Economy-wide Impacts of Climate Change on Water Resources in Africa: A CGE Approach

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Abstract

Water resources are facing several stresses in terms of quantity and quality. These pressures are closely related to the human interventions in fields like: agriculture, land-use/land use change, and pollutant emissions, among others. Within this context, the expected changes in climate pattern will exacerbate the challenges faced by water resources. Considering the critical role that water plays for agricultural production, any shock in water availability will have great implications for agricultural production, and through agricultural markets these impacts will reach the whole economy with economy-wide consequences. In this paper a new modeling approach is developed aiming to include water explicitly within the ICES CGE model. In order to reach this objective a new database was built considering explicitly the water endowment, precipitation changes, and unitary irrigation costs. The results suggest different economic consequences of climate change on depending on the specific country. The impacts are related to change in crop production, endowment demands, and international trade.

Keywords: CGE Models, Climate Change, Agriculture, Water Resources, Irrigation

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1. Introduction

Water resources are facing several stresses in terms of quantity and quality. These pressures are closely related to the human interventions in fields like: agriculture, land-use/land-use change, construction/management of reservoirs, pollutant emissions, and water/wastewater treatment, among others. Within this context, the expected changes in both demographic trends and climate patterns will exacerbate the challenges faced by water resources (Bates et al, 2008). Considering the current and expected pressures over water resources, both the competition for water and the conflicts among users are expected to increase.

Climate change is already hitting the African Region, the region is already facing higher temperatures than 100 years ago. Regarding precipitations, even though Africa has always been a drought prone region, specially the sub-Saharan region, the evidence suggests that this feature has increasing over the past century (Touchan, Anchukaitis, Meko, Sabir, Attalah, & Aloui, 2011).

According to the Intergovernmental Panel on Climate Change (IPCC) on its Fourth Assessment Report, Africa is one of the most vulnerable regions to the expected changes in the climate patterns. For instance, there is very high confidence about the expected impacts of climate change on agricultural production, with yields losses up to 50% by 2020. There is very high confidence about the negative impact on safe access to drinking water in many countries. Finally, the extreme poverty currently faced by the African region, will contribute to increase the vulnerability associated to the future climate conditions (Parry, M.L.; Canziani, O.F.; Palutikof, J.P.; et al., 2007).

The agricultural activity is a key component of the African economic and social sectors. The agricultural production accounts, in average, for the 14% of the GDP. The range goes from 2.2% in Botswana to 66.6% in Liberia (The World Bank, 2011). Considering the critical role that water plays for the agriculture, any shock in water availability will have great implications for the agricultural production, and through agricultural markets these impacts will reach the whole economy. Besides, considering only the expected population increase, a large investment in the agricultural sector will be needed in order to assure food supply, which implies to re-allocate resources from other economic sectors. Due to these economy-wide implications, the main focus of this paper is the use of the general equilibrium approach to study agricultural water related issues.

The general equilibrium approach uses Computable general equilibrium (CGE) models as analytical tools. The CGE models simulate the equilibrium theory formalized by Arrow and Debreu (Arrow & Debrau, 1954) with real economic data, with the objective to solve numerically for different economic variables (supply, demand and prices) that support equilibrium across specified set of markets.

The aim of this paper is to present a new methodological approach in order to include water within the **I**ntertemporal **C**omputable **E**quilibrium **S**ystem, the ICES CGE model developed by Fondazione ENI Enrico Mattei. The ICES model is used in order to explore the economy-wide consequences of a reduction in water availability for the African region. The model bases its structure on the GTAP-E model (Burniaux & Truong, 2002).

The paper is organized as follows: section two presents a literature review of CGE studies addressing water and climate change issues at global scale. Section three presents the proposed model structure, while section four shows the main results. Finally, section five concludes.

2. Literature Review

Considering the data requirement that a CGE model at global scale has, the database provided by the Global Trade Analysis Project (GTAP) is the most used in the modeling of water related issues.[1]

The GTAP database is distributed with a CGE model, the GTAP model. The GTAP model makes use of the Walrasian perfect competition conditions to simulate adjustment processes. Within GTAP, industrial sector is modeled using a representative firm that maximizes profits in perfectly competitive markets. The production functions are specified using nested Constant Elasticity of Substitution (CES) functions. According to the ‘‘Armington assumption’’, there is no perfect substitution across domestic and foreign inputs, this feature accounts for product heterogeneity.

The consumer side of the economy is represented through a representative consumer in each region who receives income defined as the service value of the national primary factors. In the case of capital and labor, the model assumes that they are perfectly mobile domestically, but immobile internationally. National income is allocated between aggregated household consumption, public consumption and savings.

