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Climate Change, Agricultural Productivity and its Impacts on the Food Industry: A General Equilibrium Analysis

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Table of Contents

INTRODUCTION	1
LITERATURE REVIEW – IMPACTS OF CLIMATE CHANGE ON FOOD SYSTEMS.....	2
METHODOLOGY – A GENERAL EQUILIBRIUM APPROACH	6
Data	7
Scenarios.....	9
Limitations.....	11
RESULTS	12
CONCLUSIONS	19
REFERENCES	21

List of Tables

Table 1. Regions analyzed and description

Table 2. Sectors analyzed and description

Table 3. Regional 5-GCM-mean climate change and CO₂ fertilization impacts on crop yields (percent change in 2046-2055 relative to 1996-2005) on current (2000) crop land.

List of Graphs

Figure 1. Share of Food processing in production and trade, 2004

Figure 2. Figure 2. Share of total world exports of processed food products, 2004

Figure 3. World impact on crop yields in 2050 relative to 2000.

Figure 4. Change in Output of Food Processing Sectors (percentage)

Figure 5. Change in Exports and Imports of Food Processing Sectors (percentage)

Figure 6. Change in Crops and Livestock supply prices (percentage)

Figure 7. Change in Food Industry Prices (percentage)

Abstract

This paper analyses the impacts of climate change of food processing sectors worldwide. Specifically, we analyze the impacts that changes in agricultural productivity might have for seven food industry sectors, namely meat, vegetable oils and fats, dairy, sugar, processed rice, other food products and beverage and tobacco products. We analyze two different scenarios of crops yield changes based on Müller et al. (2009), one with full CO₂ fertilization and one without CO₂ fertilization. We use a general equilibrium approach, given the advantages that this methodology provides for worldwide analysis of productivity and its impacts on production, trade and prices of primary agriculture, and ultimately, food processing sectors. We use the GTAP computable general model with version 7 of the GTAP database, with a base year of 2004. We aggregate this database into 10 regions and 12 sectors, with special emphasis on food processing sectors. The results show that overall, the impacts on food processing depends whether we consider CO₂ fertilization or not. With full fertilization,

JEL Classification:

Keywords: Climate change, productivity, agriculture, food industry

Introduction

Agricultural practices are major anthropogenic contributors to climate change (IPCC, 2001). According to the World Bank (2008), they account for 30 percent of greenhouse emissions. Conversely, the agricultural sector is also very susceptible to climate change, which threatens food security globally, especially with the projected population increase. Various agencies report yield declines as one of the main foreseen consequences, which will result in decreased foodstuffs availability and incremental prices (World Bank, 2010; Nelson et al., 2009). These trends are especially significant for basic grains. Hence, their consumption as well as of animal protein is thought to decline. The decreased consumption is projected to reduce caloric intake and thus increased childhood malnutrition by 2050 (Nelson et al., 2009).

Various reports have focused on mitigation or adaptation efforts against the effects of climate change on the agricultural sector. Smith et al. (2008) describes improved cropland and grazing land management, restoration of degraded lands and cultivated organic soils and to a lesser extent water and rice management as significant measures to mitigate greenhouse gas emissions. Nelson (2009) focused on estimating the investment needed in agricultural research, irrigation and road construction that could generate the incremental productivity. That report points out to the need to increase investment on agricultural productivity and research as means to adapt to the negative effects of climate change on agriculture, food security and potentially on malnutrition (Nelson 2009).

Food security and food availability is a consequence not only of food production, but of food processing. Food processing and distribution is a major source on employment and income, especially in developing economies. According to the World Bank (2008), agribusinesses account for approximately the 30 percent of the GDP in transforming and urbanized countries. In low income countries, industries and services linked to agriculture amount to 50 percent of the total manufacturing value added (World

Bank, 2008; UNIDO, 2009). The transformation, storage and transport of raw agricultural products involve activities that cut across the agricultural, manufacturing and transport sectors.

Most of the studies that focus on the impact on climate change and agriculture concentrate mostly on food production and impacts on food prices of basic commodities such as coarse grains. However, there is little attention to the impacts of climate change on the food industry. Thus, the effect of climate change on the agroindustrial sector has not been fully analyzed and understood.

The purpose of this study is to fill the gap about the impacts of climate change on the food industry. Specifically, the objective of this study is to understand the decline of crop yield as a result of climate change and to determine whether the global impact on the food processing sector is positive or negative. Research focused on the effects of climate change on the food industry and the value chain, from farm to fork, is an essential component to develop solutions capable to meet the current challenges in agriculture.

The rest of the paper is divided various sections. The second section briefly reviews the literature on the impacts on changes in agricultural productivity on food production and food security, and the food industry. Section 3 describes the methodology used, the general equilibrium model and data used. Section 4 presents and analyzes the results, and finally section 5 presents some conclusions and policy implications for the food industry.

Literature Review – Impacts of Climate Change on Food Systems

According to FAO (2002), food security exists “when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life”. According to Gregory et al (2005), access, use and availability of foods need to be addressed to

understand this issue. However, in depth analysis of foods systems relationship with climate change has been focused on the latter.

Various factors such as population growth, incremental urbanization and rising incomes (FAO, 2009) affect the ability of the food supply to meet its demand. Besides these socio-economic factors, changes in the actual crop production affect directly food availability. Climate change impact on arable land, crop production and yields has been analyzed by various investigators to understand how it affects food availability.

Increases in carbon dioxide concentration in the atmosphere, or carbon fertilization (CF), has been suggested to result in an increase in crops biomass and yields (IPCC, 2001). However, Nelson et al. (2009) projected yield of maize and wheat to decrease significantly with CF by 2050. The same report showed that temperature increases and changes in the rainfall patters will affect negatively yields of various crops and regions without CF, regardless if they are irrigated or not (Nelson et al., 2009).

