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Water reliability, irrigation adoption, and land use changes in the presence of biofuel production

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

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Water reliability, irrigation adoption, and land use changes in the presence of biofuel production

Farzad Taheripour, Thomas W. Hertel, and Ling Liu

1. Introduction

The role of irrigation in agriculture is expected to gain greater promise over the coming decades. This will be fueled by increasing global demand for food and biofuels as well as irrigations-based adoption to higher temperatures and uncertain rainfall. The economic incentives to expand irrigation, biophysical factors on water availability for irrigation in some regions, and future changes in climate condition will force significant adjustment in current irrigation pattern and mix of crops produced across the world. These changes which affect the global distribution of crop production will eventually alter trade of these commodities which in turn will affect international trade and the future global economy.

For the first time in the history of economic modeling, this paper introduces water resources as an explicit input into a global general equilibrium modeling framework at a river basin level to examine economic and land use consequences of changes in crop yields due to climate change in the presence of water constraints and biofuel production. The current paper addresses important issues related to water resources and their interaction with agricultural activates, climate changes, choices between rainfed, and irrigation practices at a global scale.

This paper first reviews the literature in three different yet related areas of economic modeling, climate change and food production, and water availability for crop production. Then it introduces the implemented modeling approach and the experiments which are designed to assess the consequences of changes in climate conditions and water availability for irrigation in the presence of biofuel production. Finally, it presents the results on three important subjects of changes in crop production, crop trade balances, and land use implications at a global scale. The paper indicates that: 1) Future changes in the climate conditions could increase crop outputs at the global scale and improve profitability of irrigated crops. 2) Changes in water supply have the potential to reverse some positive impacts of climate change and limit crop outputs in China, India, South and South East Asia, and Middle East and North Africa; 3) Finally, biofuel production alters the mix of crops produced in favor of corn and oilseeds across the world, reallocating distribution of water among irrigated crops, and increasing incentives to adopt irrigation.

2. Literature Review and Background

Numerous studies have examined the consequences of global warming for food security at regional, national, and international levels (few examples are: Parry et al. (2007); Lobell et al. (2007); Nelson et al. (2009); Nelson et al. (2010), Lobell et al. (2011); and Lobell and Gourdji (2012)). A group of these studies estimated the impacts of changes in temperature, precipitation, and CO_2 concentration on crop yields by region and then projected supplies of and demands for food items under alternative assumptions on: technological progress in crop production; the expected changes in climate variables in future decades; and expansion in income and population in future (for example see Lobell et al. (2007)). In an alternative approach several studies have used a combination of biophysical and economic models to examine food security. In this approach impacts of changes in climate variables on crop yields are obtained from biophysical models and then the results are introduced into either partial or general equilibrium economic models which represent agricultural activities and some macro aspects of the global economy at regional levels and capture changes in consumer's demands for food items due to income and population growth (for example see Nelson et al. (2010)). These studies provide valuable economic and biophysical analyses, demonstrating how changes in climate variables and CO_2 concentration in atmosphere affect food security across the world, determine the gap between supply and demand for food under alternative climate scenarios, and discuss policy options which can be used to mitigate adverse impacts of climate change. However, they do not provide a clear picture on interactions between climate variables and available water resources at the global scale in an economic environment with limited land, labor, and capital resources.

Today there are many partial and general equilibrium models which are designed and/or modified to assess the impacts of changes in climate factors on economic variables and vise versa. These models are typically capable of examining the impacts of climate variables on agricultural and non-agricultural activities, asses environmental consequences of national air pollution mitigation policies, study land use implications of biofuel production and polices, trace the economic and environmental consequences of international agreements on trade and GHG emissions reduction policies, and to accomplish many other tasks and goals. However, in general the existing global economic models, except for a few cases[1], do not bring water as an explicit input into their analytical frameworks.

Water is an important factor of production in many industries and particularly in agriculture. Additionally, water is vital in maintaining human life. While the need for water for agricultural, industry, power generation, and municipal uses are growing rapidly worldwide, water resources are shrinking in some regions due to climate change. Furthermore, depletion of underground water reserves and lack of investment in expanding water resources limit

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[1] Some partial equilibrium multiregional models (e.g. IMPACT model (Rosegrant et al. (2002) and Rosegrant et al. (2010)) have introduced demand for and supply of water into their modeling framework. Some national general equilibrium economic models have introduced water into their modeling framework as well (e.g. Jonas et al. 2011).

sustainable supply of water in several river basins across the world. A few studies have investigated future challenges regarding water resources and examined the expected regional gaps between the demand for and supply of water based on biophysical data with limited economic analysis and insights (examples are: Rosegrant et al. (2010) and Addams et al. (2009)).

Introducing water resources into a multi-regional economic model which represents the global economy is a challenging task. To accomplish this task, an immense amount of information is needed to quantify demands for water in its alternative uses and determine supplies of surface and groundwater water resources at the global scale. Collecting reliable data on regional demands and supplies of water is not an easy task. Furthermore, since water is not a tradable commodity in the market place, in almost all regions across the world, it is difficult to determine the monetary value of water as a commodity and introduce it into an economic model.

In this paper for the first time in the history of economic modeling activities, we introduce water as an explicit input into the production functions of irrigated crop industries of a multiregional general equilibrium model which traces production, consumption, and trade of a wide range of economic activities at a global scale. The goal is to assess the economic and environmental impacts of changes in climate conditions and available water for irrigation in the presence of biofuel production.