The first effort in order to analyze water issues using a CGE approach was done by Berritella *et al* (Berrittella, Hoekstra, Rehdanz, Roson, & Tol, 2007(a)). Based on the GTAP-E model (Burniaux & Truong, 2002), using the aggregation of the GTAP 5 database (based on 1997) authors propose

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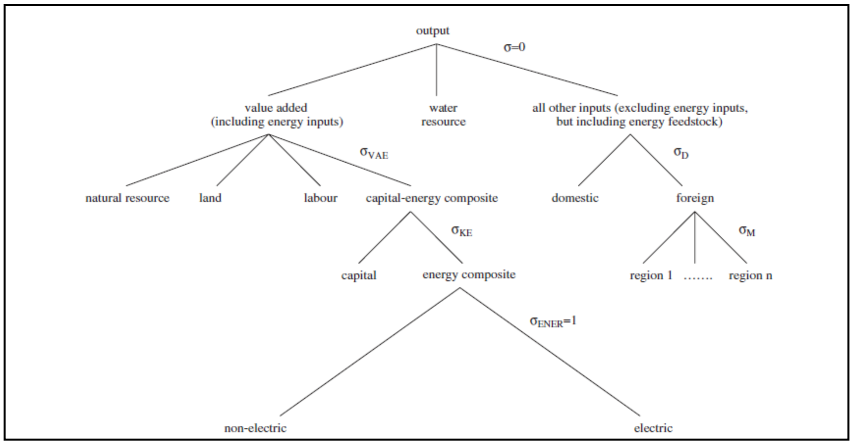
[1] For a full description of the GTAP database, see https://www.gtap.agecon.purdue.edu/databases/v5/v5_doco.asp. For the sector disaggregation see: Dimaranan, B., & McDougall, R. (2002).

a new modeling approach called GTAP-W that explicitly considers water as a production factor[2]. The GTAP 5 aggregation presents a detailed representation of the world economy with 16 regions and 17 sectors, 6 of which are in agriculture.

Using the Leontief formulation, water is combined with the value-added-energy nest and the intermediate inputs at the top of the production tree. This formulation implies no substitution among these three components, thus water cannot be substituted with any other input (Figure 1).

Figure 1. GTAP-W Production Tree



Source: (Berritella et al, 2007(a))

According to this modeling approach, water is supplied to both the sectors, agriculture (5 crops and livestock) and water distribution services. Water is completely mobile within sectors, but it is immobile across them. The benchmark scenario assumes an unconstraint water supply.

Using information provided by AQUASTAT and FAOSTAT authors define the Water Intensity Coefficient (WIC). The WIC is defined as the amount of water used by sector *j* in order to produce one unit of commodity *i*. The WIC includes the total water requirement per sector, both green and blue water[3].

In order to include water, the CGE modeling framework requires a price signal from the water sector. Considering that water does not have a price for the agricultural sector, authors simulate price signals through the emergence of economic rents due to water scarcity. If water supply does not meet water demand, consumers would be willing to pay a price in order to get access to the

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[2] A previous version of GTAP-W called GTAP-EWF was published before as working paper. (Berrittella, M., Hoekstra, Y., Rehdanz, K., Roson, R., & Tol, R. (2005)).

[3] Green water is defined as the amount of rainfall that is stored in the root zone, while blue water is defined as the amount of water diverted from the water system and applied to the crops.

resource. The model assumes that water resources are privately or collectively owned, in which case water scarcity will drive the emergence of economic rent.

Using the water price elasticites estimated by Rosegrant *et al* (Rosegrant, Cai, & Cline, 2002), authors estimate the impact of water variability on the WIC. According to the model, when water supply decreases, assuming negative water price elasticity, it implies an increase in water prices, which at the same time drives a decrease in water use (decrease in WIC).

The GTAP-W model has been applied to the analysis of virtual water, water pricing, water supply, the China South-North Water Transfer (SNWT) project, and the impact of trade liberalization.

Berritella *et al* (Berrittella, Hoekstra, Rehdanz, Roson, & Tol, 2005) use a previous version of the GTAP-W model, GTAP-EFW, to analyze virtual water flows as consequence of a decrease in water availability. In this study authors simulate four different scenarios:

- Sustainable Water Supply. This scenario excludes the use of groundwater. This scenario has two versions: Optimistic and Pessimistic. In the former, water availability is restricted only for North Africa (NAF 44%), while in the latter water supply is restricted for NAF (44%), United States of America (USA 1.58%), South Asia (SAS 1.58%), and China (3.92%)
- China Water Transfer. This scenario implies a 7% increase in water availability for China due to the SNWT project.
- Water Pricing. This scenario considers water charge per cubic meter (m^3) of water used. The charges are: ¢1, ¢5, and ¢10.
- Trade Liberalization. This scenario considers a full removal of all trade barriers for agricultural products.

Results show that water restrictions imposed by the sustainable water supply scenario implies an increase in the imports of water intensive products by water scarce countries. The welfare impacts will depend on the specific country and scenario.

In the case of China Water Transfer project, the increase in water availability has a positive effect over its virtual water trade balance, but it has a negative impact over the trade balance. This is because the increase in the production of water intensive products drives a decrease in the production of all other products. As a consequence China's gross domestic product (GDP) decreases by 0.11%.

Simulations related to water pricing confirm the expected impacts: decrease in water demand, increase in water intensive products' prices, the regions with lower water productivity are worse off after the water charge. Finally, the simulated trade liberalization has positive effects on the world welfare, this positive impact is reached without increasing the total demand for water.

