The Role of International Trade in Climate Change Adaptation

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By Gerald Nelson, Amanda Palazzo,
Claudia Ringler, Timothy Sulser, Miroslav Batka
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Gerald Nelson is Senior Research Fellow, Amanda Palazzo is Senior Research Assistant, Claudia Ringler is Senior Research Fellow, Timothy Sulser is Research Assistant, and Miroslav Batka is Scientist at the International Food Policy Research Institute.

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International Centre for Trade and Sustainable Development (ICTSD)
International Envrionment House 2
7 Chemin de Balexert, 1219 Geneva, Switzerland
Tel: +41 22 917 8492 Fax: +41 22 917 8093
E-mail: ictsd@ictsd.ch
Visit ICTSD's website at: www.ictsd.org

And

International Food & Agricultural Trade Policy Council (IPC)

1616 P St., NW, Suite 100, Washington, DC 20036, USA

Tel +1 202 328 5056 Fax +1 202 328 5133

Email: agritrade@agritrade.org

Visit IPC's website at www.agritrade.org

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ICTSD and IPC welcome feedback and comments on this document. These can be forwarded to Marie Chamay Peyramayou, mchamay@ictsd.ch and/or Christine St Pierre, stpierre@agritrade.org.

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FOREWORD

Early studies on the potential impacts of climate change indicated that agriculture was not likely to be severely affected, as carbon fertilization and trade flows were thought to be able to compensate for any productivity declines related to climate change. Recent work, however, has raised doubts about whether carbon fertilization laboratory test results can be replicated in the field. With the effects of carbon fertilization in question, the role of trade in the context of climate change becomes even more important. Climate change is anticipated to increase the incidence of food insecurity around the world, but trade has the potential to help counteract this effect by delivering agricultural goods to areas experiencing productivity declines. This ICTSD-IPC Platform on Climate Change, Agriculture and Trade paper by Gerald Nelson and his colleagues at the International Food Policy Research Institute (IFPRI) builds on IFPRI's important work on estimating the costs of adaptation, and projects a significant increase in agricultural trade flows, in particular from developed to developing countries.

In its recommendations to policymakers released in October, the ICTSD-IPC Platform on Climate Change, Agriculture and Trade emphasized that an open and equitable agricultural trade system is necessary to address both climate change and food security concerns. Yet, as this paper also argues, it would be unwise to rely solely on trade to help us adjust to climate change. Alongside ongoing efforts to maintain an open and equitable global food system, the international community must also importantly commit to sustained investment in agricultural productivity. We are pleased to release this paper, trusting that it will enhance the Platform's efforts to increase understanding of the linkages between climate change, agricultural production, trade and food security, which in turn will yield greater policy coherence among these issues.

Ricardo Meléndez-Ortiz
Chief Executive, ICTSD

Charlotte Hebebrand,
President /CEO, IPC

1. INTRODUCTION

Until recently, the climate change adaptation literature has tended to downplay the impacts on agriculture. Two different effects – CO_2 fertilization and changes in trade flows – were together assumed to offset much of the negative effects of climate change. Experiments in the laboratory show that higher CO_2 levels increase yields, especially of the so-called C3 plants such as rice, wheat, soybeans and sorghum.[1] The "positive effect of trade" logic relies on the assumptions that changes in trade flows will allow exploitation of changing comparative advantage brought about by climate change and that trade liberalization might further reduce the costs.

In this paper, we discuss why trade flows are especially important in agricultural adjustments to climate change, particularly in light of recent research that suggests the CO_2 fertilization effects in farmers' fields are less than in the laboratory. We review the important literature on climate change, agriculture and international trade. We then present results from a new analysis to assess the extent of adjustment via trade flows in much more detail than previously done. Our results suggest that agricultural trade is an important part of the adjustment to climate change but that agricultural productivity investments are crucial.

2. WHY TRADE FLOWS ARE IMPORTANT FOR AGRICULTURAL ADJUSTMENT TO CLIMATE CHANGE

Agricultural trade flows depend on the interaction between comparative advantage in agriculture, which is determined by climate and resource endowments, and a wide-ranging set of local, regional, national and international trade policies. Crop and animal production is affected by changes in temperature and precipitation. Because climate change results in new patterns of temperature and precipitation, agricultural comparative advantage also changes, setting up the possibility of changes in trade flows as producers respond to changing constraints and opportunities.

As with any change in comparative advantage, unfettered international trade allows comparative advantage to be more fully exploited. Restrictions on trade risk worsening the effects of climate change by reducing the ability of producers and consumers to adjust. It is also important to point out that if climate change reduces productivity of some crops in some regions and doesn't increase productivity adequately in other regions, trade cannot fully compensate for the global reduction in productivity. Climate change projections indicate that if temperature increases are severe enough, a global net reduction in productivity will be unavoidable.

3. CLIMATE CHANGE, AGRICULTURE AND TRADE—REVIEW OF THE LITERATURE

Uncertainties in future climate outcomes make it difficult to determine the effects on agricultural productivity, and therefore world trade flows. The uncertainties of future agricultural policy regimes make simulations doubly uncertain. Nonetheless, some researchers have attempted to do so. Papers in 1992 (J. Tobey et al., 1992) and 1994 (John Reilly et al., 1994) concluded that agricultural impacts of climate change would in some cases be positive and would be manageable

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[1] "Most economically important crop and weed species can be classified as either a C3 or C4 type, the names referring to whether the early products of photosynthesis are compounds with three or four carbon atoms. It has been well known for many years that the C3 photosynthetic pathway is less efficient than the C4 pathway. Because of this, C3 plants benefit much more from increases in CO2 than C4 plants." http://www.gcrio.org/USGCRP/sustain/wolfe.html, accessed 2 December 2009.

globally. Negative yield effects in temperate grain producing regions would be buffered by interregional adjustments in production and consumption and corresponding trade flows. A key assumption was that part of the production losses from temperature and rainfall would be offset by CO_2 fertilization. Another key result was that agricultural trade flows would support an agricultural system relatively resilient in the face of uncertain effects of climate.

A widely cited 2004 publication (M. L. Parry et al., 2004) based on more complex modeling of both climate and agriculture using the climate modeling results of the IPCC's Third Assessment was still relatively sanguine about global food production but with more caveats than earlier papers.