Fisher at al (2002) reported a possible increase arable area in higher latitudes and a parallel decrease in lower latitudes as a result of climate change. This study is corroborated by Nelson et al. (2009), who reported that developing economies, typically in lower latitudes, will be the regions most severely affected. Not only arable land could be affected by climate change, but actual food production is projected to decrease significantly (Nelson et al., 2009). Probably as a consequence of a decreased production, incremental food prices were also foreseen in this report, which could decrease by 10 percent, if CF is effective. Additionally, it was suggested that incremental prices of basic grains could result in prices increments of animal protein (Nelson et al. 2009).

Changes in food production due to climate change have significant consequences in human health that have not been thoroughly assessed. Incremental prices in foodstuffs are expected to reduce calorie availability worldwide and possibly cause an increase in malnutrition, which was shown to decrease slightly with CF (Nelson et al., 2009). Conversely, a report by IPCC (2001) suggested that the nutritional make-up of crops

could be negatively affected by CF. Thus, the potential combined effects lower caloric intakes and lower nutritional density of crops need to be studied.

Besides the potential detrimental effects of climate change on human nutrition, reports suggest possible increase of food- or waterborne related illnesses (Confalonieri et al., 2007; Schmidhuber and Tubiello, 2007). Elevated temperatures were shown to cause an increase in the possibility of occurrence of foodborne diseases, like Salmonellosis (D'Souza et al., 2004). Also, warmer sea water temperatures are thought to increase the likelihood of shellfish and fish food poisoning outbreaks, since incremental growth of toxic dinoflagellates and pathogenic *Vibrio* species has been associated with warm sea water (Hunter, 2003).

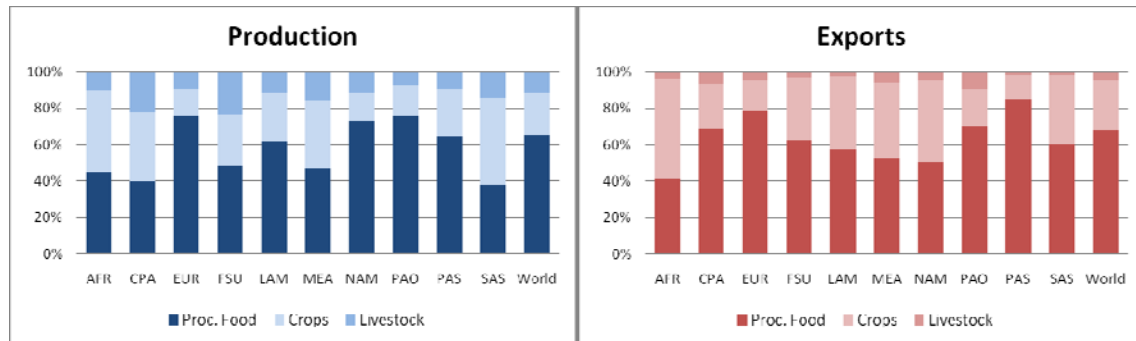
Food processing and transportation are key parts of the agri-food system as they encompass all operations that assure the safe processing and distribution of food to consumers. According to Edwards et al. (2009), processing and transportation of food stuffs contribute with 15-35 percent of greenhouse gas emissions in the food system. Most of these emissions are related to the energy used during processing and packaging, and are growing as international air freight increases with a more global food supply. However, the effects of climate change on the processing and distribution of foodstuffs are not well understood.

Gregory et al. (2005) mentioned that access and utilization of food, and not only food availability (crop production), relates to the issue of food security. Moreover, climate change implications in the food supply could influence directly how foodstuffs are processed and distributed to ensure its nutrition and safety. Thus, complete food systems including operations from food production, storage to transportation and processing should be studied.

Figure 1 shows the share food processing in value of production and exports in the food system. The world average share of food processing in production is 65 percent. That is, two thirds of the value of food that is produced around the world corresponds to processed food products. This is no surprise, as processed products have a higher value

than primary products. In the most developed regions such as Europe (EUR), Australia, New Zealand and Japan (PAO) and North America (NAM), the share is higher (around 75 percent). For less developed economies such as Sub-Saharan Africa (AFR), Centrally Planned Asia (CPA) and South Asia (SAS), the share is much lower. This denoted the development of the food processing sector in each region. As income increases, there is a larger share of processed foods. This increased share of processed food products is a result of several processes, including urbanization, changes in diet, more emphasis in supermarkets, etc., that have increased the demand and consumption of processed food products.

Figure 1. Share of Food processing in production and trade, 2004

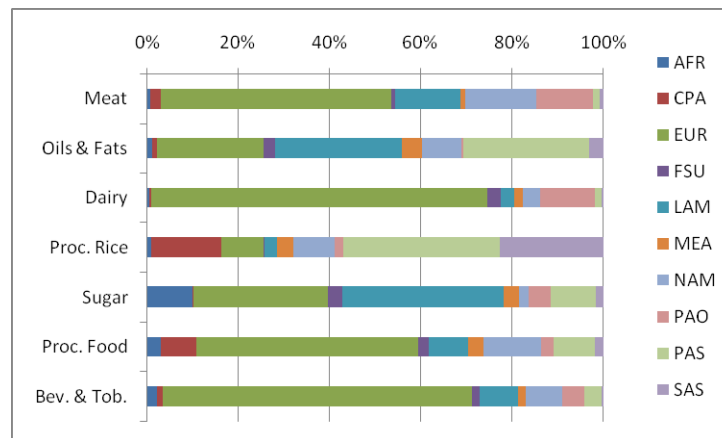


Source: Own estimation based on GTAP 7 Data Base

This change is also reflected in food trade. Analyzing the food system as a whole, food processed products account for 68 percent of total food system exports (primary crops and livestock and food processing) (Figure 1). Of that percentage, Europe is the larger exporter with 51 percent of total processed food exports. It is the larger exporter of dairy (74 percent), beverages and tobacco (68 percent), meat (50 percent), and other processed food (49 percent). North America, Latin America and East and South Asia (except Japan) account for 11 percent each. Latin America (LAM) is the larger exporter of sugar (35 percent) and vegetable oils and fats (28 percent), while Pacific Asia and South Asia are the largest exporters of processed rice (34 and 23 percent, respectively). Sub-Saharan

Africa, Middle East and North Africa and Centrally Planned Asia represent only a small share of total exports of processed food products.