Water pricing is analyzed by Berritella *et al* (Berrittella, Rehdanz, Roson, & Tol, 2006). In this study they simulate the economic impacts of a tax policy applied to water resources. They simulate six different scenarios, in all of them tax is redistributed, *lump sum*, to households[4]. The six scenarios are:

- Water tax equal to ¢1/ m^3 for all industries.
- Water tax equal to ¢0.5/ m^3 for all industries.
- Water price elasticities equal to zero for all industries.
- Water taxes only for the agricultural sector (¢1/ m^3).
- Water taxes only for NAF, USA, SAS, and China (¢1/ m^3).
- Taxes over final consumption, according to the water used to produce a good (¢1/ m^3)

Simulations results show that as a consequence of the water tax, water demand decreases in many regions around the world. Nevertheless, some regions increase their production of water intensive products in order to export them. The final impact of the water tax is closely related to water efficiency, the lower the efficiency, the stronger the impact.

The restricted water supply topic is analyzed by Berritella *et al* (Berrittella, Hoekstra, Rehdanz, Roson, & Tol, 2007(a)). In this study authors simulate the economic impacts of restricted water supply in water scarce regions. They simulate 5 scenarios:

- Market scenario. In this case authors assume the existence of water property rights and simulate the following water shortages: NAF (10%), USA (1.58%), SAS (1.58%), and China (3.92%).
- Severe Shortage in NAF. In this case NAF faces a decrease in water availability of 44%. All the other regions remain the same.
- Water Specific. In this case water is sector specific for each agricultural sector.
- Water price elasticities equal to zero for all industries.

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[4] A similar study, considering only 4 scenarios, was published later on 2008: Berrittella, M., Rehdanz, K., Roson, R., & Tol, R. (2008).

As expected, the regions that face water shortage decrease their productions and regions that are not constrained increase their productions. As a consequence, the world is worse off because of the restricted water supply. The intensity of the welfare changes are associated to the level of water restriction, so for higher water constraints, the welfare gains (losses) are higher. Nevertheless, welfare gains respond less than proportionally, and welfare losses more than proportionally, to the water constraint.

In the analysis of the China SNWT project (Berrittella, Rehdanz, & Tol, 2007(b)), authors analyze the economy-wide impacts of the SNWT project that is intended to transfer water (44 billion m^3) to the north region of China by 2050. They simulate three scenarios:

- Water availability. It considers an increase of 7% of Chinese water availability.
- Investment. It considers only the investment needed to implement the project. This investment is about $US7 billion per year.
- Investment and Water. It considers both scenarios at the same time.

For the benchmark, results show that due to the project the Chinese economy will be stimulated and the country will have an increase in welfare. When water is included into the model, the gains of the project are marginal. This is because more water will reduce water price, affecting water "owners". At global scale, the project has minimal negative impacts.

Berritella *et al* (Berrittella, Rehdanz, Tol, & Zhang, 2007(c)), analyzed the impacts of trade liberalization, as Doha, over water resources. Authors do not focus the analysis on water reallocation, instead they look into the reallocation of water intensive products. The scenarios analyzed are:

- Reduction of 25% of agricultural tariffs, zero agricultural subsidies and reduction of 50% in domestic farm support.
- Reduction of 50% of agricultural tariffs, zero agricultural subsidies and reduction of 50% in domestic farm support.
- Reduction of 75% of agricultural tariffs, zero agricultural subsidies and reduction of 50% in domestic farm support.
- For developed countries the reduction of the tariff is 75%, while in developing countries is 50%.

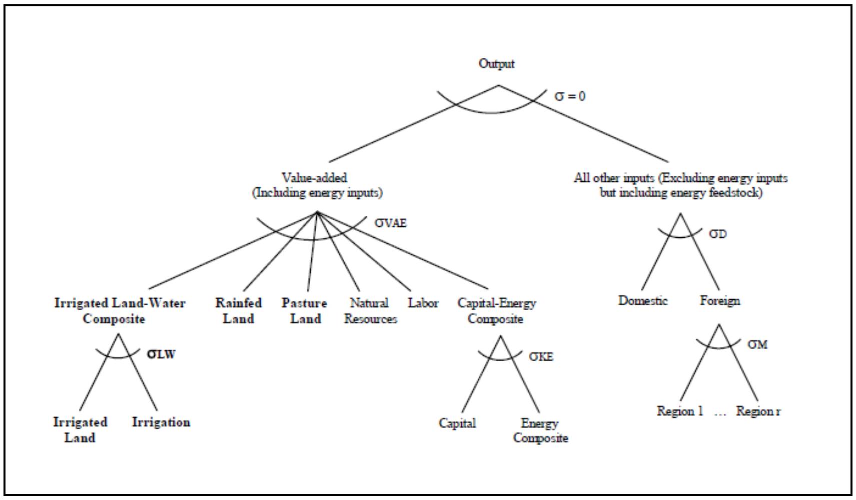
As general conclusion, authors find that the impact of trade liberalization over water demand is small, less than 10% of water use, for the most aggressive reduction in tariffs. Even though the effect is small, trade liberalization puts the incentives in the right place, decreasing water use in those regions in which is scarce and increasing water use in water abundant regions.

Calzadilla *et al* (Calzadilla, Rehdanz, & Tol, 2008) present a new CGE model addressing water related issues. This model presents a major improvement in contrast to the previous version presented by Berritella *et al* (Berrittella, Hoekstra, Rehdanz, Roson, & Tol, 2007(a)). This new version considers the difference between water provision systems, such us: rainfall and irrigation. This difference is considered using an indirect approach, differentiating between rainfed and irrigated crops. The model is based on the GTAP 6 (dated on 2001)[5].