3. Method

Global warming and GHG emissions affect agricultural activities in many parts of the world. However, the impacts of these factors vary across regions, crops, management practices, and nature of agricultural activates (Lobell et al. 2011). On the other hand, water resources are subject to changes in the future due to economic and biophysical factors. The combination of these two factors will alter the global supply of agricultural commodities and its geographical distribution. From the demand side producing biofuels from agricultural resources will affect the need for crop products and their regional distribution. These changes will affect crop, livestock, food, feed, and energy sectors and many other economic activities directly and indirectly. These alterations will lead to changes in relative prices of goods and services which in turn affect household demands for goods and services. These changes will eventually alter regional prices and affect comparative advantages of countries in the global markets for agricultural and non-agricultural commodities which eventually will affect the trade pattern. To examine the economic and environmental consequences of these massive global changes we implement a general equilibrium modeling framework in this paper. The modeling framework used in this paper is a modified version of the GTAP-BIO[2] model which brings water as an endowment into the production functions of irrigated crops. The GTAP-BIO model is a multiregional computable general equilibrium model which simulates consumer and producer behaviors and traces production, consumption, and trade of a wide range of goods and services including biofuels and their by-products at a global scale. The GTAP-BIO model which is designed and frequently utilized to assess induced land use changes due to biofuel production and policy (examples are: Birur et al. (2008), Hertel et al. (2010); Taheripour et al. (2010), Tyner et al. (2010), Taheripour et al. (2011)) takes into account resource constraints and links economic and biophysical information through the market for land where agricultural, livestock, and forestry compete for limited land resources. We made major modifications in this modeling framework to introduce water as an input into the production functions of irrigated crops. The next section outlines these modifications.

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[2] The GTAP-BIO model is an extend version of the GTAP standard model (Hertel, 1997)

Model

We begin with the modeling framework developed by Taheripour, Hertel, and Liu (2013): henceforth THL). These authors considered water as an implicit input embedded in irrigated cropland. Then they extended the crop industries of the GTAP-BIO model into rainfed and irrigated categories and modified the GTAP-BIO model to handle crop production by irrigation type. This approach can be effectively used to examine impacts of changes in economic and biophysical factors which affect supply of cropland to the irrigated and rainfed crop industries. However, since this method considers water as an implicit input embedded in irrigated land, it has limited application in analyzing impacts of changes in water supply to agricultural activities. In general, supply of water to agricultural activities can change over time due changes in economic and biophysical factors. While investment in water resources can increase the water supply to agriculture, expansion in water demand for non-agricultural uses (such as increases in municipal and industrial uses) limits supply of water to irrigated agriculture. Climate change also could affect available water for irrigation. To examine consequences of changes in water supply for irrigated agriculture we introduce water as an explicit input in irrigated crop production of the GTAP-BIO model.

As shown in Figure 1 the new model, henceforth called GTAP-BIO-W, traces both water and land resources at a regional level by River Basin (RB) and Agro-Ecological Zone (AEZ) and allows competition between rainfed and irrigated crop industries to compete in market for each crop. In this model producers (including land using industries) compete for scarce resources such as labor and capital at a national level. However, the competition for land and water occurs at a RB-AEZ level. In each region there are several RBs (maximum 20 RBs) and each river basin serves water among its AEZs (maximum 18 AEZs). In each RB-AEZ land using sectors (including forestry, crop, and livestock) compete for land resources. Then irrigated and rainfed agriculture compete for available cropland in each RB-AEZ. On the other hand, irrigated crop producers compete for limited water resources for irrigation at the RB level. In this model, water can move across AEZs of each river basin. Hence, the model traces competition for land among crops, livestock, and forest industries at a RB-AEZ level in each region and assumes completion for water occurs at a RB level within each region. The model assumes no water trade among RBs and regions and takes supply of water for irrigation as an exogenous variable in each river basin. Finally, as shown in Figure 2 the model assumes that water and land are compliment inputs at the RB-AEZ level. The land supply component of this model follows the land supply structure developed by THL at the RB-AEZ level.

Unlike the standard GTAP model which uses a one-to-one relationship between industries and commodities, in the GTAP-BIO-W model some industries produce two commodities (e.g. ethanol or vegetable oil industries) and each crop product is produced by two industries (irrigated and rainfed). In the new model the irrigated and rainfed industries which produce the same crop (e.g. wheat) receive the same price, irrigated and rainfed industries operate at zero profit condition, and irrigated industries pay for water for irrigation. In this model it is possible for irrigated production of any given crop to be completely eliminated if completion for irrigation is sufficiently intense in a RB-AEZ. This is the case for rainfed production if productivity goes down significantly due to external shocks such as climate change.

In the new model the market clearing condition for land operates at RB-AEZ level by industry. This means than the price of land (and hence productivity of land) varies across RB-AEZs and industries. However, the marker clearing condition for water operates at the RB level in each region and hence the price of water varies only among RBs in each region and within each RB producers who irrigate crops pay the same price for water. Several major changes are made in the GTAP code to handle these modifications.

Data

THL has used the SAGE data-base documented in Monfreda et al. (2008) and the data base developed by Portmann et al. (2010) to incorporate crop industries by irrigation type into the GTAP-BIO model. The data base developed by THL represents the global land cover, harvested areas and crops produced by region at the AEZ level. We reconstruct these data items at the RB-AEZ level. In addition, the data base developed by Siebert and Döll (2010) is utilized to introduce water used for irrigation by region and crop at the RB-AEZ level into our biophysical data base. THL has distinguished between irrigated and rainfed cropland rents in each region by crop and AEZ. In this paper we assigned the difference between the irrigated and rainfed cropland rents in each RB-AEZ to the water used for irrigation in that RB-AEZ.

The new data base aggregates land cover, harvested areas, crop production, water used, and payments to land and water into 20x18 matrixes by region, industry and irrigation type. In each matrix rows represent river basins and columns represent AEZs. The maximum numbers of river basins and AEZs in each region are about 20 and 18, respectively. In this paper, crops are aggregated into six crop categories and each crop is divided into two subcategories of irrigated and rainfed. In this work, the whole world is divided into 125 river basins and 19 geographical regions. Some river basins serve more than two geographical regions. When a river basin serves more than one region, we divided that river basin into independent segments. Hence there is no water trade between the segments of a river basin which serves more than one region. Appendix A lists these river basins.