Figure 2. Share of total world exports of processed food products, 2004



Source: Own estimation based on GTAP 7 Data Base

Methodology – A General Equilibrium Approach

To analyze the global impacts of climate change, changes in crop productivity and the impacts on food processing, we need a methodology that accounts for impacts of yields changes on crop production and the channels through which the food processing sector might be affected.

In this study we use a general equilibrium model of the world economy to estimate the impacts of changes in productivity in crops on the food processing sector. This methodology provides us with the necessary tools to analyze the global implications of climate change in different regions of the world, as it accounts for differential rates of productivity change in crop production. As discussed by Müller et al. (2009), the impacts of climate change on crop productivity will depend on various factors. Most importantly, they will vary greatly depending whether we consider carbon fertilization or not. Carbon

fertilization has yield enhancing effects, as it reduces water stress and promotes faster growth in plants (Long et al., 2006).

The global general equilibrium model used is the Global Trade Analysis Project (GTAP) model (Hertel, 1997). The GTAP model is a static multi-region and multi-sector general equilibrium model with perfect competition, constant return to scale, fixed factor endowment and full factor use. The advantage of the GTAP model to evaluate global changes in productivity and its impacts on food processing, is that it can account for adjustments within domestic markets in each region, but also how relative changes in crop yields affect food production and processing across the globe through international trade. The model includes an explicit treatment of international trade and transport margins, which is modelled using an Armington specification. This allows differentiating bilateral trade flows by country or region of origin.

The GTAP model has been extensively used in the analysis of climate change in terms of adaptation and mitigation. In adaptation, several authors have analyzed the impacts of climate change (mainly) on crop productivity (Tsigas et al., 1997). Other authors have analyzed mitigation of greenhouse gases and the reduction of CO₂ emissions. For this, they use a modified version of the GTAP model called GTAP-E. The GTAP-E model (Burniaux and Truong, 2002) modifies the standard GTAP model and introduces energy-capital substitution, which expands the substitution possibilities in production and consumption.

Data

We use the GTAP Data Base, version 7.0, which is a snapshot of the world economy in the year 2004 with 113 regions or countries and 57 sectors. We aggregate the data base into 10 regions and 12 sectors. The regional aggregation follows the 10 regions outlined in Müller et al. (2009). For sectors, we aggregate the GTAP Data Base in 12 sectors, with a special focus on food processing sectors (total of six out of twelve). The regions are described in Table 1 and sectors in Table 2.

Table 1. Regions analyzed and description

Regions	Description
1. Sub-Saharan Africa (AFR)	Nigeria, Senegal, Ethiopia, Madagascar, Malawi, Mauritius, Mozambique, Tanzania, Uganda, Zambia, Zimbabwe, Botswana, South Africa, etc.
2. Centrally Planned Asia (CPA)	China, Cambodia, Lao P.D.R., Viet Nam, Rest of East Asia
3. Europe (EUR)	Austria, Belgium, Cyprus, Czech Rep., Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom, Switzerland, Norway, Albania, Bulgaria, Croatia, Romania
4. Former Soviet Union (FSU)	Belarus, Russian Federation, Ukraine, Kazakhstan, Kyrgyzstan, Armenia, Azerbaijan, Georgia
5. Latin America and the Caribbean (LAM)	Mexico, , Argentina, Bolivia, Brazil ,Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Rest of South America, Costa Rica, Guatemala, Nicaragua, Panama, Rest of Central America, Caribbean
6. Middle East and North Africa (MEA)	Iran, Turkey, Egypt, Morocco, Tunisia, Rest of North Africa, Rest of Western Asia.
7. North America (NAM)	Canada, USA, Rest of North America
8. Pacific OECD (PAO)	Australia, New Zealand, Japan
9. Pacific Asia (PAS)	South Korea, Taiwan, Indonesia, Malaysia, Philippines, Singapore, Thailand, Rest of Southeast Asia, Oceania
10. South Asia (SAS)	Myanmar, Bangladesh, India, Pakistan, Sri Lanka, etc.

Note 1: There were some disparities between the country aggregations between the source of the changes in agricultural yields (Müller et al., 2009) and the GTAP Data Base. In some cases, countries were not identified individually in the GTAP Data Base, and are included in aggregate regions of the GTAP Data Base.

Table 2. Sectors analyzed and description

Sectors	Description
1. Crops	Paddy rice, wheat, cereal grains, fruits and vegetables, oilseeds, sugar cane, plant based fibers, beverage crops
2. Livestock	Cattle, other animal products, raw milk, wool
3. Mining and Extraction	Coal, oil, gas, mining of metal ores, quarrying
4. Meats	Cattle Meat: fresh or chilled meat and edible offal of cattle, sheep, goats, horses, asses, mules, and hinnies. raw fats or grease from any animal or bird. Other Meat: pig meat and offal. preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal; greaves
5. Vegetable Oils and Fats	Vegetable Oils margarine, fats and oils, flours and meals of oil seeds or oleaginous fruits, etc.
6. Dairy Products	Milk, cheese, yogurt, dairy products
7. Processed rice	Processed Rice: rice, semi- or wholly milled
8. Sugar	Sugar
9. Food Products Nec.	Prepared and preserved fish, fruits, nuts and vegetables, fruit juices and vegetable juices, all cereal flours, starches and starch

	products; sugars and sugar syrups, bakery products, cocoa, chocolate and sugar confectionery, macaroni, noodles, couscous and similar farinaceous products, etc.
10. Beverages and Tobacco Products	Beverages and Tobacco products
11. Manufactures	Manufacturing
12. Services	Services

Scenarios

As mentioned by Müller et al. (2009), the estimates of changes in crop productivity account for changes in changes in climate and changes in atmospheric CO₂ concentration (CO₂ fertilization). They do not account for other factors that may affect future changes in crop productivity such as changes in management and breeding, and changes in cropland.