> "… the combined model and scenario experiments demonstrate that the world, for the most part, appears to be able to continue to feed itself under the SRES scenarios during the rest of this century. The explanation for this is that production in the developed countries generally benefits from climate change, compensating for declines projected for developing nations. While global production appears stable, regional differences in crop production are likely to grow stronger through time, leading to a significant polarisation of effects, with substantial increases in risk of hunger amongst the poorer nations, especially under scenarios of greater inequality (A1FI and A2) (page 66)".

These results are strongly influenced by the assumed CO_2 fertilization effect of over 10 percent for wheat, rice and soybeans and five percent for maize. Without CO_2 fertilization, the prognosis is not nearly so bright.

A 2007 study (J. Reilly et al., 2007) that simulates agricultural response to climate change and incorporates general equilibrium economic effects finds that yields would likely increase in all regions, with smaller gains in the temperate regions than previous models but positive yield changes in the tropics. As with the earlier studies, their results are strongly affected by the CO_2 fertilization effect. In addition, they make fairly strong assumptions about crop biological behavior in response to climate and other changes.

Two important questions stand out when evaluating these studies. First, the benefits of CO_2 fertilization are extremely important in essentially mitigating the rainfall and temperature effects of climate change. As mentioned above, the CO_2 fertilization effect works most strongly with C3 crops. The two most important food crops – rice and wheat – use C3 photosynthesis, as do soybeans and potatoes. Maize, sorghum, millets, and sugar cane are examples of important crops that use C4 photosynthesis and where the fertilization effect is smaller, even in the laboratory.

Recent field experiments on CO_2 fertilization (Stephen P. Long et al., 2006), find that the effects in the field are approximately 50 percent less than in experiments in enclosed containers. And another report (Jorge A. Zavala et al., 2008) finds that higher levels of atmospheric CO_2 increase the susceptibility of soybean plants to the Japanese beetle and maize to the western corn rootworm. So the actual benefits of CO_2 fertilization in *farmer fields* remain uncertain.

Second, the results in the earlier literature all depend on a relatively open world trading system where climate-induced shortfalls in some regions can be offset by imports from others. The recent lack of progress in the Doha Round and significant trade restrictions imposed during the 2008 food price crisis suggests that we should not be sanguine about the role of trade flows in agricultural adjustments to climate change. The recent disruptions in trade and in food availability with sharp price increases highlight the fragility of the food system in many poor countries, and its vulnerability to the kinds of variations in production that many predict with climate change.

Finally, these studies tend to focus on staple food crops, but the recent history of agricultural trade is driven by the rapid growth in production and export of high-value agricultural crops from the developing world, often produced in niche agroclimatic zones. These exports have provided part of the foreign exchange needed to allow developing countries to import the food and feed demanded with growing incomes. Essentially no research has been done on the extent to which those products would be affected negatively or positively by climate change. One could imagine, however, that sea level rise would negatively affect developing-country exports of seafood (in particular, shrimp raised in low-lying ponds) and relatively small temperature increases would affect temperate crops such as horticulture crops grown in niche environments elsewhere. This is clearly an area where new research is badly needed.

4. CLIMATE CHANGE, AGRICULTURE, AND TRADE – NEW RESULTS

A recent study (Gerald C. Nelson et al., 2009) and related research conducted at the International Food Policy Research Institute (IFPRI) provides the most current evidence on the effects of climate change on agriculture.[2] In this section we summarize the key findings and provide new results on the role of international trade flows in climate change adjustments.

Because climate change simulations are inherently uncertain,[3] two climate models (GCMs) —the National Centre for Atmospheric Research, US (NCAR) and the Commonwealth Scientific and Industrial Research Organization, Australia (CSIRO) models —using the A2 scenario of the IPCC Fourth Assessment Report— were used to simulate future climate. We refer to the combination of GCM model runs with A2 inputs as the NCAR and CSIRO scenarios.

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[2] The climate change modeling system combines a biophysical model (the Decision Support System for Agrotechnology Transfer (DSSAT) crop modeling suite, (J. W. Jones et al., 2003) of responses of five important crops (rice, wheat, maize, soybeans, and groundnuts) to climate, soil, and nutrients with the ISPAM data set of crop location and management techniques (Liang You and Stanley Wood, 2006). These results are then aggregated and used in IFPRI's global agricultural supply and demand projections model, IMPACT2009. The IMPACT model was originally developed at IFPRI for projecting global food supply, food demand, and food security to 2020 and beyond (M.W. Rosegrant et al., 2008). It covers 32 crop and livestock commodities in 281 regions of the world—called food production units (FPUs)—which cover 115 countries (or in some cases groups of countries) and subdivides large countries into major river basins. The model links countries and regions through the production and demand relationships of international trade. It simulates growth in crop production, determined by crop and input prices, external rates of productivity growth and area expansion, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth and contains four categories of commodity demand—food, feed, biofuels, and other uses. The model solves by adjusting world prices until annual global net trade is zero for each commodity in the model. The 2009 version of the model includes a hydrology model and links to the DSSAT crop simulation model, with yield effects of climate change at 0.5 degree intervals aggregated to the FPU level.

[3] To understand the uncertainty it is useful to describe briefly the process by which the climate results are derived. They start with global (or general) circulation computer models (GCMs) that simulate the physics and chemistry of the atmosphere and its interactions with oceans and the land surface. Several GCMs have been developed independently around the world. Next, integrated assessment models (IAMs) simulate the interactions between humans and their surroundings, including industrial activities, transportation, agriculture and other land uses and estimate the emissions of the various greenhouse gasses (carbon dioxide, methane and nitrous oxide are the most important). Several independent IAMs exist as well. The emissions simulation results of the IAMs are made available to the GCM models as inputs that alter atmospheric chemistry. The end result is a set of estimates of precipitation and temperature values around the globe often at 2 degree intervals (about 200 km at the equator) for most models (see Table 8.1 in Randall, et al. (2007) for details about the models used in the 4th IPCC assessment). Periodically, the Intergovernmental Panel on Climate Change (IPCC) issues assessment reports on the state of our understanding of climate science and interactions with the oceans, land and human activities. The fourth assessment reports (AR4) were issued during 2007, and work has begun on AR5.