The new approach consists of splitting the original land endowment, in the value-added nest, into 3 components: pasture land, rainfed land and irrigated land. Under this specification pasture land is the land devoted to animal production and animal products, its value is computed according to the value of land in the livestock industry. The remaining types of land differ from each other related to the value of irrigation: irrigated land is more valuable as yield per hectare is higher. Authors split land into rainfed land and irrigated land using its proportional contribution to the total production.

Finally, the authors split irrigated land into the value of land itself and the value of irrigation through a CES irrigated land-water composite. For the last step, they use the ratio irrigated yield to rainfed yield provided by the IMPACT model (Rosegrant, Ringler, Msangi, Sulser, Zhu, & Cline, 1998). The productive structure is presented in figure 2.

Figure 2. Production Tree



Source*:* Calzadilla *et al* (Calzadilla, Rehdanz, & Tol, 2008)

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[5] The aggregation of the GTAP 6 database presents a detailed representation of the world economy with 16 regions and 22 sectors, 7 of which are in agriculture.

Considering that authors only split the original database, the social accounting matrix remains balanced avoiding calibration problems. This new formulation allows for substitution between irrigation and irrigated land, in this case the key parameter is the elasticity of substitution in the irrigated land-water composite.

The new production structure, as well as the data used (provided by IMPACT model), allows the model to account for differences related to the type of water used for the agricultural sector (blue/green). This is because the IMAPCT model accounts for the amount of green water used by rainfed production, and the amount of green and blue water used in irrigated production.

In the benchmark it is assumed that all the water used by the irrigation sector is blue water. Using information related to the volume of the green water used by each sector and region, as well as information about payments to the factors of production, it is possible to compute the specific shadow price of water for each sector and region. This approach cannot be used for green water, because this input is free. Within this framework the expected changes in water availability are modeled as exogenous changes in both productivity of rainfed and irrigated land.

The model has been applied to the analysis of irrigation improvement, sustainable water use, and climate change.

Calzadilla *et al* (Calzadilla, Rehdanz, & Tol, 2008) analyze the economy-wide consequences of an improvement in irrigation management. Authors define the irrigation efficiency as the "ratio between the volume of irrigation water beneficially used by the crop to the volume of irrigation water applied to the crop". They simulate three different scenarios:

- Improvement in irrigation efficiency only in water stressed regions, considering only developing regions.
- Improvement in irrigation efficiency independent of the development level.
- Improvement in irrigation efficiency in all the GTAP regions.

For all simulations, the simulated improvement in irrigation efficiency is 73% for all the crops.

The results show that higher levels of irrigation efficiency would have significant effects on: water use, crop production, and welfare. In some regions water use goes up for a specific crops, while in others it goes down. Due to the increase in water use efficiency the rainfed sector is worse off, but its welfare losses are offset by the aggregated benefits of the whole economy.

In the study of sustainable water use in agriculture (Calzadilla, Rehdanz, & Tol, 2010), authors define sustainable water use as the suppression of groundwater over-exploitation by 2025. In this study they simulate the scenarios proposed by Rosegrant *et al* (Rosegrant, Cai, & Cline, 2002):

- Business as usual. It assumes water withdrawal according to current trends.
- Water Crisis Scenario. A deterioration of water conditions worldwide. This scenario is characterized by an increase in water use (surface and groundwater).
- Sustainable water use. The overexploitation of groundwater is gradually eliminated by 2025.

The analysis assumes that more water diverted for agricultural production implies less water available for environmental uses, as consequence the results show a trade-off between agricultural production and human welfare. In the water crisis scenario there is more water available for agriculture than in business as usual scenario, and welfare is higher. In contrast, the sustainable water use scenario has less water for agriculture, and lower welfare. Nevertheless, the water available to the natural environment goes in the other way around, more water for agriculture means less water for the environment. In this sense, authors argue that the costs of a more sustainable water use are quite small ($US1.3 per person).

The study of climate change impact in regional agriculture (Calzadilla, Zhu, Rehdaz, Tol, & Ringler, 2009(a)) is devoted to analyze the economy-wide impacts of climate change over Sub Saharan Africa (SSA) agricultural sector. Using output information from the IMPACT model, such as: demand and supply of water/food, rainfed and irrigated area/production, food prices, and trade; this study simulates two different adaptation strategies, under the IPCC scenarios SRES B2 (Intergovernmental Panel on Climate Change, 2000), for SSA agricultural sector by 2050:

- Increase in irrigated land. It assumes an increase of 100% of irrigated land.
- Increase in agricultural productivity. It assumes an increase in both rainfed and irrigation yields of 25%.

Results show that both adaptation strategies allow farmers to reach higher yields and revenues of agricultural production. For the first scenario the increase in regional welfare is small ($US119 million), while in the second scenario the welfare gains are multiplied more than hundred times ($US 15,434 million).

Calzadilla *et al* (Calzadilla, Rehdaz, & Tol, 2010) analyze climate change impacts in global agriculture using expected changes in average river flows, according to the IPCC SRES A1B and A2 (Intergovernmental Panel on Climate Change, 2000). They include the expected changes in river flows as changes in the irrigation endowments and rainfed land productivity.