We evaluate two basic scenarios of impacts of climate change on crop productivity. These two scenarios are based on estimates from Müller et al. (2009), which evaluate various scenarios from 1950 to 2055 for 3 different emission scenarios (SRES A1b, A2, B1) each implemented by 5 different general circulation models (GCM). The two scenarios evaluated are one with full CO₂ fertilization and a second without CO₂ fertilization.

The estimates used in the GTAP global general equilibrium model are presented in Table 3. The table contains the projected changes in crop productivity in the year 2050 (average 2046-2055) relative to the year 2000 (1996-2005) for both scenarios with and without CO₂ fertilization. In general, crop productivity changes with full CO₂ fertilization increases productivity for all regions, except for Middle East and North Africa (MEA). The impacts are not uniform and vary across regions, with higher productivity gains in countries in the former Soviet Union (FSU) and East and South Asia (PAS and SAS). Without crop fertilization most regions register productivity losses except for Europe (EUR) and the former Soviet Union. As with full fertilization, there are differential impacts between regions. This is important, as relative productivity levels between regions will determine changes in production and trade which will directly influence how food processing is affected within each region.

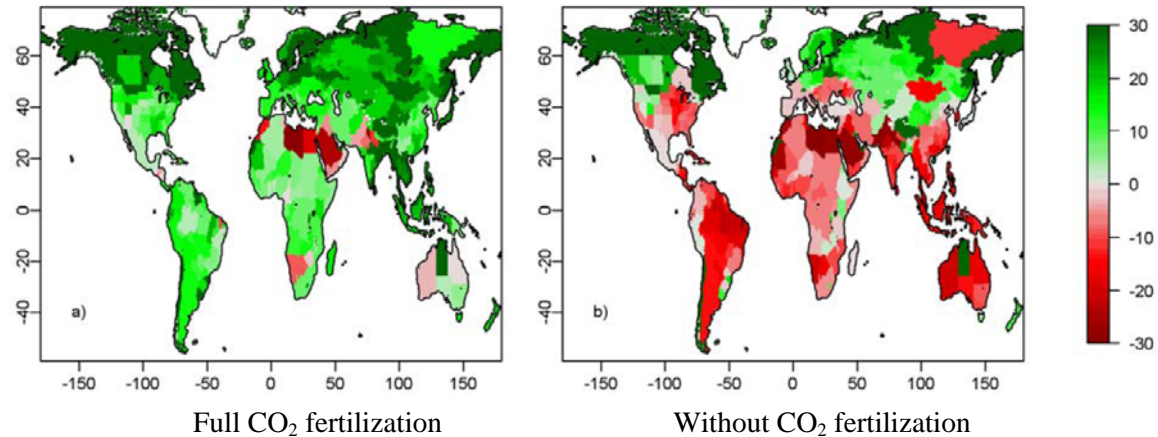
Table 3. Regional 5-GCM-mean climate change and CO₂ fertilization impacts on crop yields (percent change in 2046-2055 relative to 1996-2005) on current (2000) crop land.

Regions	Full CO2 Fertilization	No CO2 Fertilization
Sub-Saharan Africa (AFR)	7.5	-7.6
Centrally Planned Asia (CPA)	14.3	-3.4
Europe (EUR)	16.8	1.2
Former Soviet Union (FSU)	21.4	0.9
Latin America (LAM)	11.8	-8.2
Middle East and North Africa (MEA)	-2.1	-14.8
North America (NAM)	12.2	-7.1
Pacific OECD (PAO)	3.5	-13.5
Pacific Asia (PAS)	21.9	-16.0
South Asia (SAS)	19.8	-16.4
World	12.6	-6.5

Source: Based on Table 2.2.1 in Müller et al. (2009).

Finally, Figure 3 shows a graphic representation of changes in crop yields to 2050 relative to levels in the year 2000. Notice that with full fertilization, countries in North Africa and the Middle East are the most noticeably affected (red areas). However, there are other countries and regions that show crops yield losses, such as Pakistan and North West India, North East Brazil, West Australia, Namibia and Botswana. Without carbon fertilization, all tropical countries present productivity losses. Regions that show productivity gains (green areas) are mostly in the northern hemisphere, including Western China and Central Asia, North Europe and the Russian Federation, Canada and some parts of Australia and New Zealand.

Figure 3. World impact on crop yields in 2050 relative to 2000.



Source: Figure 2.2.2 in Müller et al. (2009).

Limitations

As with any other methodology, the approach used in this study has several limitations. First, it is a static general equilibrium approach, and does not account for the dynamic and long term aspects of climate change. These include capital accumulation, changes in dietary needs, and other factors that might affect the impacts on food processing in the next 40 years. As income increase in developing countries, a higher proportion of food consumption comes from meat, dairy and other food products, and less coming from staple grains. Additionally, the proportion of food on the overall household budget decreases. These two changes in food demand are not accounted, and might underestimate the effects on the food processing sector.

The model also does not account for land use changes and the expansion of the agricultural production frontier. The model regards land endowment as fixed, and does not allow for its increase. This limitation would underestimate the ability of crop production to expand to new areas, which would affect the estimates on price changes in land prices, primary crop production, and ultimately, impacts on food processing. Also, Cline (2007) mentions three key factors on modeling changes in yields due to climate change: carbon fertilization, trade and irrigation. With the methodology used in this paper we can account for the first two factors directly, but not for irrigation.