Table 1 shows the changes in temperature and precipitation averaged by World Bank regions and highlights the substantial differences. Both scenarios project higher temperatures in 2050, resulting in higher evaporation and increased precipitation as this water vapor returns to earth. The "wetter" NCAR scenario foresees average precipitation increases on land of about 10 percent, whereas the "drier" CSIRO scenario has increases of about 2 percent. Although average temperature increases everywhere, the effect is not uniform. Increases in minimum temperature by region range from 1.57 to 4.35°C. Maximum temperature differences range from 1.56 to 3.65°C. Precipitation changes are both negative and positive. For example, average precipitation declines by 0.6 percent in Latin America and the Caribbean with the CSIRO scenario and increases 22.1 percent in the Middle East and North Africa with the NCAR scenario.

Table 1. Precipitation and temperature regional average changes, 2000 to 2050

	GCM	Precipitation (mm)	Precipitation (%)	Monthly average minimum temperature (°C)	Monthly average maximum temperature (°C)
East Asia and Pacific	CSIRO	21.9	2.1	1.66	1.56
East Asia and Pacific	NCAR	76.21	7.6	2.61	2.08
Europe and Central Asia	CSIRO	26.21	6.1	1.82	1.67
Europe and Central Asia	NCAR	56.14	13.2	4.35	3.65
Latin America and the Caribbean	CSIRO	-8.36	-0.6	1.57	1.62
Latin America and the Caribbean	NCAR	28.39	1.9	2.03	1.91
Middle East and North Africa	CSIRO	-2.36	-2.0	1.65	1.56
Middle East and North Africa	NCAR	26.96	22.1	2.80	2.54
South Asia	CSIRO	14.51	1.6	1.79	1.64
South Asia	NCAR	100.95	11.2	2.37	1.76
Sub-Saharan Africa	CSIRO	-27.75	-3.5	1.69	1.79
Sub-Saharan Africa	NCAR	69.58	8.6	2.29	1.77
All Developing	CSIRO	6.44	0.8	1.71	1.66
All Developing	NCAR	56.85	7.5	3.08	2.58
World	CSIRO	9.09	1.8	1.30	1.22
World	NCAR	45.55	9.1	2.28	1.91

Source: Authors' calculations.

Note: The last two columns in this table report the regional average monthly temperature change, either average monthly minimum or maximum. For example, in the East Asia and Pacific region the increase in monthly average minimum temperature (the coldest temperature of each day averaged over a month) with the CSIRO model over the entire region is 1.66°C.

Figure 1 and Figure 2 graph the changes in average maximum temperature between 2000 and 2050 for the CSIRO and NCAR scenarios. Figure 3 and Figure 4 show changes in average precipitation. In each set of figures the legend colors are identical; i.e., a specific color represents the same change in temperature or precipitation across the two scenarios. A quick glance at these figures reinforces the message of Table 1 about the substantial differences that exist across the two climate scenarios. For example the NCAR scenario has substantially higher average maximum temperatures in the northern hemisphere than the CSIRO scenario. The CSIRO scenario has substantial precipitation declines in the western Amazon while NCAR shows declines in the eastern Amazon. The NCAR scenario has higher precipitation in Sub-Saharan Africa than does CSIRO. Northern China has both higher temperature and more precipitation under NCAR than under CSIRO. These figures illustrate qualitatively a range of potential climate outcomes with current modeling capabilities and are thus an indication of the uncertainty of climate change impacts.

Figure 1. **Change in average maximum temperature, 2000 - 2050, CSIRO**

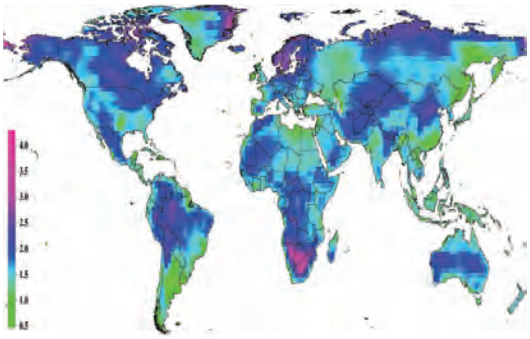


Figure 2. **Change in average maximum temperature, 2000 - 2050, NCAR**

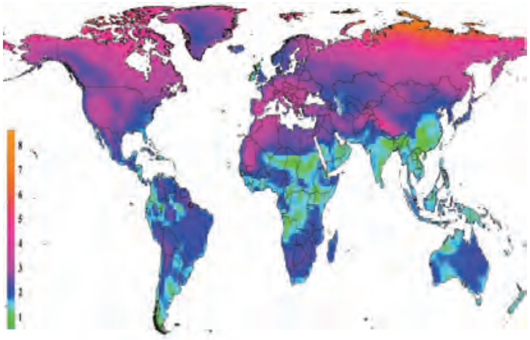


Figure 3. **Change in precipitation, 2000 - 2050, CSIRO**

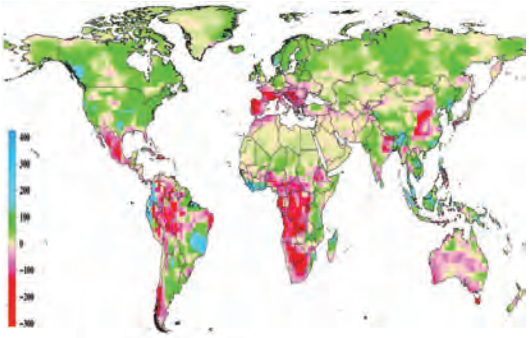
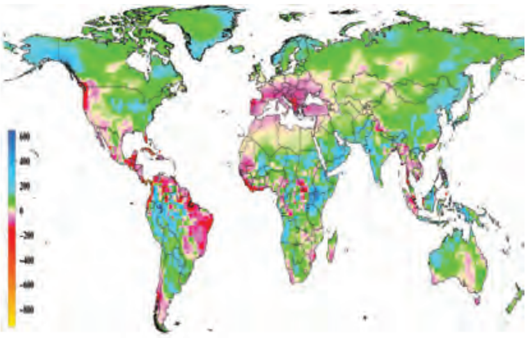


Figure 4. **Change in precipitation, 2000 - 2050, NCAR**



Source: Nelson, Rosegrant, et al (2009).