Simulations suggest that climate change impacts would modify agricultural production worldwide. At global level, total crop production decreases for the 2020 period and increases for the 2050 period. The same pattern follows the GDP evolution.

Using the standard GTAP-E, Roson & Sartori (Roson & Sartori, 2010) analyze water related issues associated to the water scarcity and virtual water trade in the Mediterranean region. The database used is dated on 2004, GTAP 7.1. GTAP 7.1 presents a detailed representation of the world economy with 113 countries and 57 sectors, 13 of which are in agriculture. In order to deal with water scarcity, they translate trade flows into virtual water equivalents, using the same approach proposed by Berritella *et al* (Berrittella, Hoekstra, Rehdanz, Roson, & Tol, 2005).

Authors compute, using the mean annual runoff (MAR), an index of water constraint (IWC) that indicates till which extent a specific country is constrained by its water resources. The index is computed as the ratio of agricultural water use to MAR net of agricultural use. Using this index, the authors classify countries as: water constraint (IWC>1), partially water constraint (1<IWC<0.25), and no constraint (WIC=0).

The authors assume that water scarcity is driven by climate change, in this sense they link climate change with expected changes in MAR according to climate models. Furthermore, authors assume that the expected changes in MAR by 2050, are equal to the changes in the multifactor productivity for agricultural sector (multiplied by WIC). Using this model, authors simulate five scenarios: wetter scenario, drier scenario, intermediate average of extreme scenarios, virtual water trade constraint for Spain, and reduction of 50% for all the elasticities of substitution for agricultural products.

Results shows that virtual water trade may reduce the negative impacts of water scarcity. Nevertheless, the expected impacts on income and welfare are relevant. For instance, for Morocco is expected a decrease of 14.4% on its GDP due to the water constraint.

Roson & Van der Mensbrugghe (Roson & Van der Mensbrugghe, 2010) use the previous approach to account for climate change impacts on water resources. Using the ENVISAGE model (van der Mensbrugghe, 2009), authors simulate six different climate change impacts: agricultural productivity, sea level rise, water availability, energy demand, human health and labor productivity. According to the results, the main impact is related to a decrease in labor productivity. At regional level, the higher impacts are faced by the Middle East and North Africa.

3. Model Description

Considering that agriculture is one of the major water intensive sectors worldwide, the inclusion of water has been limited to the agricultural sector. On the other hand, the expected impacts of climate change on the agricultural sector are function of the technology used by each agricultural sector. The model considers two different technologies associated to water provision for the agricultural sector: irrigation and precipitation. If we consider irrigation as an adaptation strategy to climate change, it would be reasonable to expect diverse impacts for both rainfed crops and irrigated crops. The model considers these diverse impacts accounting for differences between rainfed and irrigated land.

Considering that water does not have a market price, it is not possible to compute its value and include it into the model's structure. In order to overcome this shortcoming, the methodology considers water as a physical endowment that affects the productivity of the agricultural sector. Thus, it would not be necessary a price for that endowment, nevertheless it is assumed that the water endowment and its variations also due to changes in precipitations would influence the productivity of the agricultural sector.

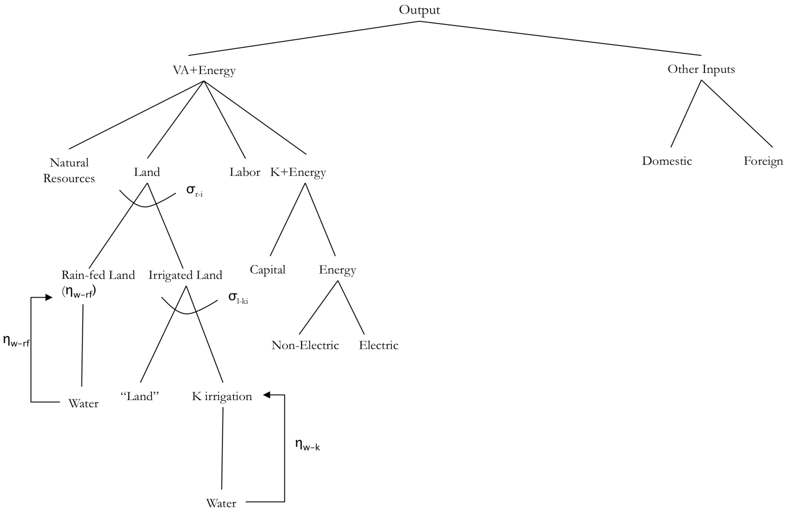
The rationale behind this formulation is that water affects agricultural productivity depending on the type of land: *i*) for rainfed land it depends on precipitation, *ii*) for irrigated land it depends on specific investments made to provide irrigation services and on the actual stock on water reservoirs.

In order to represents the rationale of the model, we consider investments in a specific type of capital, which is extracted from the existing physical capital stock and classified from now on as "irrigation capital". Furthermore, the positive externality provided by water use is modeled as an increase in the factor specific productivity of irrigation capital in agriculture that depends on changes of water availability.

The proposed production structure of the model is depicted on figure 3. As shown on this picture, on the third level the model considers four inputs: natural resources, land, labor and the capital-energy composite. On the fourth level, the model differentiates between rain-fed land and irrigated land, in order to account for productivity differences, as well as for climate change impacts.