Experiments

In this paper we develop three different experiments to examine and highlight only the economic and land use consequences of changes in climate variables and water supply for irrigation in the presence of biofuel production at a global scale. Hence in developing our experiments we assume only these factors are changing and other factors which could alter the global economy will remain unchanged. To isolate the impacts of climate change, water supply for irrigation, and biofuels from other major drivers of the global economy we developed three sets of different exogenous shocks for a two-decade time horizon, 2001-2021. The first shock measures impacts of changes in temperature of CO2 concentration on crop yields. The second shock represents changes in water supply for irrigation. The last shock considers expansion in the global biofuel industry. These shocks and our experiments are defined below.

Experiment 1

This experiment isolates the joint impacts of changes in temperature, precipitation, and CO_2 concentration on crop yields from other economic and biophysical factors which may affect crop yields and evaluates the consequences of changes in yields due to these factors for the global agricultural markets, regional crop trade balances, and land use changes.

Numerous studies have examined impacts of changes in temperature, precipitation, and CO_2 concentration on crop yields by region (examples are: Parry et al. (2007); Lobell et al. (2007); Nelson et al. (2009); Nelson et al. (2010), Lobell et al. (2011); and Lobell and Gourdji (2012)). In general, these studies confirms that: higher levels of CO_2 concentration contribute to higher crop yields, particularly for C3 crops; global warming negatively affected crop productivities in many regions across the world, particularly for rainfed crops; and changes in precipitation do not significantly contribute to changes in crop yields. Unlike these general agreements there are huge uncertainties about the magnitudes of these impacts. A common approach has been used to estimate impacts of climate change and CO_2 fertilization on crop yields. In this approach, estimates for changes in these factors at a grid cell level along with some assumptions on adoption strategies are introduced into biophysical models to determine how they will affect productivities of crops by region. Since there is no common ground on the future of climate change and there are major differences among biophysical models used in this area, the estimates for impacts of climate change vary from on study to another one significantly even for a particular crop in a certain region.

Unlike this common approach, some studies have estimated the impacts of changes in temperature, precipitation, and CO_2 on crop yields using econometric methods and historical observations. For example, Lobell et al. (2011) estimated the impacts of these variables on corn, wheat, rice and soybean yields by region from real observation for the time period of 1980 to 2008. In another attempt, Lobel and Gourdji (2013) have conjectured future impacts of climate and CO_2 trends on crop yields from their past trends. We will use the results of these two studies to define a set of productivity shocks in crop products due to the expected future changes in temperature and CO_2 emissions. In determining these shocks we used the following assumptions:

i. Climate trends in 2001-2021 will be follow its trend in 1980-2008,

ii. Irrigated crops will not be affected by temperature and precipitation,

iii. Change in CO2 concentration will improve irrigated and rainfed crop yields by 1% per decade except for coarse grains.

In addition to these assumptions, following Nelson et al. (2010 and 2011) it is assumed that the climate trend impacts on non-soybean oilseeds are identical to the trend impacts on soybean and for sugarcane and other crops are equal to the average impacts for soybean, wheat, and rice.

Experiment 2.

This experiment imposes two sets of shocks on the global economy. The first sock is identical to the shock defined in the first experiment. The second shock captures the impacts of changes in available water for irrigation. Hence the second experiment highlights the consequences of changes in water supply for irrigation and climate change and their interactions for the global economy.

In the future, supply of water for irrigation could vary due to changes in demand for water in non-agricultural uses and/or due to changes in investment in water management projects. Liu et al. (2013) have estimated changes in available water for irrigation by river basin for 2001-2030. We relied on this work and defined a set of shocks which represent changes in water supply by river basin for the time period of 2001-2021.

Experiment 3

In addition to the shocks defined in the second experiment, here we impose a set of biofuel shocks on the global economy to evaluate consequences of producing biofuels in the presences of changes in water supply for irrigation and climate change. To define the biofuel shocks it is assumed that in 2021 the US, EU27, and Brazil will produce: 15 billion gallons of ethanol and 1 billion gallons of biodiesel; 2 billion gallons of ethanol and 4 billion gallons of biodiesel; and 6 billion gallons of sugarcane ethanol respectively.

4. Simulation Results

Crop Production

The anticipated changes in the climate conditions will affect the irrigated and rainfed yields at different rates among crops and across regions around the world. In general the simulation results obtained from the first experiment show that the changes in climate conditions will increase the global output of irrigated crops by 4.2% (about 153.4 million metric tons (MT)) for a two-decade time period (i.e. 2001-2021), if we ignore other factors which may affect the supply side of crop markets. A big portion of this gain will happen in China, Russia, regions categorized under other parts of former Soviet Union, and Brazil. In response to the expansion in irrigated crops, the global rainfed crop production will be decreased by 2.7% (about 138.7 million MT). The rainfed crop output will be decreased in several regions, mainly those which gain in irrigated crops. Hence the global crop output is expected to increase by 14.7 million MT during a two-decade time period due to changes in climate conditions. In general, these results confirm that the changes in climate conditions enhance irrigation and penalize rainfed agriculture at the global scale. The results obtained from the first simulation show than at the global scale the changes in climate conditions negatively affect production of wheat and coarse grains. On the other hand this factor improves production of rice, oilseeds, sugar crops and other crops.

Several regions such as EU27, Brazil, Russia and regions classified under other parts of former Soviet Union, and Oceania will lose a portion of their crop products while some other regions in particular, US, China, India, and countries located in East and South East of Asia will gain from changes in temperature, precipitation, and CO_2 concentration. Table 1.1 illustrates the expected changes in irrigated and rainfed crops due to changes in climate conditions by regions.