4.1 Climate Change Effects on Yields

We model the climate change effects on crop yields by growing a crop virtually (i.e., in the DSSAT model with location-specific soil and nutrient inputs) with 2000 climate and with one of the 2050 climate scenarios, and then calculating the ratio of the yields. Selected results are reported in Table 2. For most crops, yield declines predominate when CO_2 fertilization is not included. Irrigated and rainfed wheat and irrigated rice are hard hit, and crops in South Asia are particularly negatively affected. The East Asia and Pacific region includes both China, which is temperate for the most part, and tropical Southeast Asia, so the differential effects of climate change in these two climate zones are masked. In China, some crops fare reasonably well because higher future temperatures are favorable in locations where current temperatures are at the low end of the crop's optimal range.

With the CO_2 fertilization effect included, yield declines are reduced and in many locations some yield increases occur relative to 2000. However, irrigated maize and irrigated and rainfed wheat still see substantial areas of reduced yields. Sub-Saharan Africa sees mixed results with small declines or increases in maize yields and large negative effects on rainfed wheat. The Latin America and Caribbean region has mixed yield effects, with some crops up slightly and some down.

Table 2. Yield changes by region, crop and management system under current climate and two climate change scenarios (2050 climate) with and without CO2 fertilization effects (% change from yields with 2000 climate)

REGION	CSIRO NOCF	NCAR NOCF	CSIRO CF	NCAR CF
Maize, irrigated				
East Asia and the Pacific	-1.3	-2.6	-0.8	-1.9
Europe and Central Asia	0.0	-1.3	0.1	-1.2
Latin America and the Caribbean	-2.8	-3.0	-2.3	-2.5
Middle East and North Africa	0.1	-1.0	-0.4	-1.1
South Asia	-6.4	-5.5	-4.4	-3.6
Sub-Saharan Africa	0.3	0.6	0.5	0.8
Developing Countries	-2.0	-2.8	-1.4	-2.1
Developed Countries	-1.2	-8.7	-1.2	-8.6
World	-0.8	-5.6	-0.6	-5.2
Maize, rainfed				
East Asia and the Pacific	1.5	-3.9	3.7	-2.0
Europe and Central Asia	25.0	3.7	32.8	12.4
Latin America and the Caribbean	-0.4	-1.9	2.2	0.4
Middle East and North Africa	58.6	-46.7	61.8	-46.3
South Asia	-2.9	-7.8	0.2	-4.9
Sub-Saharan Africa	-2.4	-4.6	-0.8	-2.7
Developing Countries	0.2	-2.9	2.6	-0.8
Developed Countries	0.6	-5.7	9.5	2.5
World	1.0	-3.4	5.3	0.5

REGION	CSIRO NOCF	NCAR NOCF	CSIRO CF	NCAR CF
Rice, irrigated				
East Asia and the Pacific	-13.0	-19.8	4.4	-1.1
Europe and Central Asia	-4.1	-15.1	15.0	5.7
Latin America and the Caribbean	-6.4	-0.8	-1.2	7.0
Middle East and North Africa	-13.3	-29.5	1.7	-14.4
South Asia	-15.5	-17.5	2.5	1.4
Sub-Saharan Africa	-11.4	-14.1	5.7	2.4
Developing Countries	-14.4	-18.5	2.4	-0.5
Developed Countries	-3.5	-5.5	10.5	9.0
World	-13.8	-17.8	2.8	-0.0
Rice, rainfed				
East Asia and the Pacific	-4.5	-5.8	2.5	1.8
Europe and Central Asia	49.8	-1.0	61.3	-6.1
Latin America and the Caribbean	5.3	-1.8	12.7	6.7
Middle East and North Africa	0	0	0	0.0
South Asia	0.1	2.6	8.5	10.2
Sub-Saharan Africa	0.1	-0.5	8.1	7.3
Developing Countries	-1.3	-1.4	6.5	6.4
Developed Countries	17.3	10.3	23.4	17.8
World	-1.3	-1.4	6.5	6.4
Soybean, irrigated				
East Asia and the Pacific	-8.2	-13.4	9.1	3.6
Europe and Central Asia	31.9	30.1	32.9	30.5
Latin America and the Caribbean	-1.2	-2.5	19.5	18.2
Middle East and North Africa	-4.2	-14.0	5.6	-5.0
South Asia	-9.5	-11.5	12.0	10.3
Sub-Saharan Africa	4.6	5.0	17.8	17.8
Developing Countries	-8.0	-12.3	10.3	5.8
Developed Countries	2.5	-2.7	15.0	9.0
World	-0.4	-5.4	13.7	8.0
Soybean, rainfed				
East Asia and the Pacific	-3.6	-8.6	17.0	11.5
Europe and Central Asia	25.5	5.9	37.0	5.9
Latin America and the Caribbean	-2.6	4.2	19.1	19.1
Middle East and North Africa	17.5	-84.2	26.0	-76.4
South Asia	-13.8	-13.6	4.4	7.9
Sub-Saharan Africa	-3.5	-5.8	19.1	17.8
Developing Countries	-2.3	1.7	19.5	18.0
Developed Countries	14.1	6.6	19.5	15.1
World	1.1	2.3	18.0	16.3

REGION	CSIRO NOCF	NCAR NOCF	CSIRO CF	NCAR CF
Wheat, irrigated				
East Asia and the Pacific	-2.7	-7.1	3.7	-0.6
Europe and Central Asia	-9.4	-19.8	-3.3	-14.7
Latin America and the Caribbean	0.3	-5.6	6.5	0.9
Middle East and North Africa	-12.8	-19.7	-5.8	-13.4
South Asia	-47.1	-53.9	-38.3	-45.8
Sub-Saharan Africa	0.7	1.4	7.3	9.7
Developing Countries	-28.3	-34.3	-20.8	-27.2
Developed Countries	-5.7	-4.9	-1.3	-0.1
World	-25.6	-31.1	-18.5	-24.4
Wheat, rainfed				
East Asia and the Pacific	-14.8	-16.1	-5.4	-9.2
Europe and Central Asia	-0.3	-1.8	8.5	8.0
Latin America and the Caribbean	2.3	4.2	12.2	11.8
Middle East and North Africa	-2.6	-8.1	8.8	2.0
South Asia	-44.4	-43.7	-28.9	-28.0
Sub-Saharan Africa	-19.3	-21.9	-11.2	-15.9
Developing Countries	-1.4	-1.1	9.3	8.5
Developed Countries	3.1	2.4	9.7	9.5
World	1.0	0.8	9.7	9.1

Source: Nelson, Rosegrant, et al (2009) and authors' calculations.