On the next level, irrigation land is a composite of land itself and the capital devoted to irrigation. The capital devoted to irrigation is a sector specific input associated to irrigated-land. Finally, the model assumes that the productivity of the capital devoted to irrigation, as well as the productivity of rainfed land, depends on the endowment of water and precipitation in each region.

Figure 3. ICES-W Production Tree



Including water within this new framework implies gathering additional information to incorporate it in the existing database. On this regard, the needed steps are:

a. Splitting the capital endowment for agricultural sectors in:
  - Irrigation capital (IrCapital)
  - Rest of physical capital (Capital)

b. Splitting the land endowment in:
  - Rainfed land (Land)
  - Irrigated Land (IrLand)

c. Building an external module representing the behavior of the irrigation sector.

The capital for irrigation was extracted computing the capital rents of irrigation projects worldwide. Four were the main sources of information used: FAO (FAO, 2003), IWRMI (Inocencio, et al., 2007), You *et al* (You, et al., 2009), and information collected from the World Bank Implementation, Completion and Results Report (The Word Bank, 2007).

Regarding land, it was splitting using the share of area actually irrigated over the total cultivated area, according to information contained on the global groundwater irrigation inventory (Siebert, Burke, Faures, Frenken, Doll, & Portman, 2010).

Finally, the model differentiates the expected impacts of changes in water availability for both rainfed and irrigated land. For rainfed land, the model assumes a direct linkage between precipitation and agricultural production. On the other hand, for irrigated land the lineal relationship does not hold considering that the capital devoted for irrigation, moderates the impact of changes in water availability on the agricultural productivity. The model accounts for this relationship through the use of a reduced-form hydrologic module.

The hydrologic module represents the output flow used for irrigation as function of both changes in precipitation (input flows) and evolution of the reservoir capacity (water stock). This relationship is modeled using a set of differential equations.

The module assumes that each region has a unique water storage device (reservoir), with a capacity that is equal to the sum of the reservoirs capacities of the different countries within the region. It also assumes that the installed capacity of water storage is equivalent to the current water endowment. The impact of climate change on the productivity of capital for irrigation is computed as the change on the irrigated areas due to the water restriction. The information about water storage capacity was collected from the International Commission on Large Dams (ICOLD).

4. Data

Regarding capital for irrigation, the FAO (FAO, 2003) published information for 248 irrigation projects. The geographical disaggregation includes 5 regions: Eastern Asia (EA); Southern Asia (SA); sub-Saharan Africa (SSA); Near East & North Africa (NENA); Latin America and the Caribbean (LAC). The database is focused on developing countries (33 countries). The information includes: delivery method (gravity/pumped), On-farm irrigation technology, donor, year of project, type of investment (rehabilitation/ new development), and Investment cost (2000 USD). The projects collected by FAO include investment for USD 8 billion and an irrigated area of 7,3 million hectares during the period 1980-2000.

Inocencio *et al* (Inocencio, et al., 2007) present a comparative study of investment costs for different regions. The sample includes 314 irrigation projects in 6 regions: Sub-Saharan Africa (45), Middle East and North Africa (51), Latin America and the Caribbean (41), South Asia (91), Southeast Asia (68), and East Asia (18). The total sample includes 51 countries.

The report includes information about: project name, region, country, year of project started, area under new construction, area under rehabilitation, and total irrigation costs (2000 USD). The study reports projects for 43.9 billions and 53.6 million hectares from the period 1965-1998.

You *et al* (You, et al., 2009) present a study regarding irrigation spending needs in Africa in order to reach the irrigation potential within the region. The study includes large and small-scale irrigation facilities as operational alternatives. Regarding large-scale irrigation, the study considers 620 dams, covering 41 countries. Information about dams includes: country, number of dams (operational, rehabilitated, planned), hydroelectric capacity (operational, rehabilitated, planned), reservoir capacity (operational, rehabilitated, planned), investment expenditure, increase in irrigated area, and water used. Authors present different investment scenarios, according to different cost structure (high costs and medium costs).

The internal rates of return for the irrigation projects were extracted from the World Bank Implementation, Completion and Results Report (The Word Bank, 2007)

By merging the information presented above, a new database was built containing information for over 1,200 irrigation projects worldwide.

The area under irrigation was collected from the global groundwater irrigation inventory (Siebert, Burke, Faures, Frenken, Doll, & Portman, 2010). The inventory includes information about area equipped for irrigation (AEI), area actually irrigated (AAI), and consumptive water use for irrigation (ICWU). The information is available for 204 countries worldwide. The model considers as irrigated area, the area equipped for irrigation.

Finally, the water storage capacity was collected from the ICOLD database that has information for more than 33,900 dams worldwide (ICOLD, 2012). Considering that dams could have multiple uses, for the model we include only those having irrigation as one of the possible uses: 18,353 dams in 104 countries.

5. Simulation Design and Results

The ICES-W model has 20 regions, 13 of which are in the Africa region (Nigeria, Senegal, Ethiopia, Madagascar, Malawi, Mauritius, Mozambique, Tanzania, Uganda, Zambia, Zimbabwe, Rest of Western Africa, Rest of Central Africa), and 18 sectors among of which 7 are in agricultural sector (rice, wheat, cereal crops, vegetables and fruits, oilseeds, sugar, plant fiber).