Adding the impacts of changes in water supply for irrigation to the changes in climate condition significantly affects the simulation results of the first experiment, as shown in Table 1.2. The important changes are:

1) The changes in water supply wash out the positive impacts of the changes in climate conditions on the global crop output. In experiment 2 the global crop output goes up only by only 2.9 million MT which is significantly lower than the corresponding figure obtained from the first experiment (i.e. 14.7 million MT).
2) Changes in water supply wash out the positive impacts of changes in climate conditions in several regions including China, India, East and South East Asia, Middle East and North Africa. These regions are expected to lose a portion of their available water for irrigation in future decades.
3) Changes in water supply in combination with climate impacts on yields will improve the agricultural outputs of several regions including but not restricted to US, EU, and Brazil. These regions will not face major reduction in water resources for irrigation in general.
4) Changes in water supply wash out the positive impact of changes in climate conditions on the global output of rice. Alterations in climate condition increase global rice production by about 4.1million MT. This effect becomes slightly negative in the second experiment when both water and climate changes were included. However, rice production shifted from irrigated to rainfed.
5) Changes in climate condition increase irrigated wheat (by 25.4 million MT) and reduce rainfed wheat (by 27 million MT) in the first experiment. In the second experiment, when we include both the reduction in water supply and changes in climate conditions, the

production of irrigated wheat only goes up by 16.3 million MT, and the production of rainfed wheat goes down 20.6 million MT. This means that the changes in water supply exacerbate the negative impacts of changes in climate condition on wheat production. The negative impact of the joint imposed shocks on the global production of wheat (-4.3 million MT) is larger than the impact of the first set of shocks alone (-1.6 million MT).

6) In the absence of changes in water supply, the changes in climate conditions alter the global outputs of irrigated and rainfed coarse grains by 36.1 million MT and -38.5 million MT, respectively. Adding the changes in water supply slightly alter these figures to 28 million MT and 31.6 million MT.
7) The expected changes in water supply worsen the positive impacts of the changes in climate conditions on the irrigated oilseeds (from -1.2 million MT in the first experiment to -1.3 MT in the second experiment) and elevate the impacts on the rainfed oilseeds (from 1.6 million MT in the first experiment to 5.2 MT in the second experiment).
8) The changes in climate conditions increase the global output of sugar crops by 3.7 million MT in the first experiment. Adding the changes in water supply reduces the global output of this crop category by 1.5 million MT.
9) Finally the expected changes in water supply significantly deflate the impacts of the changes in climate conditions on the outputs of other crops.

We now examine the impact of biofuel production on the crop outputs in the presence of changes in water supply and climate conditions in the third experiment. Biofuel production extends croplands and diverts agricultural resources toward the feedstock crops needed for biofuel production. As a result, outputs of coarse grains, oilseeds and sugar crops go up significantly and outputs of rice, wheat, and other crops go down as shown in Table 3. In this process the following phenomena can be observed:

1) Expansion in water supply in some regions, such as USA, EU27, Brazil and some other regions expands irrigated crops.
2) Reduction in water supply in some regions such as China, India, and several other regions transfers the available water to the less water intensive crops and more productive AEZs in each river basin.
3) These changes plus yield improvements due to changes in climate conditions lead to expansion in irrigated crop outputs even in the areas which will be faced with reduction in water for irrigation.
4) Biofuel production in the USA, EU27 and Brazil alters the mix of crops produced in these regions and all across the world in favor of corn, oilseeds, and sugarcane.

Finally, the results obtained from experiments 1, 2, and 3 confirm that biofuel production increases the share of irrigation in crop production at the global scale. This confirms the positive impacts of biofuel production on irrigation adoption. Biofuels increase crop prices significantly and that induces incentives to invest in irrigated crops more than rainfed crops.

Trade impacts

The simulation results obtained from the first experiment indicate that changes in the climate condition worsen the crop trade balances of EU27, Brazil, Russia and regions classified under other parts of Former Soviet Union On the other hand the crop trade balances of several regions including USA, China, India, East and South East Asia, and Middle east will be improved due to changes in climate condition. Table 2.1 represent changes in crop trade balances by region and crop obtained from the first experiment. This table indicates that changes in climate conditions have minor impacts on the trade of sugar crops. In addition, this table demonstrates that: 1) the US will gain on wheat, coarse grains, and other crops and lose on rice and oilseeds; 2) EU27 will lose on almost all crop categories, except for oilseeds; 3) Brazil will lose on almost all crop categories, except rice; 4) China, India, and East and South East Asia will gain on almost all crops; and 5) Russia will lose on all crop categories and Sub Saharan Africa will not observe important changes.

Including the impacts of changes in water supply in the second experiment worsens the crop trade balance of China, India, East and South East of Asia, and Middle East and North Africa and improves the trade balances of several regions including US, EU27 and several of other regions. Finally, allocating a portion of crop outputs to biofuel production worsens the crop trade balances of USA and EU27 (major biofuel producers) and improves the balances of many other regions. This is because USA and EU27 reduce their net crop exports and other regions reduce their net crop imports due to higher crop products.

Land Use Impacts

The simulation results obtained from the first experiment confirms that changes in climate conditions have major land use consequences, as shown in table 3.1. The global irrigated and rainfed cropland areas will change by about 21.7 million hectares and -25.5 million hectares during a two-decade time period due to changes in climate conditions. This shows that the changes in climate condition will increase profitability of irrigated crops and reduce profitability of their rainfed counter parts. Due to the changes in the irrigated and rainfed cropland, the global cropland area will go down by 3.5 million hectares. This is because in several regions across the world the crop yields will be improved due to the changes in climate conditions. The reduction in cropland will occur almost across the world except for Russia. As shown in table 3.1 changes in the climate conditions increase/decrease irrigated/rainfed areas everywhere.