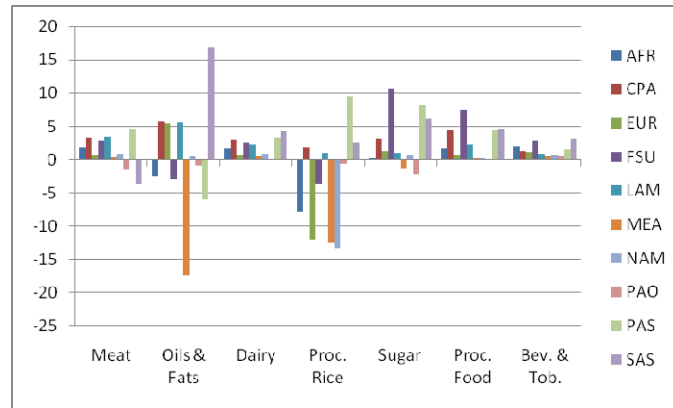
Finally, the changes in productivity in agriculture used in this study refer to the overall crop sector, and do not account for changes in individual crop yields, such as in Nelson et al. (2009). This might affect the various food processing sectors, as the differential impacts of changes in crop yields depend on the importance of these various crops as inputs in the food industry. For example, the productivity changes used in this study might differ from the productivity changes that might occur with rice production, which in turn might affect the processed rice sector.

Despite these limitations, which have more to do with primary agriculture, rather than the food processing industry itself, the methodology used in this study provides us with appropriate estimates on the impact of crop yield change on food processing. The advantage of a multi-regional, multi-sector model that reflects inter-sector relationships within each region and the economic links between regions is invaluable. The model captures the differential impacts of changes in crop yields in each region, and through trade, is able to show the general equilibrium effects of climate change on crop productivity worldwide.

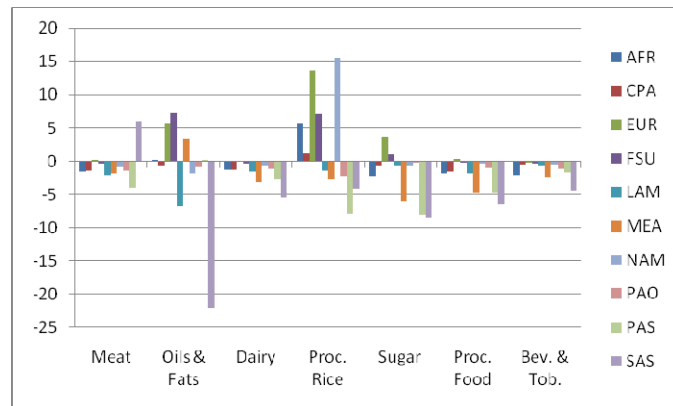
Results

To discuss the impacts of climate change on the food processing sector, we are going to focus on changes on production, trade and supply prices. First, we are going to discuss the direct impacts of changes in crop yields on production of food processing sectors. Figure 4 present the impacts on food processing output for all seven food processing sectors analyzed. With full fertilization, food industry output worldwide increases for most sectors in all regions, with some exceptions. In Dairy products and beverages and tobacco, output increases for all regions, mainly in the former Soviet Union and Central, East and South East Asia. In these two sectors, the increase in production comes mainly from an effect of increased domestic demand of these products rather than increased exports (Figure 5).

Figure 4. Change in Output of Food Processing Sectors (percentage)



Full CO₂ fertilization



Without CO₂ fertilization

Source: Author's own estimations.

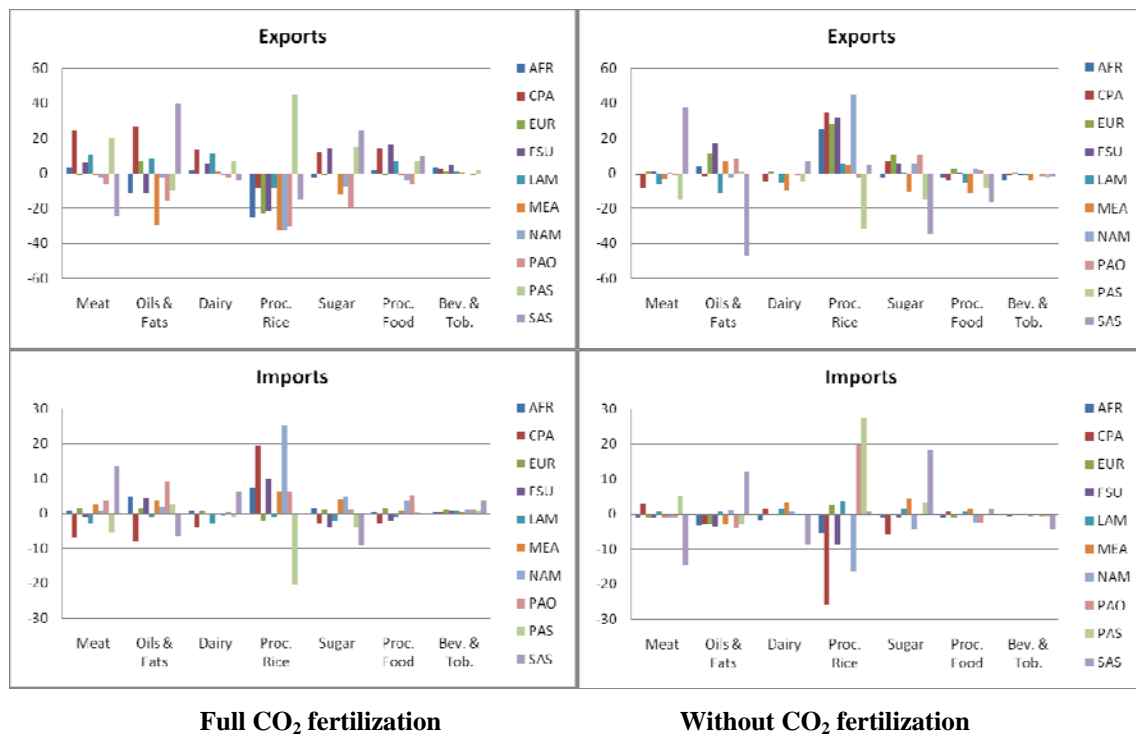
For meat, output increases for all regions, except Pacific OECD (PAO) countries (Australia, New Zealand and Japan) and South Asia (SAS). Output increases in Asian countries driven by domestic demand, while in Latin America, is exports which drives the increase in production. In Pacific OECD countries output falls mainly due to a decline in exports, as well as a decline in domestic demand. Meanwhile, for South Asia a decline in export demand outmatches the increase in domestic demand of meat products (Figure 5).