Regarding the climate shock, the model simulates a decrease of 10% in precipitation for all regions. This decrease in precipitations drives a decrease on rainfed yield of 10%. For the irrigated crops, the hydrologic module predicts a decrease of 5% in the productivity of the capital for irrigation.

In the benchmark scenario, the average irrigated land is 6.4%, while the capital devoted to irrigation represents 2.1% of the total capital rents. Details per regions are presented in table 1.

Table 1. Benchmark: Irrigated Land and Irrigation Capital

Region	Irrigation Capital	Irrigated Land
Nigeria	0.2%	1.5%
Senegal	2.8%	2.3%
RoWAF	1.5%	1.1%
RoCAF	0.5%	0.5%
Ethiopia	0.5%	1.9%
Madagascar	2.8%	30.4%
Malawi	5.3%	1.7%
Mauritius	0.3%	22.1%
Mozambique	1.3%	0.8%
Tanzania	0.5%	1.7%
Uganda	0.5%	0.1%
Zambia	3.6%	5.2%
Zimbabwe	6.4%	3.0%
RoEAF	10.3%	3.5%
RoSCAF	0.1%	0.4%
Botswana	0.0%	0.2%
SouthAfrica	0.2%	9.7%
RoSAC	0.4%	4.0%
RoNAF	3.2%	21.6%
RoW	1.1%	17.3%

According to the preliminary results, all the agricultural products show an increase on the price paid for the use of both rainfed land (Land) and capital for irrigation (IrCapital). The magnitude of the change depends on the specific region and sector, ranging from 25.7% on the land price paid in Botswana for vegetables and fruits, to 87.45% on the irrigated capital price paid in South Africa for rice. This increase on prices drives different reactions depending on the region and the agricultural sector.

At the global level, the total agricultural output increases 0.96%, with changes ranging from -1.01% for sugar beet, to 2.42% on rice. The African region shows an increase on the agricultural production of 1.05%, while for the Rest of the World this figure is -0.7%. At country level, the change on the average agricultural output ranges from -4.15% (Malawi) to 7.17% (Mauritius). The increase on the agricultural output implies a reduction on the size of the other economic sectors. For the African region, the reduction is -0.23%, while for the RoW the reduction is -0.09%.

Results per sector show that wheat production has the biggest variation: Malawi is the most affected by the change in agricultural production (-12.3%), while in Senegal wheat production increases 13.9%. On the other hand, sugar production ranges from -3% in Zimbabwe to 1.2% in Botswana.

Regarding prices, all the agricultural prices increase within the range 1.83% (sugar in Tanzania), to 13.7% (rice in Zimbabwe). In Tanzania, sugar output decreases 0.21%, while rice output in Zimbabwe decreases 2.41%.

Considering that the climate shock is uniform across regions, the different consequences faced by both countries could be associated to the initial endowment of both irrigated land. Within the African region, Uganda has the smallest share of irrigated land, while Madagascar has the largest share. Therefore, Madagascar has a greater adaptive capacity to deal with the decrease in rainfed yields. On this regard, Uganda shows a decrease on the agricultural output of 0.32%, while Madagascar presents an increase of 2.9%.

Finally, the expected impacts of climate change imply a decrease on the GDP for all regions in -0.24%, with Uganda as the most affected country (-0.5%).

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Annex 1

Table 1. Rice and Wheat Production (%change)

Region	Rice	Wheat
1 Oceania	4.989003	-13.487272
2 China	-1.087451	-0.03095
3 India	-4.512749	-4.677902
4 Asia	-1.838382	-1.465752
5 USA	-1.400777	-15.164994
6 RoNAmerica	-12.419873	10.482667
7 Argentina	3.063695	-9.853701
8 Brazil	-2.751041	1.811548
9 Bolivia	-9.081851	-3.012707
10 Chile	-2.139656	-1.710374
11 Peru	-1.820605	-10.168092
12 RoLAC	-4.672959	-13.380533
13 EU_27	24.706373	3.10425
14 MENA	8.517338	8.228807
15 SSA	-0.270374	3.806678
16 RestofWorld	-1.372086	-4.912769

Table 2. Endowment Demand for Rice Production

qfe[*Rice*]	1 Land	2 IrLand	3 Lab	4 Capital	5 IrCapital
1 Oceania	6.472202	13.8442	13.268646	13.303363	12.222019
2 China	-1.084942	2.191041	4.94454	5.207063	2.000996
3 India	0.862731	2.016032	4.988874	5.308715	2.016031
4 Asia	1.98668	3.573796	6.95414	6.983531	4.55196
5 USA	1.254897	4.629681	6.685266	6.613508	4.632045
6 RoNAmerica	-9.53069	-5.746619	-6.165491	-6.104003	-5.867185
7 Argentina	5.974749	8.49168	9.145017	9.913068	8.491682
8 Brazil	-2.627327	-0.111514	3.041763	3.079255	-0.074227
9 Bolivia	-1.808521	0.335318	-1.822423	-1.711742	0.335318
10 Chile	-6.47308	-4.369679	3.698953	3.778459	-4.36968
11 Peru	1.674053	3.831726	6.183561	6.276711	3.831727
12 RoLAC	-1.009561	2.921235	3.039471	3.269896	2.518693
13 EU_27	15.164416	17.278429	30.67359	30.617775	21.221327
14 MENA	-4.529206	-2.81309	10.774542	10.896892	-3.126351
15 SSA	-0.382825	1.603861	4.498038	4.756326	0.746129
16 RestofWorld	-2.348536	0.733381	2.257385	2.296585	0.454376