Including the impacts of changes in water supply reduces the expansion in irrigated areas in the second experiment to 12.4 million hectares due to the shortage in water supply for irrigation in several regions such as China, India, and South and South East Asia. In the second case the reduction in the global rainfed area is limited to 10.8 million hectares and the global cropland goes up only by 1.6 million hectares. This means than unlike the climate factors which positively affect crop yields and hence reduce the demand for cropland, the limits in water for irrigation increase the need for cropland.

Finally, the simulation results obtained from the third experiment indicate that the area of global cropland goes up by about 15.5 million hectares in response to the changes in available water for irrigation, climate change, and biofuel production. Compared to the second case we can conclude that about 13.9 million hectares of this expansion is due to the biofuel production. Compared to the second case where rainfed cropland goes down and irrigated cropland goes up, in the third case both irrigated and rainfed land go up to satisfy the demand for biofuel feedstock.

5. **Conclusion**

This paper first reviews the literature in three different yet related areas of economic modeling, climate change and food production, and water availability for crop production. Then it introduces the implemented modeling approach and the experiments which are designed to assess the consequences of changes in climate conditions and water availability for irrigation in the presence of biofuel production. Finally, it presents the results on three important subjects of changes in crop production, crop trade balances, and land use implications at a global scale. The paper indicates that: 1) Future changes in the climate conditions could increase crop outputs at the global scale and improve profitability of irrigated crops. 2) Changes in water supply have the potential to reverse some positive impacts of climate change and limit crop outputs in China, India, South and South East Asia, and Middle East and North Africa; 3) Finally, biofuel production alters the mix of crops produced in favor of corn and oilseeds across the world, reallocating distribution of water among irrigated crops, and increasing incentives to adopt irrigation. Biofuels increase crop prices significantly and that induces incentives to invest in irrigated crops more than rainfed crops.

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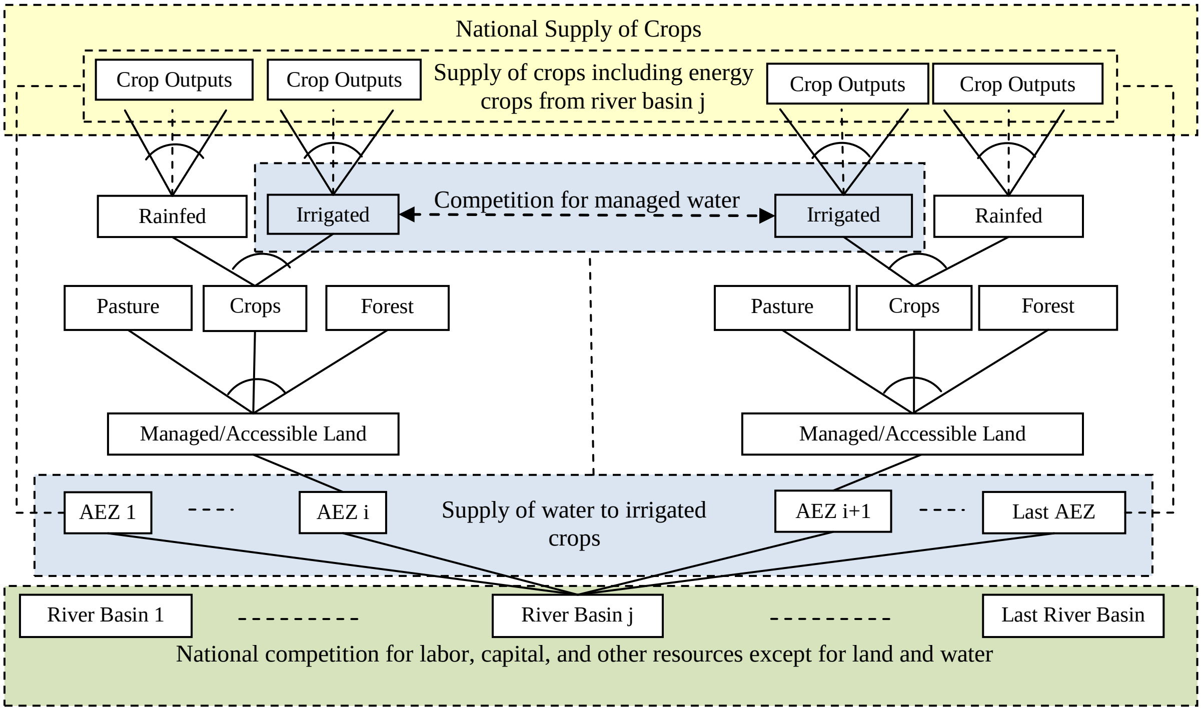