Note: For each region, crop and management system, this table reports the area weighted average change in yield for a crop grown with 2050 climate instead of 2000 climate. CF = with CO2 fertilization; No CF = without CO2 fertilization.

4.2 World Price and Production Impacts of Climate Change

The biological effects of climate change are used to alter the so-called intrinsic productivity growth rates in the IMPACT model that capture exogenous investments in productivity enhancements. The equilibrium outcomes reported below assume three scenarios for climate in 2050 – a no-climate change-scenario that assumes the 2050 climate will be identical to that around 2000 and the climate outcomes from the NCAR and CSIRO scenarios.

World prices are a useful single indicator of the diverse effects of climate change on agriculture. Table 3 shows prices in 2000 and 2050 for major crop and livestock products with the three climate change scenarios assuming no CO_2 fertilization effect, and the percentage changes between the with- and without- CO_2 fertilization effects for the two climate change scenarios. Figure 5 shows the world price effects for the major grains, assuming no CO_2 fertilization effects.

There are two important summary points to make from the table and figure. First, even without climate change, the model results show world price increases between 2000 and 2050, a consequence of assumed population and income growth that are greater than the productivity and area growth. However, climate change makes the price increase much greater. Even with no climate change, the model estimates an increase in the price of rice of 62 percent, maize of 63 percent, soybeans of 72 percent, and wheat of 40 percent. Climate change results in additional price increases – 32 to 37 percent for rice, 52 to 55 percent for maize, 94 to 111 percent for wheat, and 11 to 14 percent for soybeans. If CO_2 fertilization is effective in farmers' fields, the 2050 price increases are smaller, with the effect varying by crop.

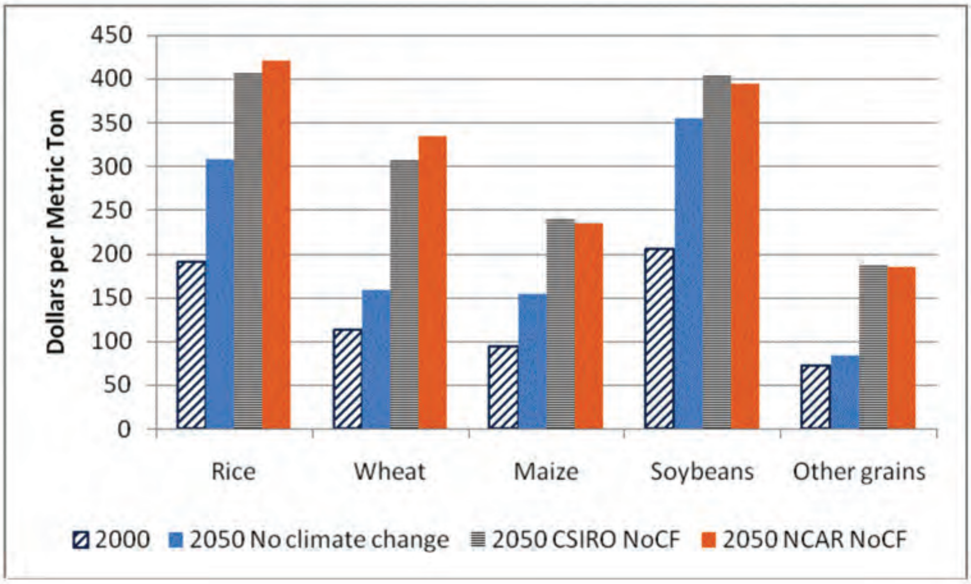
Table 3. World prices of selected crops and livestock products (constant 2000 US$/metric ton)

AGRICULTURAL PRODUCTS	**2000**	**2050**				
		No climate change	**NCAR No CF**	**CSIRO No CF**	**NCAR CF effect**	**CSIRO CF effect**
		US$/metric ton			**% change from 2050 No CF results**	
Rice	190	307	421	406	-17.0	-15.1
Wheat	113	158	334	307	-11.4	-12.5
Maize	95	155	235	240	-11.2	-12.6
Soybeans	206	354	394	404	-60.6	-62.2
Beef	1,925	2,556	3,078	3,073	-1.3	-1.5
Pork	911	1,240	1,457	1,458	-1.3	-1.5
Poultry	1,203	1,621	1,968	1,969	-1.9	-2.1

Source: Nelson, Rosegrant, et al (2009) and authors' calculations.

Notes: Prices are in 2000 US$. The last two columns in this table report the percentage difference between the price in 2050 with and without the CO2 fertilization effect. For example, with the NCAR scenario, assuming CO2 fertilization is effective in the field results in a 17.0 percent reduction in the world rice price relative to the level reached with no CO2 fertilization. The decline in prices of livestock products with CO2 fertilization reflects the reduced cost of feed.

Figure 5. World prices of major grains (2000 US$)



Source: Nelson, Rosegrant, et al (2009).

Production results in 2000 and 2050 with the three climate scenarios are reported in Table 4 and Figure 6 to Figure 13. Without climate change, production of all major crops increases in developing countries. For example, in developing countries, production of rice increases by 17 percent, wheat by 76 percent and maize by 73 percent. Climate change reverses much of this increase, with the extent of the change depending on the region, crop, and climate model. For example, in South Asia, maize production increases by 15 percent with no climate change but is 9 percent below that level with the NCAR scenario and 19 percent below with the CSIRO scenario. In Sub-Saharan Africa, maize production increases by 45 percent without climate change but is 10 percent below that level with the CSIRO scenario and 7 percent lower with the NCAR scenario.