Sugar production increases in all regions, except in the Middle East and North Africa (MEA) and PAO. The decline in domestic demand, as well as in exports, drives down production in these two regions. For those regions with the largest increase in

production (FSU and East and South Asian countries), the increase is driven by higher domestic demand. Other food processing production increases in all regions, except PAO. Regions that experience the largest increased production are FSU and East and South Asian countries, driven mainly by an increase in domestic demand.

For vegetable oils and fats and processed rice, results are mixed across regions. For oils and fats results output increases mainly in South Asia (17 percent), Latin America, CPA and Europe (6 percent, each). There are large drops in production, especially in the Middle East and North Africa (18 percent) and in East and South East Asia (6 percent). For processed rice, output increases in Asia (PAS, SAS and CPA) and Latin America. In these regions, the increase in output is mainly driven by domestic demand. For those regions where output declines, the change in production is between 4 and 14 percent. We observe the largest declines North America (14 percent), Europe (13 percent), MEA (13 percent) and in Sub-Saharan Africa (8 percent).

Figure 5. Change in Exports and Imports of Food Processing Sectors (percentage)



Source: Author's own estimations.

Without CO₂ fertilization, output declines for all regions in dairy products, beverages and tobacco and in other processed food.¹ The decline in output in these sectors is mainly due to a decline in the domestic demand of these products within each region. In meat and sugar, output declines in most regions, also driven by a decline in domestic demand. In meat, South Asia is the only region with an important increase (6 percent) in production, which is driven by an increase in exports. For sugar, Europe and the former Soviet Union's output increases (4 and 1 percent, respectively). This output increase in these two regions is driven by an increase in exports.

For processed rice, output declines mainly in Asia-Pacific (2-8 percent), in the Middle East and North Africa and in Latin America. With this decline in production in major producing regions, output in North America and Europe increases driven by an increase of exports in these two regions. For vegetable oils and fats output increases mainly in Europe, the Middle East and North Africa and in the FSU, due to increased exports. Output decreases sharply in South Asia (22 percent) and to a less extent in Latin America (7 percent) and North America (2 percent). In South Asia and North America, the decrease in output is driven by a decline in domestic demand, while in Latin America is driven by a relative decline in exports.

Overall, if we compare both scenarios with and without carbon fertilization, the results show that in general output change increases or decreases less with full carbon fertilization. This holds in all regions for dairy products, beverages and tobacco and other food products. However, the results across regions are mixed for vegetable oils and fats and processed rice, and to a lesser extent, meat and sugar.

For vegetable oils and fats, output under full fertilization drops for Sub-Saharan Africa, former Soviet Union, MEA and Pacific Asia, while it increases without full fertilization. This is mainly due to an increase in the demand for exports in these regions.

¹ In this last sector the only exception is Europe, where output of other processed food products increases by 0.4 percent.

For processed rice, we also observe a drop in output with full fertilization but an increase in production in Africa, Europe, former Soviet Union and North America. This disparity between the two scenarios is due to increase domestic demand under no carbon fertilization.

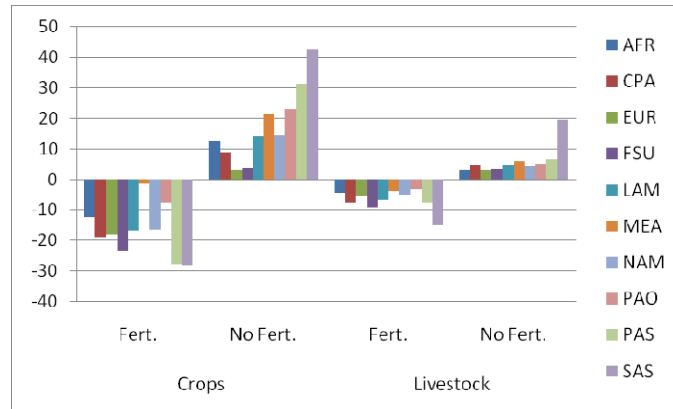
For meat products, only South Asian countries output reverts. Without carbon fertilization meat production increases by 6 percent, while it falls with carbon fertilization by 4 percent. For sugar, output with full fertilization increases more for all regions, except Europe, Australia, New Zealand and Japan (PAO). In Europe, output increases from 1.3 percent to 3.6 percent, mainly driven by an export effect. In PAO, output decreases less without carbon fertilization, also due to an export effect.

These changes in production, domestic demand and exports are partially driven by changes in prices, both domestically and for traded commodities. As projected crop yields differ from one region to the other, the relative competitive advantage of regions varies. This differential competitive effect comes from the change in crop yields that not only affect crop prices but also land rents. To analyze the impact of crop yields on food processing sectors, it is important to first analyze the impacts of primary food production.