Figure 1. Modeling framework

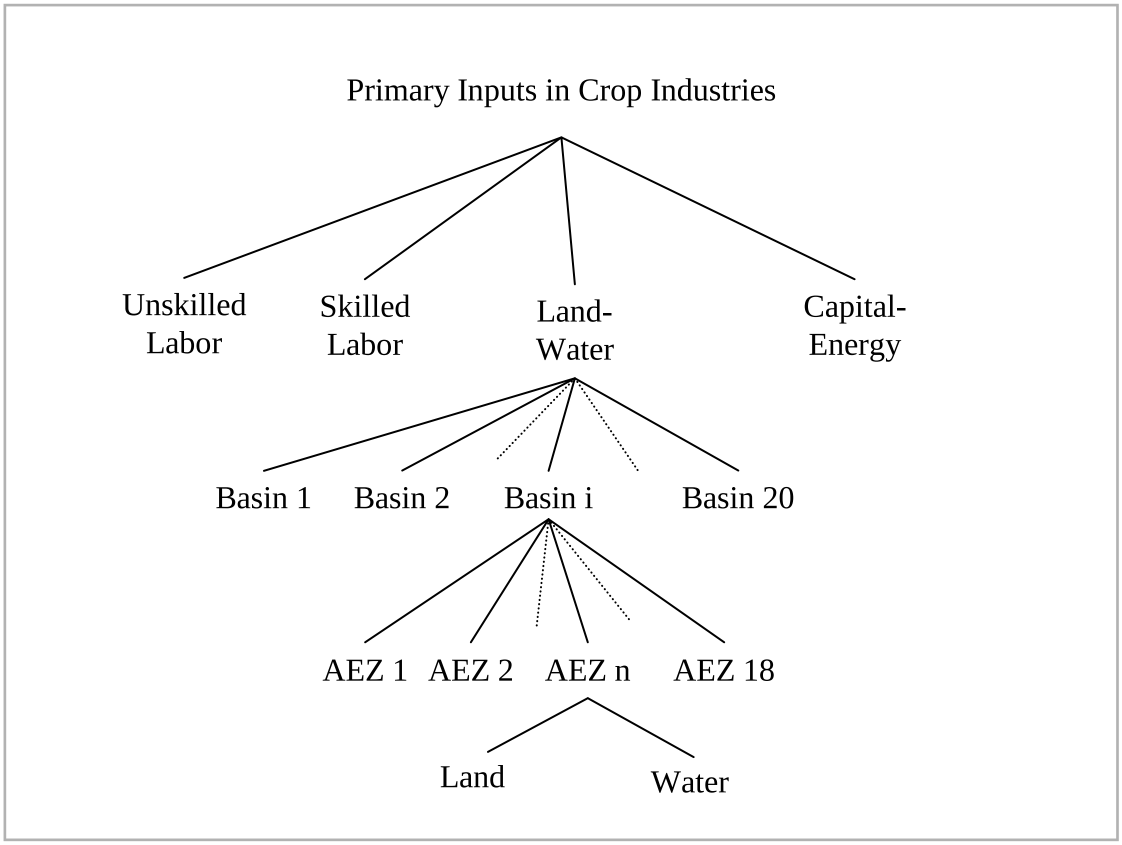

Figure 2. Primary inputs used in crop industries

Table 1.1. Changes in crop production due to changes in temperature, participation, and CO_2 concentration in a two-decade time period (figures are in 1000 metric ton)

Production	Paddy Rice		Wheat		Coarse Grains		Oilseeds		Sugar Crops		Other Crops	
	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed
USA	-2.4	-34.5	322.8	2484.0	3559.6	-3418.0	345.9	207.7	-107.0	142.2	2830.1	6280.7
EU27	-131.4	0.8	520.2	-2101.2	4224.9	-5227.4	-1473.0	1603.5	1566.1	-1780.1	-912.0	648.0
BRAZIL	-411.6	437.7	5.4	-416.5	169.3	-1414.9	36.0	-1302.0	10063.6	-10545.0	169.6	-3086.2
China	1563.8	292.8	5382.0	-3622.4	17523.1	-15649.7	2132.0	-1891.4	867.3	-933.6	17627.3	-15974.5
India	1342.7	-660.7	1258.3	-684.1	13.9	119.2	69.8	172.2	1163.6	54.4	3738.2	-2572.1
E. & S. E. Asia	2241.4	-536.8	722.4	-299.0	261.8	-316.8	20.2	1354.0	656.8	189.2	1367.4	977.7
Russia & FSU	-101.4	0.1	14166.0	-21373.0	8240.5	-10414.1	23.8	-247.3	4823.9	-2956.0	31913.5	-32565.3
M. E. & N. Afr.	77.6	-0.6	2005.8	-1065.7	653.1	-454.0	20.2	-0.7	182.3	-1.5	5005.3	-4139.8
S. S. Afr.	181.4	-104.7	142.2	-50.2	129.4	-80.8	11.5	202.7	289.3	-28.5	1243.8	-571.6
Others	-28.3	72.4	874.9	63.3	1343.2	-1665.0	55.1	1551.9	875.3	-804.1	2579.2	-6566.8
Total	4731.8	-533.5	25400.1	-27064.9	36118.7	-38521.5	1241.5	1650.6	20381.2	-16662.9	65562.4	-57569.8

Table 1.2. Changes in crop production due to changes in available water for irrigation, temperature, participation, and CO_2 concentration in a two-decade time period (figures are in 1000 metric ton)

Production	Paddy Rice		Wheat		Coarse Grains		Oilseeds		Sugar Crops		Other Crops	
	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed
USA	96.6	10.7	479.3	2965.0	3314.5	-3050.2	346.0	468.9	-168.2	201.4	3514.1	6421.6
EU27	40.5	1.3	525.5	-1509.7	4401.1	-5366.2	-1443.5	1719.7	1824.0	-2009.9	185.2	2068.7
BRAZIL	-146.7	226.0	5.3	-410.5	151.5	-1342.2	54.6	-1183.3	8229.8	-9052.4	106.5	-2584.0
China	-1929.8	1096.8	1992.0	-1666.5	12308.6	-11715.1	1094.0	-1429.0	-1987.0	1641.5	10392.4	-11282.6
India	-1324.5	1105.8	210.3	-315.7	-737.0	778.0	-1159.1	1220.3	-573.7	294.3	-3198.1	3024.2
E. & S. E. Asia	-1704.5	2130.5	-1955.2	71.9	-146.4	11.0	-155.5	2489.0	-2070.5	1801.9	-3167.2	3380.4
Russia & FSU	-93.1	0.3	12939.9	-19953.9	7435.5	-9484.7	-48.5	-187.0	3462.6	-2246.8	29163.4	-29551.5
M. E. & N. Afr.	36.6	-0.2	1124.0	-462.6	226.7	-178.6	-55.1	58.5	-456.1	164.1	1844.8	-1716.1
S. S. Afr.	-145.4	100.7	142.5	-18.5	-188.4	238.3	6.3	241.8	-909.5	194.0	755.6	1031.0
Others	96.1	50.5	886.0	687.4	1285.3	-1503.8	43.6	1833.8	841.7	-755.5	2714.1	-4364.9
Total	-5074.2	4722.4	16349.5	-20613.2	28051.4	-31613.4	-1317.1	5232.9	8193.1	-9767.4	42310.8	-33573.2

