decline due to uncertainty in climate change impacts. Similarly, in 2050, the estimated percentage change in US wheat export availability relative to the reference case level can vary from a 2% increase to a 5% decline.

Estimated changes in Canadian wheat self sufficiency ratio and export availability ratio (Figure 2) are broadly similar to the US results. However, the variation in wheat productivity due to climate change is relatively more favourable to Canada than for the US, as shown by Hertel et al. (2010) (see Table 2). This could be due to its higher latitude, enhanced photosynthesis due to warming, or enhanced productivity of marginal land. In 2050, the estimated percentage change in Canadian wheat self sufficiency ratio relative to the reference case level can vary from a 10% increase to a 19% decline due to uncertainty in climate change impacts. Furthermore, in 2050, the estimated percentage change in Canada's wheat export availability relative to the reference case level can vary only slightly due to uncertainty in climate change impacts, from a 0.3% increase to a 0.6% decline.

For Australia, in 2050, the estimated percentage change in wheat self sufficiency relative to the reference case level can vary from a 30% increase to a 9% decline due to uncertainty in climate change impacts. Furthermore, in 2050, the estimated percentage change in Australian wheat export availability relative to the reference case level can vary from a 4% increase to a 2% decline. It is important to note that US, Canadian and Australian impact estimates have longer tails, implying a greater degree of variation in agricultural sector responses to climate change in these countries (Figures 1 to 3).

China and Indonesia are rapidly growing economies with large populations and increasing levels of urbanisation. The growing demand for food in these countries is influenced by several factors including population and income growth and changing food consumption patterns. Climate change impacts on agriculture could have important implications for food security in these countries. The estimated rice self sufficiency and import dependency ratios for China and Indonesia are illustrated in Figures 4 and 5. In China, rice self sufficiency is estimated to decline over time in baseline and in counterfactual scenarios. This implies that domestic rice production is unlikely to meet growing domestic demand due to population and income growth. It could be argued that climate change potentially could exacerbate the adverse impacts on rice self sufficiency in China. Rice import dependency in China will in general be lower than in the baseline (reference case) in the case of improved domestic rice

sector productivity, and be greater than the baseline for decreased domestic rice sector productivity. In 2050, the estimated percentage change in Chinese rice import dependency relative to the reference case level can vary from a 14% increase to a 4% decline due to uncertainty in climate change impacts. Declining import dependency may be due to a fall in exports. It is important to note that the simulation results for China are less sensitive to the agricultural productivity shocks than those in US, Canada and Australia.

Estimated changes in Indonesian rice self sufficiency (Figure 5) are broadly similar to the results reported for China in that the range of impacts (variation) in the self sufficiency ratio is low. Import dependency for rice in Indonesia is estimated to increase over time, highlighting the growing demand for staples driven by growth in population which is less likely to be met by domestic production alone. In 2050, the estimated percentage change in Indonesian rice import dependency relative to the reference case level can vary from a 23% increase to a 4% decline due to uncertainty in climate change impacts. It is important to note that the Indonesian rice productivity shocks used in scenario analysis were between 0 % and 14 % (see Table 2).