With carbon fertilization, as crops yields rise prices for crops tend to drop on average between 10 and 30 percent (Figure 6). Even for MEA, where there is productivity loss, crop prices also slightly drop (1.5 percent).² As prices are reduced for crops, supply prices for other sectors that have a close relationship with the sector also tend to drop. One of those sectors is livestock, where feed grains are an important cost component in cattle (beef and milk), pork and poultry production. The decline in feed prices affects livestock prices, and these decrease between 4 and 15 percent. This decline in livestock prices has important impacts in the food processing sectors.

Figure 6. Change in Crops and Livestock supply prices (percentage)

² In MEA prices drop, as crop imports from other regions become more competitive due to the productivity gains in those regions. This drives down the local price of crops, even though local production decreases.



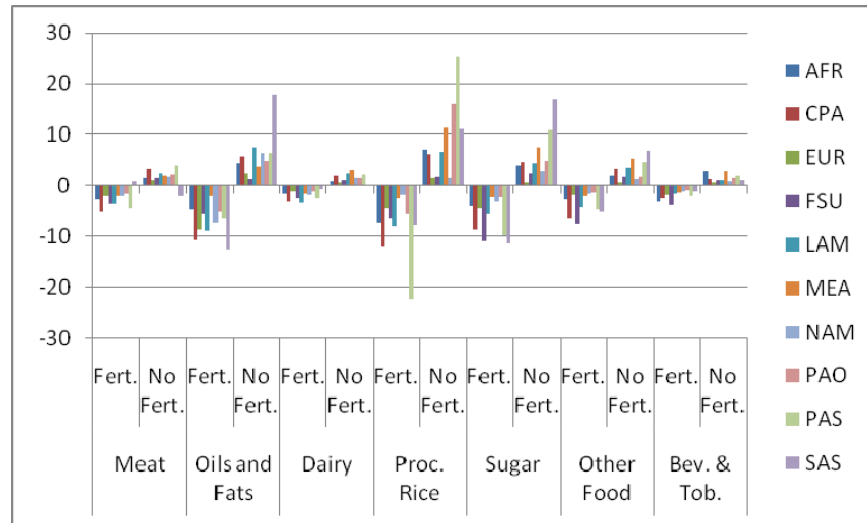
Source: Author's own estimations.

Figure 7 shows the change in supply prices for all regions in each food processing sector. In almost all cases, as prices of primary crops decrease, so does supply prices of food sectors. This is mainly due to the fact that a large portion of costs in the food processing sector is primary agriculture. For example, livestock represents 42 percent³ of total costs in meat and one fifth in dairy. For vegetable oils and fats and sugar, these cost shares are around one third of total costs. For rice, these cost shares are higher and close to half of total costs, with some regions such as East and South East Asia reaching as high as 80 percent of total production costs.

To some extent, these costs shares explain the differences in price changes between food processing sectors. That is, the price changes for vegetable oils and facts, processed rice and sugar are closer to the magnitudes in price changes observed in primary crop production (up to 30 percent). For meat and dairy production, as a larger share of costs comes from livestock production, the change in price for this sector is captured by the change in the supply price of these two processing sectors. As we observed in Figure 6, the change in price in primary livestock is as much as 15 percent. This price drop in livestock production results in a change in meat and dairy prices of around 1 to 5 percent.

³ The exception is South Asia, where primary livestock has on average a share of 4 percent in meat production.

Figure 7. Change in Food Industry Prices (percentage)



Source: Author's own estimations.

Without carbon fertilization, as crop yields decrease for most regions (except Europe and the former Soviet Union), there are price increases in both primary agriculture (crops and livestock) and ultimately, in the food processing sector. Crop prices increase between 3 and 43 percent across regions. The largest increase in crop prices is in South Asia, which has the largest drop in crop yields (16.4 percent). For livestock prices increase between 3 and 7 percent.⁴ Accordingly, food industry prices increase, especially in vegetable oils and fats (2-18 percent), processed rice (2-25 percent) and sugar (1-17 percent).

As previously observed with the case of the Middle East and North Africa, although crop yields increase in Europe and the former Soviet Union, these productivity gains are not enough to stop the increase in food processing prices. This is mostly due to the price increase in other regions, which drives up the prices of imports in these two regions. It should be observed that crop prices in Europe and FSU have the lowest increase compared to other regions. However, these lower crop prices do not have much

⁴ South Asia prices increase by 20 percent, mostly driven by the large increase in crop prices of 43 percent.

effect in livestock and food processing prices of these regions, as trade has an important role in diluting the effects of the increase in crop yields in these two regions.

Conclusions

In this study we have analyzed the impacts of climate change of the food processing sectors worldwide. Specifically, we have estimated the effect of changes in crop productivity in primary agriculture and the effects on production, trade and prices of the food processing sector. We focus on food processing sectors, as most previous studies on the impact of climate change on agriculture usually focus on primary production.

We evaluated these impacts under two different scenarios. One with full carbon fertilization, where crop yields increase for most regions except the Middle East and North Africa, and one without full CO₂ fertilization, where crop yields decrease for most regions, except for Europe and the Former Soviet Union.

We use a general equilibrium approach that enables us to capture the differential effects of relative productivity growth rates across regions. The computable general equilibrium allows us to capture the changes of agriculture productivity on each region's agricultural productivity, linking these regions through bilateral trade flows. With this framework we are able to capture the general equilibrium effects within each region, but also across regions around the world.

Results show that overall, and not surprisingly, food output increases or decreases less with full fertilization. This holds for all regions in dairy products, beverages and tobacco and other food products. As crop yields increase with full fertilization, prices drop for primary crops, which in turn makes it more attractive to increase production in the food processing sectors, as primary crops are an important cost component of processed foods.

Results across regions are mixed for vegetable oils and fats, as well as for processed rice, and to a lesser extent, for meat and sugar. This denotes the general

equilibrium effect across regions. Some of the decline in output for these sectors is mostly due to a reduction in exports, as some regions become more competitive in some products relative to other regions. That is the case of East and South East Asian countries in processed rice.