Table 1.3. Changes in crop production due to changes in available water for irrigation, temperature, participation, and CO_2 concentration in the presence of biofuel production in a two-decade time period (figures are in 1000 metric ton)

Production	Paddy Rice		Wheat		Coarse Grains		Oilseeds		Sugar Crops		Other Crops	
	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed	Irrigated	Rinfed
USA	-1140.9	187.6	-1335.0	-772.1	27092.1	24566.8	1627.9	2833.0	-638.4	339.1	-10726.3	-21945.2
EU27	35.3	2.6	220.5	1362.0	2916.9	-8079.0	3031.1	6546.2	2808.1	-2750.4	-10454.5	-1589.0
BRAZIL	-400.8	275.4	1.3	-486.5	30.2	-1774.9	45.2	2576.7	95531.2	8966.0	-1330.3	-1419.7
China	-2465.0	1185.0	2911.2	-1596.7	12834.3	-10976.3	1859.9	-284.0	-2165.9	1688.5	11273.3	-10437.7
India	-1666.3	1486.0	411.0	-233.7	-780.0	763.2	-908.9	1651.5	-1272.5	305.6	-3256.4	4677.0
E. & S. E. Asia	-2625.0	2395.9	-1696.2	128.5	-146.7	36.3	119.4	18163.4	-2170.4	1578.9	-3237.6	4930.4
Russia & FSU	-80.0	0.3	11371.5	-17427.9	6440.9	-7926.3	158.8	438.0	1908.2	-1445.0	27836.0	-26827.8
M. E. & N. Afr.	-56.4	0.2	1305.9	-15.5	310.5	13.0	270.1	84.7	-1058.4	345.2	830.5	512.3
S. S. Afr.	-443.8	166.6	240.5	84.2	-240.2	541.0	268.1	2372.3	-2428.4	693.6	1416.9	5736.1
Others	360.1	100.8	320.5	1684.8	592.4	198.5	723.1	7917.6	558.6	-584.5	-2049.7	2961.0
Total	-8482.6	5800.3	13751.2	-17273.0	49050.2	-2637.9	7194.7	42299.5	91072.1	9137.0	10302.0	-43402.7

Table 2.1. Changes in crop trade balance due to changes temperature, participation, and CO_2 concentration for a two-decade time period (figures are in million US dollar)

Production	Paddy Rice	Wheat	Coarse Grains	Oilseeds	Sugar Crops	Other Crops	Total
USA	-11.7	204.9	73.8	-46.7	0.1	500.3	720.7
EU27	-10.2	-97.5	-15.1	7.8	-0.3	-42.4	-157.7
BRAZIL	6.7	-51.2	-31.2	-188.6	0.0	-266.5	-530.8
China	2.4	26.3	10.7	98.7	0.1	91.4	229.7
India	13.5	51.4	1.7	15.6	0.3	98.8	181.2
E. & S. E. Asia	41.8	71.5	-23.3	68.2	0.4	341.5	500.1
Russia & FSU	-19.6	-495.3	-36.9	-55.3	-0.4	-635.6	-1243.1
M. E. & N. Afr.	4.9	294.7	-2.7	14.1	0.2	140.9	452.1
S. S. Afr.	-0.3	16.0	1.9	2.9	-0.2	-21.8	-1.5
Others	-28.8	-17.1	23.0	78.8	0.1	-171.1	-115.2

Table 2.2. Changes in crop trade balance due to changes in water supply for irrigation, temperature, participation, and CO_2 concentration for a two-decade time period (figures are in million US dollar)

Production	Paddy Rice	Wheat	Coarse Grains	Oilseeds	Sugar Crops	Other Crops	Total
USA	4.5	317.6	136.4	33.6	0.1	594.2	1086.5
EU27	16.2	-14.3	-8.9	-3.1	0.5	179.0	169.6
BRAZIL	11.6	-59.3	-22.2	-144.0	0.0	-218.1	-431.9
China	-6.5	-1.3	-5.1	25.7	-1.1	-107.7	-96.0
India	-8.3	3.3	2.1	-2.7	-0.9	-46.4	-52.9
E. & S. E. Asia	-34.4	-101.4	-58.6	13.7	0.9	-61.8	-241.7
Russia & FSU	-21.1	-479.5	-34.6	-51.7	-0.3	-618.8	-1205.9
M. E. & N. Afr.	5.6	177.8	-33.6	0.2	0.0	45.8	195.8
S. S. Afr.	-0.2	11.7	2.3	7.7	0.3	137.7	159.4
Others	31.1	140.8	23.7	114.6	0.5	138.1	448.7

Table 2.3. Changes in crop trade balance due to changes in water supply for irrigation temperature, participation, and CO_2 concentration in the presence of biofuel production for a two-decade time period (figures are in million US dollar)

Production	Paddy Rice	Wheat	Coarse Grains	Oilseeds	Sugar Crops	Other Crops	Total
USA	-46.9	89.5	212.3	305.8	-0.8	-1922.0	-1362.0
EU27	-0.6	-399.7	-12.7	-2037.5	-0.6	-1555.7	-4006.8
BRAZIL	-2.0	-92.5	37.7	825.4	-0.1	-468.5	300.0
China	0.4	34.1	93.4	65.7	-0.8	412.6	605.3
India	5.5	97.0	4.8	114.3	-0.7	143.1	364.0
E. & S. E. Asia	-39.6	-136.6	-121.4	-141.3	2.0	630.2	193.4
Russia & FSU	-20.5	-296.7	29.8	198.1	-0.1	-85.2	-174.6
M. E. & N. Afr.	9.7	289.2	-140.6	38.1	-0.4	355.9	552.0
S. S. Afr.	-0.8	10.6	40.2	120.0	0.9	1107.5	1278.3
Others	92.5	429.9	-115.7	416.5	0.4	1338.5	2162.2