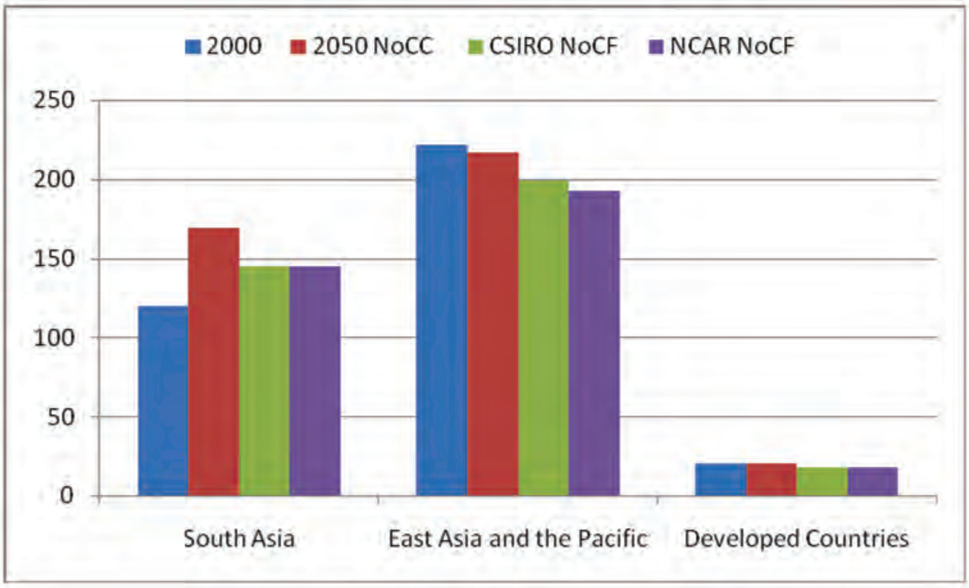
Table 4. Climate-change effects on maize, wheat and rice production, no CO$_2$ fertilization

	South Asia	East Asia and the Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	Sub-Saharan Africa	Developed Countries	Devel-oping Countries	World
Rice									
2000 (mmt)	119.8	221.7	1.1	14.8	5.5	7.4	20.4	370.3	390.7
2050 No CC (mmt)	168.9	217.0	2.6	17.8	10.3	18.3	20.3	434.9	455.2
CSIRO (%)1	-14.3	-8.1	-0.2	-21.7	-32.9	-14.5	-11.8	-11.9	-11.9
NCAR (%)1	-14.5	-11.3	-0.8	-19.2	-39.7	-15.2	-10.6	-13.6	-13.5
Wheat									
2000 (mmt)	96.7	102.1	127.5	23.5	23.6	4.5	205.2	377.9	583.1
2050 No CC (mmt)	191.3	104.3	252.6	42.1	62.0	11.4	253.7	663.6	917.4
CSIRO (%)1	-43.7	1.8	-43.4	11.4	-5.1	-33.5	-7.6	-29.2	-23.2
NCAR (%)1	-48.8	1.8	-51.0	17.4	-8.7	-35.8	-11.2	-33.5	-27.4
Maize									
2000 (mmt)	16.2	141.8	38.0	80.1	8.2	37.1	297.9	321.3	619.2
2050 No CC (mmt)	18.7	264.7	62.7	143.1	13.1	53.9	505.1	556.2	1,061.3
CSIRO (%)1	-18.5	-12.7	-19.0	-0.3	-6.8	-9.6	11.5	-10.0	0.2
NCAR (%)1	-8.9	8.9	-38.3	-4.0	-9.8	-7.1	1.8	-2.3	-0.4

Source: Nelson, Rosegrant, et al (2009).

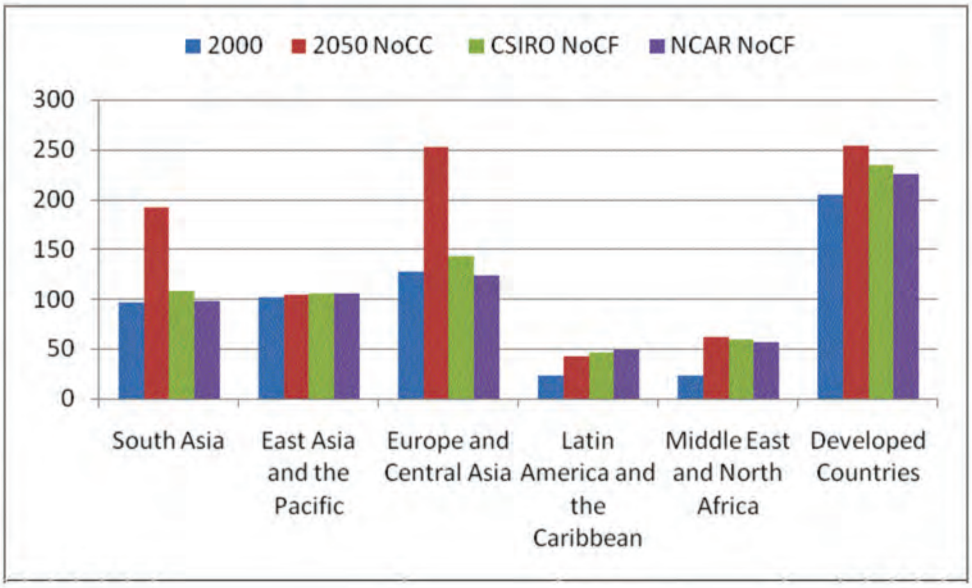
Note: The values rows labeled “CSIRO (%)” and “NCAR (%)” indicate the additional percent change in production in 2050 due to climate change relative to 2050 with no climate change. For example, South Asia maize production was 16.2 mmt in 2000. With no climate change, South Asia maize production is predicted to increase to 18.7 mmt in 2050, an increase of 15.7 percent. With the CSIRO scenario, South Asia maize production in 2050 is 18.5 percent lower than with no climate change in 2050; mmt = million metric tons.

Figure 6. Rice production, 2000 and 2050, major producing regions (million mt)



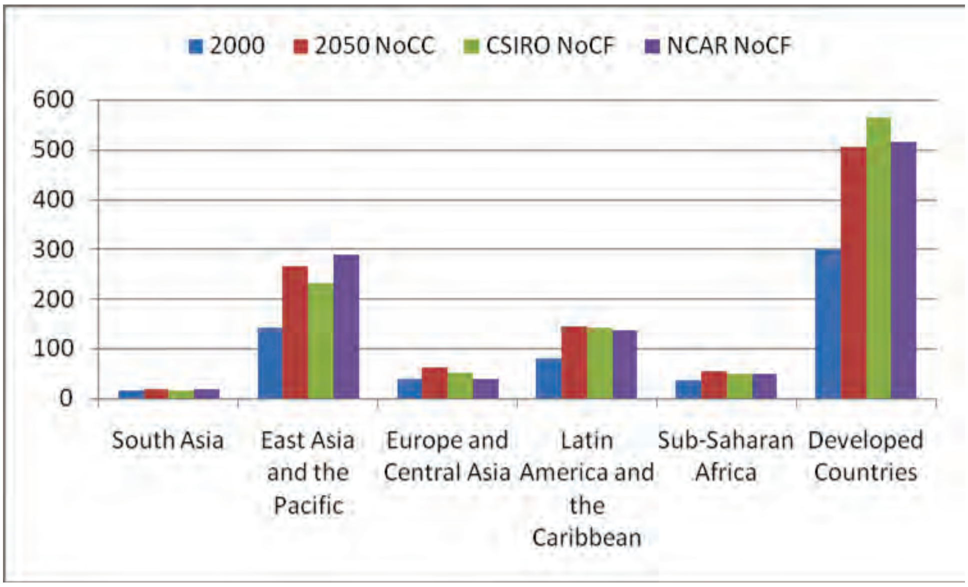
Source: Authors' estimates.