At the same time with full fertilization, prices drop for all processing sectors, specially for oils and fats, processed rice and sugar. Most of these results are driven by two factors. First, the direct effects on primary crop and livestock production, whose prices also drop. However, prices for food processing sectors do not fall as much as primary agriculture, since crops and livestock are only part of the overall cost structure of processed foods. When we assume no carbon fertilization, the effects are opposite from what we observe from full fertilization, as crop yields fall for all regions, except Europe and the Former Soviet Union, prices of food processing sector rise.

These results have important implications for food security in some regions, with lower productivity growth in primary agriculture compared to others. Some of these regions, such as the Middle East and North Africa, Sub-Saharan Africa and some regions in Asia will be positioned in a less favorable condition with respect to food security, as productivity losses will exacerbate their condition as net food importers. It is also important to note a rise in food prices will have a larger impact on the poorest households, as these households expend a larger share of their budget on food.

References

- Burniaux, J.M. and T.P. Truong. 2002. GTAP-E: An Energy-Environmental Version of the GTAP Model. GTAP Technical Paper No. 16. Center for Global Trade Analysis, Purdue University.
- Cline, W.R. 2007. Global Warming and Agriculture: Impact Estimates by Country. Center for Global Development, Peterson Institute for International Economics.
- Confalonieri, U., B. Menne, R. Akhtar, K.L. Ebi, M. Hauengue, R.S. Kovats, B. Revich and A. Woodward, 2007: Human health. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 391-431.
- D'Souza R.M., Becker N.G., Hall G., Moodie K.B. 2004. Does ambient temperature affect foodborne disease? *Epidemiology*. 15(1):86-92.
- Edwards, J., Kleinschmit J., Schoonover H. 2009. Identifying our Climate “Foodprint”: Assessing and Reducing the Global Warming Impacts of Food and Agriculture in the U.S. Institute for Agriculture and Trade Policy, Minneapolis, Minnesota.
- [FAO] Food and Agriculture Organization. 2002. The State of Food Insecurity in the World 2001. Food and Agriculture Organization, Rome, Italy. Available at <http://www.fao.org/docrep/003/Y1500E/Y1500E00.HTM>
- [FAO] Food and Agriculture Organization. 2009. WSFS Background Paper - Feeding the World, Eradicating Hunger. <ftp://ftp.fao.org/docrep/fao/Meeting/018/k6077e.pdf>
- Fischer G., Shah M., van Velthuisen H. 2002. Climate Change and Agricultural Vulnerability, A Special Report Prepared as a Contribution to the World Summit on Sustainable Development (International Institute for Applied Systems Analysis, Laxenburg, Austria). Available at http://www.start.org/Program/advanced_institute3_web/p3_documents_folder/Fischer_etal.pdf
- Gregory P.J., Ingram J.S.I., Brklacich M. 2005. Climate Change and Food Security. *Philosophical Transactions of the Royal Society B*, 360, 2139-2148. doi: 10.1098/rstb.2005.1745
- Grievink, J.W. 2003. The changing face of the global food industry. OECD conference on changing dimensions of the food economy: exploring the policy issues, The Hague, 6 February 2003.

- webdomino1.oecd.org/comnet/agr/foodeco.nsf/viewHtml/index/\$FILE/GrievinkPT.pdf.
- Hunter, P.R. 2003: Climate change and waterborne and vectorborne disease. *Journal of Applied Microbiology*. 94, 37-46.
- IPCC (Intergovernmental Panel on Climate Change). 2001. Technical Summary: Impacts, Adaptation and Vulnerability. A Report of Working Group II of the Intergovernmental Panel on Climate Change 73p. Available at <http://www1.ipcc.ch/ipccreports/tar/vol4/english/pdf/wg2ts.pdf>
- Long, S.P., E.A. Ainsworth, A.D.B. Leakey, J. Noesberger, and D.R. Ort. 2006. Food for Thought: Lower-than-Expected Crop Yield Stimulation with Rising CO₂ Concentrations, *Science*, 312, 1918-1921.
- Müller, C., A. Bondeau, A. Popp, K. Waha, M. Fader. 2009. Climate Change Impacts on Agricultural Yields. Background Note, World Development Report 2010, World Bank, Washington, DC.
- Nelson, G.C., M.W. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, C. Ringler, S. Msangi, A. Palazzo, M. Batka, M. Magalhaes, R. Valmonte-Santos, M. Ewing, and D. Lee. 2009. Climate Change: Impact on Agriculture and Costs of Adaptation. IFPRI Food Policy Report, Washington DC.
- Schmidhuber, J., Tubiello F. N. 2007. Global food security under climate change. *PNAS*. 104 (50) 19703-19708
- Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, M. Howden, T. McAllister, G. Pan, V. Romanenkov, U. Schneider, S. Towprayoon, M. Wattenbach, and J. Smith. 2008. Greenhouse gas mitigation in agriculture. *Phil. Trans. R. Soc. B* 363: 789-813.
- Tsigas, M.E, G.B. Frisvold and B. Kuhn. 1997. Global Climate Change and Agriculture. In: *Global Trade Analysis: Modeling and Applications*. T.W. Hertel (ed). Cambridge University Press.
- UNIDO (United Nations Industrial Development Organization). 2009. Industrial Development Report. Vienna, Austria. United Nations Industrial Development Organization. 143 p. Available at http://www.unido.org/fileadmin/user_media/Publications/IDR/2009/IDR_2009_print.PDF
- World Bank. 2008. World Development Report 2008: Agriculture for Development. Washington, D.C.: The World Bank.

World Bank. 2010. World Development Report 2010: Development and Climate Change.
Washington, D.C.: The World Bank.