Figure 1: Change in wheat self sufficiency and export availability: US

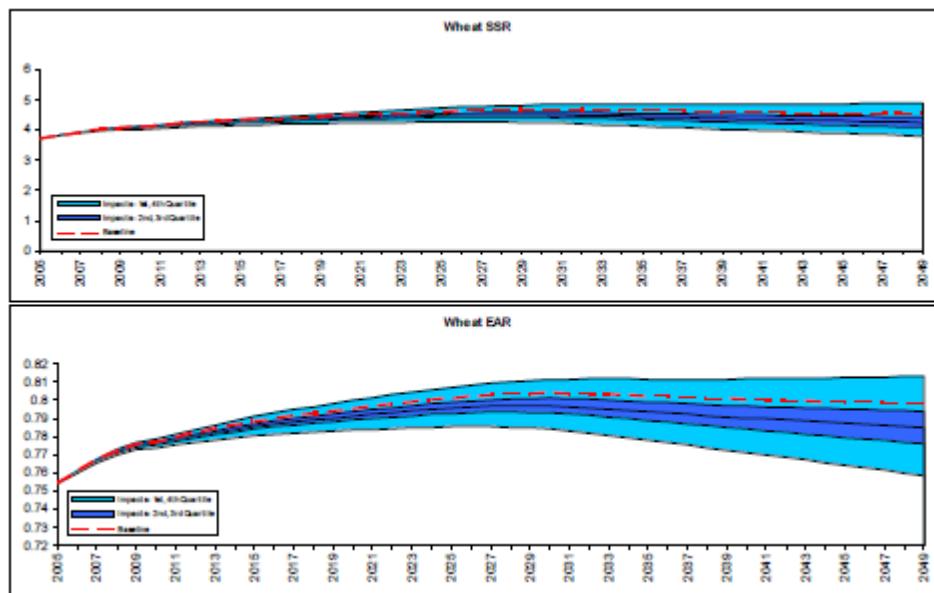


Figure 2: Change in wheat self sufficiency and export availability: Canada

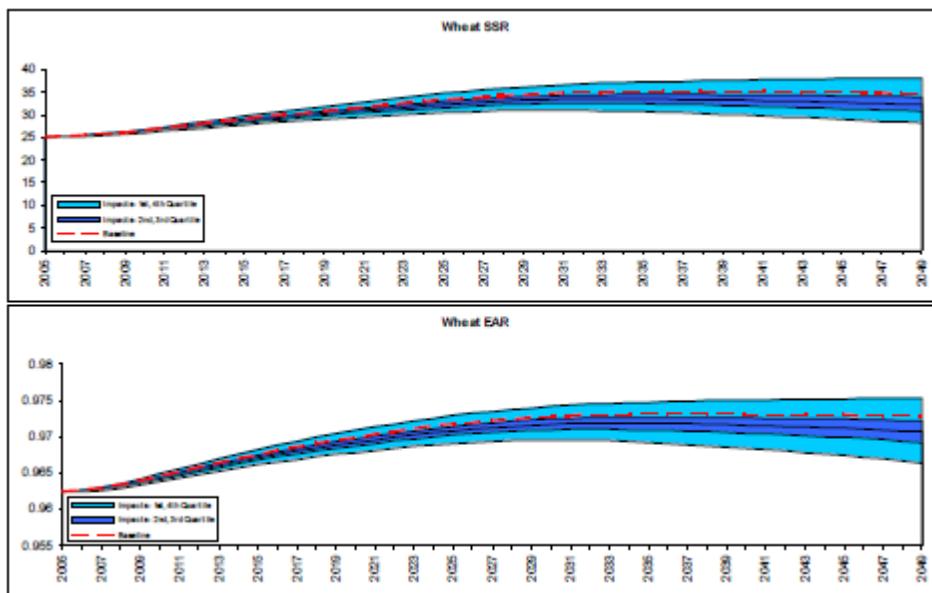


Figure 3: Change in wheat self sufficiency and export availability: Australia

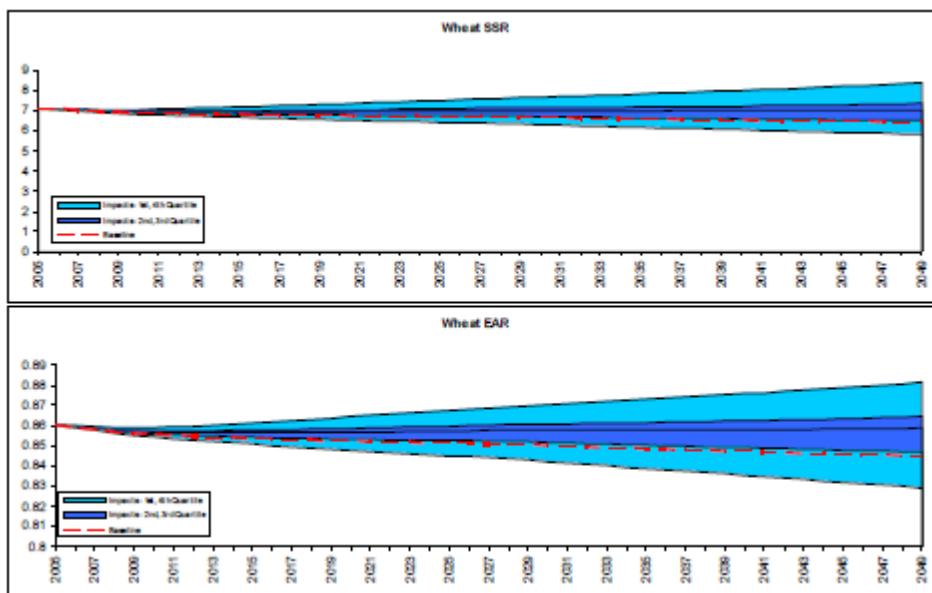


Figure 4: Change in rice self sufficiency and import dependency: China

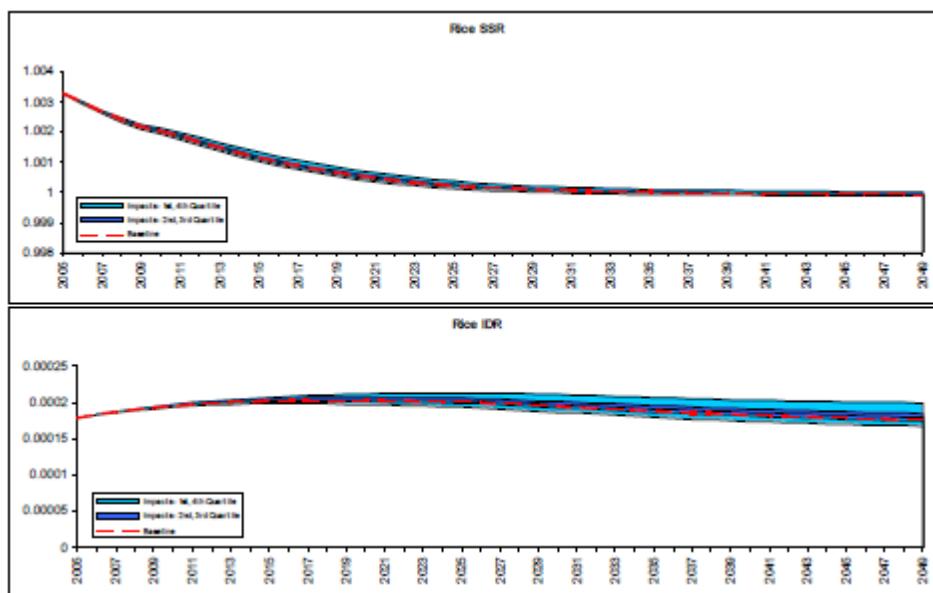
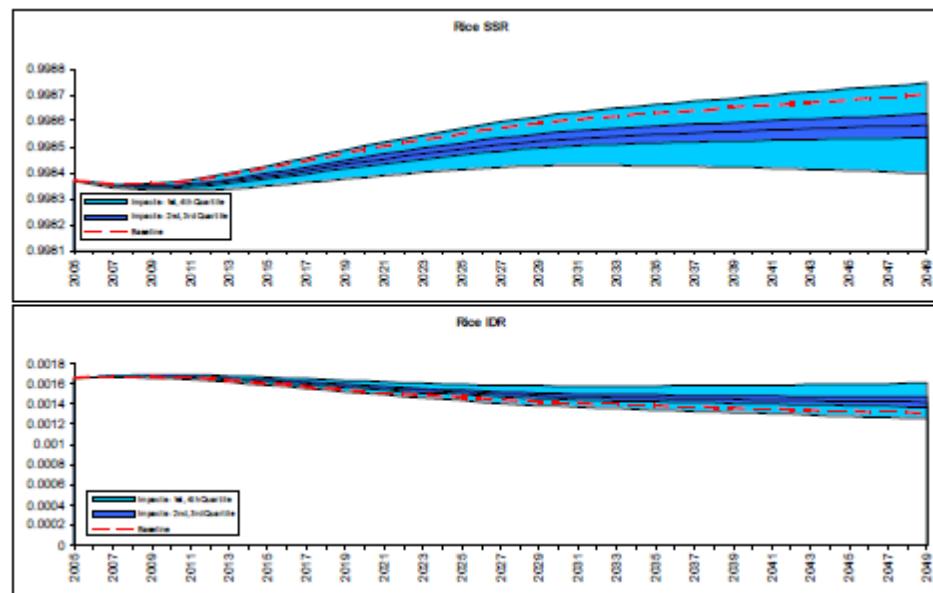


Figure 5: Change in rice self sufficiency and import dependency: Indonesia



4. Concluding remarks

The illustrative scenario examined in this paper indicates how future changes in climate may affect different regions through impacts on agricultural productivity. There are three key messages emerging from the scenario analysis.

First, at the tails of the distribution of climate change impacts simulated in this study, there is considerable variation in self sufficiency, export availability and import dependency of farm products reported for specific regions. Such wider confidence bands are likely to be further widened if other uncertainties such as the effects of distortionary economic and trade policies are added to the current analysis. In this context, it is noteworthy to highlight the potential adverse effects of market insulating agricultural trade policies in some regions. For example, Martin and Anderson (2012, forthcoming) estimate that in 2007-08 alone, insulating policies affecting the market price for rice explain 46% of the rise in the world price of rice, while 28% of the observed change in world wheat prices during 2005-08 can be explained by the changes in trade policy measures that countries used to insulate from the initial price surges.

Second, based on the trade related results (export availability and import dependency) reported here, it could be argued that unrestricted global agricultural trade could be a useful mediator between regions influenced differently by climate change. Agricultural trade flows are influenced by the interaction between comparative advantage in agriculture (as determined by relative factor and resource endowments and climate/weather conditions) and a wide ranging set of national, regional and international trade policy regimes. Unrestricted international trade allows comparative advantage to be more fully exploited. Restrictions on trade risk worsening the potential impacts of climate change by hindering the ability of producers and consumers to adjust (Nelson et al. 2010).

Third, reducing the uncertainty in climate change impacts on agriculture should be a high priority for research.

The GIAM analytical framework employed in this study has several strengths that could be further utilised in future climate change related research. These strengths include the ability of the analytical framework: to take account of the interactions between the economy and climate; to incorporate a range of plausible agricultural and other sectoral productivity outcomes due to climate change; to accommodate the changes in domestic and international production, consumption, trade and prices within an economy-wide framework; and to undertake a range of ensemble based scenario analyses to assess the impacts of climate change.

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