Figure 7. Wheat production, 2000 and 2050 (million mt)



Source: Authors' estimates.

Figure 8. Maize production, 2000 and 2050 (million mt)



Source: Authors' estimates.

4.3 Trade in Agricultural Commodities

As with the earlier studies, our simulations result in trade flow adjustments with climate change. Table 5 and Figure 9 report net cereal flows. With no climate change, developed-country net exports increase from 83.4 million mt to 105.8 million mt between 2000 and 2050, an increase of 27 percent. Developing-country net imports mirror this change. With the NCAR results and no CO_2 fertilization, developed-country net exports increase slightly (0.9 million mt) over no climate change. With the drier CSIRO scenario, on the other hand, developed-country net exports increase by 39.9 million mt.[4]

Regional results show important differences in the effects of climate change on trade and the differential effects of the three scenarios. For example, South Asia is a small net exporter in 2000 and becomes a net importer of cereals in 2050 with no climate change. Both climate change scenarios results in substantial increases in South Asian net imports relative to no climate change. The East Asia and Pacific region is a net importing region in 2000 and imports grow substantially with no climate change. Depending on climate change scenario, this region either has slightly less net imports than with the no-climate-change scenario or becomes a net exporter. In Latin America and the Caribbean, the 2050 no-climate-change scenario is increased imports relative to 2000 but the CSIRO and NCAR climate scenarios result in smaller net imports in 2050 than in 2000.

The effects of climate change on trade flow values are even more dramatic than on production because of climate change effects on prices. As shown in Table 6, without climate change, the value of developing country net imports of cereals in 2050 is 114 percent greater than in 2000. With the wetter NCAR scenario, 2050 net imports value is 262 percent greater than in 2000; with the drier CSIRO scenario it is 361 percent greater.

The climate scenario differences in trade flows are driven by geographical differences in production effects. For example, without climate change,

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[4] The results with CO2 fertilization increase developed-country exports by an additional 12 to 18 percent relative to no climate change.

2050 developed country production of maize increases by 207.2 million mt (an increase of 70 percent); in developing countries, maize production increases by 234.9 million mt (73 percent). With both CSIRO and NCAR scenarios, developed country production increases more, while developing country production increases less, but the magnitudes of these changes are much greater with CSIRO than with NCAR. The result is much greater net exports of maize (and other major rainfed crops) from developed countries with CSIRO than with NCAR. Similar differences exist for wheat, where the climate change effects on yield are much more dramatic in developing countries than in developed countries.

Table 5. Net cereal (rice, wheat, maize, millet, sorghum, and other grains) exports by region in 2000 and 2050 under scenarios with and without climate change (000 mt)

	2000	2050				
REGION		No climate change	CSIRO No CF	NCAR No CF	CSIRO CF effects (%)	NCAR CF effects (%)
South Asia	15,013	-19,791	-53,823	-51,663	-15.0	-8.1
East Asia and the Pacific	-19,734	-72,530	-55,086	8,158	9.1	-58.5
Europe and Central Asia	8,691	178,097	64,916	34,760	4.4	6.5
Latin America and the Caribbean	-11,358	-38,063	-3,114	-2,848	251.7	239.5
Middle East and North Africa	-51,753	-84,592	-66,708	-64,459	-0.0	0.6
Sub-Saharan Africa	-22,573	-65,122	-29,236	-28,011	53.1	49.5
Developed Countries	83,352	105,809	145,740	106,672	12.1	18.4
Developing Countries	-83,352	-105,809	-145,740	-106,672	12.1	18.4

Source: Authors' estimates.

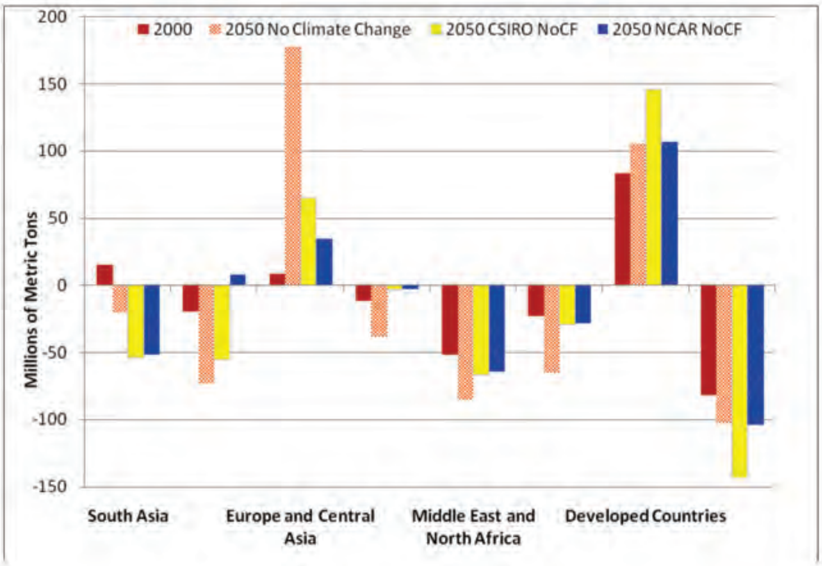
Note: The last two columns in this table report the percentage difference between the net imports in 2050 with climate change and with the CO2 fertilization effect. For example, Sub-Saharan countries import 28.0 million mt under the NCAR climate scenario and no CO2 fertilization effects. CO2 fertilization increases this number by 49.5 percent.