Table 3.1. Land cover changes due to changes in temperature, participation, and CO_2 concentration (figures are in 1000 hectare)

Region	Forestry	Cropland			Pasture
		Irrigated	Rainfed	Total	
USA	-26.3	308.1	-339.7	-31.6	57.9
EU27	-31.9	660.4	-649.8	10.6	21.3
BRAZIL	324.3	178.4	-776.0	-597.6	273.3
China	122.9	6549.8	-6905.9	-356.1	233.2
India	465.7	697.7	-1533.8	-836.1	370.4
E. & S. E. Asia	136.4	379.3	-628.9	-249.6	113.2
Russia & FSU	-135.3	11276.5	-10911.6	364.8	-229.5
M. E. & N. Afr.	7.0	772.6	-1297.4	-524.8	517.8
S. S. Afr.	267.2	380.0	-1221.9	-841.9	574.6
Others	145.0	576.6	-973.2	-396.5	251.5
Total	1274.9	21779.4	-25238.2	-3458.8	2183.8

Table 3.2. Land cover changes due to changes in available water for irrigation, temperature, participation, and CO_2 concentration (figures are in 1000 hectare)

Region	Forestry	Cropland			Pasture
		Irrigated	Rainfed	Total	
USA	-89.2	355.0	-194.2	160.9	-71.6
EU27	-205.5	751.0	-448.3	302.7	-97.3
BRAZIL	247.2	258.1	-650.4	-392.2	145.0
China	-16.4	5098.1	-5076.5	21.6	-5.2
India	-27.4	-2944.3	2963.8	19.5	7.9
E. & S. E. Asia	-91.6	-2250.3	2524.1	273.7	-182.2
Russia & FSU	-128.6	10177.3	-9451.7	725.6	-596.9
M. E. & N. Afr.	-2.8	206.7	-50.4	156.3	-153.5
S. S. Afr.	-94.3	135.8	103.2	239.0	-144.7
Others	8.1	636.4	-508.7	127.7	-135.7
Total	-400.5	12423.9	-10789.2	1634.7	-1234.2

Table 3.3. Land cover changes due to changes in available water for irrigation, temperature, participation, and CO_2 concentration in the presence of biofuel production (figures are in 1000 hectare)

Region	Forestry	Cropland			Pasture
		Irrigated	Rainfed	Total	
USA	-1028.2	2576.6	-532.6	2044.0	-1015.8
EU27	-1737.6	915.3	1631.5	2546.8	-809.2
BRAZIL	-714.5	209.3	1216.1	1425.4	-710.9
China	188.5	5363.8	-5195.8	168.0	-356.5
India	-392.3	-2810.1	3519.6	709.5	-317.2
E. & S. E. Asia	-212.0	-2553.6	3081.0	527.4	-315.4
Russia & FSU	351.2	9030.8	-7694.2	1336.6	-1687.8
M. E. & N. Afr.	-8.5	23.6	952.4	976.0	-967.6
S. S. Afr.	-846.3	246.9	2892.2	3139.1	-2292.8
Others	-323.1	127.0	2554.6	2681.6	-2358.5
Total	-4722.8	13129.6	2424.9	15554.5	-10831.7

Appendix A

List of river basins

Table A1 Water used for irrigation by river basin in 2000 (Figures are in KM^3)

River Basin Name	River Basin Name	River Basin Name
Amazon	Iberia_West_Atla	Philippines
Amudarja	India_East_Coast	Red_Winnipeg
Amur	Indonesia_East	Rhine
Arabian_Peninsul	Indonesia_West	Rhone
Arkansas	Indus	Rio_Colorado
Baltic	Ireland	Rio_Grande
Black_Sea	Italy	SE_Asia_Coast
Borneo	Japan	Sahara
Brahmaputra	Kalahari	Sahyada
Brahmari	Krishna	Salada_Tierra
Britain	Lake_Balkhash	San_Francisco
California	Lake_Chad_Basin	Scandinavia
Canada_Arctic_At	Langcang_Jiang	Seine
Carribean	Limpopo	Senegal
Cauvery	Loire_Bordeaux	Songhua
Central_African	Lower_Mongolia	South_African_Co
Central_America	Luni	South_Korea_Peni
Central_Australi	Madagascar	Southeast_Africa
Central_Canada_S	Mahi_Tapti	Southeast_US
Chang_Jiang	Mekong	Sri_Lanka
Chile_Coast	Middle_Mexico	Syrdarja
Chotanagpui	Mississippi	Thai_Myan_Malay
Colorado	Missouri	Tierra
Columbia	Murray_Australia	Tigris_Euphrates
Congo	New_Zealand	Toc
Cuba Carribean_C_A	Niger	US_Northeast
Danube	Nile	Upper_Mexico
Dnieper	North_African_Co	Upper_Mongolia
East_African_Coa	North_Euro_Russi	Ural
Easten_Ghats	North_Korea_Peni	Uruguay
Eastern_Australi	North_S_Amer_Coast	Volga
Eastern_Med	Northeast_Brazil	Volta
Elbe	Northwest_Africa	West_African_Coa
Ganges	Northwest_S_Amer	Western_Asia_Ira
Godavari	Ob	Western_Australi
Great_Basin	Oder	Western_Gulf_Mex
Great_Lakes	Ohio	Yenisey
Hail_He	Orange	Yili_He
Horn_of_Africa	Orinoco	Yucatan
Hual_He	Papau_Oceania	Zambezi
Huang_He	Parana	Zhu_Jiang
Iberia_East_Med	Peru_Coastal	