Table 6: Value of net cereal trade by region (million US$)

REGION	2000	2050 No Climate Change	2050 CSIRO	2050 NCAR
South Asia	2,589	-2,238	-14,927	-14,727
East Asia and the Pacific	-1,795	-7,980	-8,879	6,530
Europe and Central Asia	750	24,276	14,377	6,662
Latin America and the Caribbean	-1,246	-6,027	-342	480
Middle East and North Africa	-5,600	-12,654	-17,723	-17,703
Sub Saharan Africa	-2,995	-12,870	-10,914	-11,153
Developing Countries	8,500	18,184	39,219	30,733
Developed Countries	-8,500	-18,184	-39,219	-30,733

Source: Authors' estimates.

Figure 9. Net cereal (rice, wheat, maize, millet, sorghum, and other grains) trade by region in year 2000 and 2050 under scenarios with and without climate change (million mt)



Source: Authors' estimates.

5. DO TRADE FLOW CHANGES COMPENSATE FOR CLIMATE CHANGE?

As mentioned above earlier literature on the climate change effects on food availability were relatively sanguine as changes in trade flows and CO_2 fertilization offset productivity effects. Our results suggest that these conclusions were too optimistic.

Changes in production result in changes in per capita calorie availability. To assess the welfare effects of these changes we use a statistical relationship estimated by Smith and Haddad (2000) that relates child malnutrition[5] to calorie availability, maternal education, access to clean drinking water and the ratio of female to male life expectancy at birth. All variables other than calorie availability are assumed to remain constant. Table 7 reports the results.

With no climate change, only Sub-Saharan Africa would experience an increase in the number of malnourished children between 2000 and 2050 as rapid population growth offsets a declining share of malnourished children. All other parts of the developing world would experience relatively large declines in the number of malnourished children due to rapid income and agricultural productivity growth. Climate change eliminates much of the improvement in child malnourishment levels that would occur with no climate change. For example, in East Asia and the Pacific, instead of 10 million malnourished children in 2050, the number increases to more than 14 million malnourished children under both scenarios. In South Asia, instead of 52 million malnourished children in 2050, there would be more than 58 million. In Sub-Saharan Africa, climate change is expected to increase the number by more than 11 million children. If CO_2 fertilization is in fact effective in farmers' fields, the negative effect of climate change on child malnutrition is reduced somewhat.

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[5] We use the underweight definition of malnutrition (proportion of children under 5 falling below minus two standard deviations from the median weight-for-age standard set by the U.S. National Center for Health Statistics and the World Health Organization.

Table 7. Total number of malnourished children in 2000 and 2050 (million children, under 5 yrs of age).

	2000	**2050**				
REGION		**No climate change**	**NCAR No CF**	**CSIRO No CF**	**NCAR CF effects** (% change relative to NCAR no CF in 2050)	**CSIRO CF effects** (% change relative to CSIRO no CF in 2050)
South Asia	75.6	52.3	59.1	58.6	-2.7	-2.7
East Asia and the Pacific	23.8	10.1	14.5	14.3	-9.0	-9.0
Europe and Central Asia	4.1	2.7	3.7	3.7	-4.4	-4.9
Latin America and the Caribbean	7.7	5.0	6.4	6.4	-4.7	-4.8
Middle East and North Africa	3.5	1.1	2.1	2.0	-10.3	-11.3
Sub-Saharan Africa	32.7	41.7	52.2	52.1	-5.4	-5.6
All Developing Countries	147.8	113.3	138.5	137.4	-4.6	-4.8

Source: Nelson, Rosegrant, et al (2009).

Note: The values rows labeled "CSIRO (%)" and "NCAR (%)" indicate the additional percent change in production in 2050 due to climate change relative to 2050 with no climate change. For example, South Asia maize production was 16.2 mmt in 2000. With no climate change, South Asia maize production is predicted to increase to 18.7 mmt in 2050, an increase of 15.7 percent. With the CSIRO scenario, South Asia maize production in 2050 is 18.5 percent lower than with no climate change in 2050; mmt = million metric tons.

6. CONCLUSIONS

This analysis reports the consequences of climate change for agricultural trade flows. As with earlier studies, we find that changing trade flows are an important mechanism to offset partially the negative productivity effects of climate change. With climate change, developing country imports of major grains increase substantially. But they do not completely compensate for the productivity effects that result in fewer calories consumed in developing countries. Child malnutrition increases by about 20 percent relative to the no climate change scenario, or about 25 million additional malnourished children. Investments that increase agricultural productivity are necessary to complement the adjustment benefits of changing trade flows and other adjustment mechanisms available to the world's farmers.

Neither an open international trade system nor adequate investment in agricultural productivity are a given. Both require long-term commitment from national governments and the international community.

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About the Platform

In 2008 the International Food & Agricultural Trade Policy Council (IPC) and the International Centre for Trade and Sustainable Development (ICTSD) launched The ICTSD-IPC Platform on Climate Change, Agriculture and Trade. This interdisciplinary platform of climate change, agricultural and trade experts seeks to promote increased policy coherence to ensure effective climate change mitigation and adaptation, food security and a more open and equitable global food system. Publications include:

- International Climate Change Negotiations and Agriculture.
  Policy Brief No.1, May 2009

- Greenhouse Gas Reduction Policies and Agriculture: Implications for Production Incentives and International Trade Disciplines.
  Issue Brief No.1, by D. Blandford and T. Josling, August 2009

- Climate Change and Developing Country Agriculture: An Overview of Expected Impacts, Adaptation and Mitigation Challenges, and Funding Requirements.
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- The Role of International Trade in Climate Change Adaptation.
  Issue Brief No. 4, by G. Nelson, A. Palazzo, C. Ringler, T. Sulser and M. Batka, December 2009

- Climate Change and China's Agricultural Sector: An Overview of Impacts, Adaptation and Mitigation.
  Issue Brief No. 5, by J. Wang, J. Huang and S. Rozelle (forthcoming)

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The International Centre for Trade and Sustainable Development was established in Geneva in September 1996 to contribute to a better understanding of development and environment concerns in the context of international trade. As an independent non-profit and non-governmental organization, ICTSD engages a broad range of actors in ongoing dialogue about trade and sustainable development. With a wide network of governmental, non-governmental and inter-governmental partners, ICTSD plays a unique systemic role as a provider of original, non-partisan reporting and facilitation services at the intersection of international trade and sustainable development. More information is available at www.ictsd.org.

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