Table 3. Endowment Demand for Wheat Production

qfe[*Wheat*]	1 Land	2 IrLand	3 Lab	4 Capital	5 IrCapital
1 Oceania	-10.095418	-3.861492	-7.932021	-7.904438	-5.231381
2 China	-0.558435	2.734986	5.626355	5.980926	2.543929
3 India	-1.221903	-0.092439	2.331661	3.137223	-0.092439
4 Asia	-2.30746	-0.770882	4.364616	4.399188	0.16625
5 USA	-11.322283	-8.366692	-9.343245	-9.404366	-8.364621
6 RoNAmerica	11.144373	15.774863	17.49498	17.570194	15.626769
7 Argentina	-3.935933	-1.654384	-3.247377	-2.839187	-1.654382
8 Brazil	1.058883	3.669935	7.850331	7.903654	3.708635
9 Bolivia	3.985912	6.256263	5.336099	5.464427	6.256264
10 Chile	-6.183131	-4.073207	4.093707	4.163676	-4.073208
11 Peru	-6.255308	-4.265907	-3.889158	-3.715487	-4.265907
12 RoLAC	-8.602475	-4.967688	-7.065308	-6.852254	-5.339376
13 EU_27	2.994388	4.954672	10.352941	10.295313	8.483247
14 MENA	3.153314	4.980996	11.8565	11.986287	4.642612
15 SSA	3.227587	5.154286	8.990113	9.284614	4.266582
16 RestofWorld	-1.160603	1.947567	0.220939	0.29169	1.665198

Table 4. Aggregated Exports by Region

qxw	1 Rice	2 Wheat	3 VegFruits	4 IndCrops	5 CerCrops	6 Animals_Pcts	7 Animals
1 Oceania	32.663418	-15.162766	6.940258	0.830748	0.056392	0.738006	4.768889
2 China	80.64193	61.468151	13.249357	18.502645	23.429068	-4.246067	-14.584571
3 India	-73.117332	-24.207726	-25.573441	-36.000751	-32.425495	-42.49073	26.622889
4 Asia	-53.659168	-2.812854	-5.628299	-32.85643	-20.835562	-10.746885	-18.552168
5 USA	-2.930709	-19.279305	-8.489954	-8.115581	-10.690883	9.633323	-16.948933
6 RoNAmerica	-24.535173	11.262654	-5.884915	3.938885	-14.829736	-16.741112	3.741027
7 Argentina	27.713888	-10.404749	-6.162524	7.549562	-3.507312	-19.428839	-25.727022
8 Brazil	55.121998	-1.039757	9.060801	18.022076	5.694785	-8.930032	-11.072623
9 Bolivia	35.813602	37.044498	-13.59157	15.32812	-8.533932	-13.640409	-1.736072
10 Chile	89.251564	27.610823	8.483075	32.481598	30.131281	13.978191	4.279978
11 Peru	-50.286369	-50.38361	1.719689	-22.986147	-19.460609	-21.299404	-26.93696
12 RoLAC	-11.145717	-20.348995	-3.575397	-5.463696	-5.923787	-18.18092	-10.127658
13 EU_27	63.074123	12.422669	5.20346	13.911198	11.155696	4.851929	2.962904
14 MENA	155.050919	48.579067	28.2185	39.251747	64.875389	15.821465	11.689857
15 SSA	29.976336	17.558548	7.060435	13.050676	8.973454	2.716689	0.163578
16 RestofWorld	53.933292	-11.087748	0.200272	-1.67217	-7.018817	-10.391215	-11.396958

Table 5. Aggregated Imports by Region

qiw	1 Rice	2 Wheat	3 VegFruits	4 IndCrops	5 CerCrops	6 Animals_Pcts	7 Animals
1 Oceania	-6.467512	7.71406	4.03863	4.570424	2.761286	-1.503073	-1.199116
2 China	-18.978525	-11.618831	-1.87439	0.765739	-4.772483	3.047989	8.730627
3 India	91.252357	36.391609	15.967798	30.060932	16.359179	34.159939	3.177325
4 Asia	52.965012	-0.85096	10.24577	20.615171	7.44478	6.096562	11.820344
5 USA	-9.323215	19.879791	5.890763	14.896198	10.262406	-10.775561	9.276748
6 RoNAmerica	1.740795	-5.297065	-0.844324	-2.104816	3.498752	10.556919	-3.664694
7 Argentina	-19.29958	15.757801	1.234892	0.803237	-4.08742	3.701368	12.641378
8 Brazil	-5.509408	-4.639333	-4.626903	-4.89931	-4.332396	7.781431	2.194131
9 Bolivia	6.322825	-9.966355	-2.168719	5.619357	0.251644	-2.682018	-7.984089
10 Chile	-32.865242	-17.395166	1.569938	-5.274081	-4.429106	-4.598883	-1.352496
11 Peru	34.38026	13.93676	7.008773	22.607956	7.466872	10.971478	7.112084
12 RoLAC	0.096983	-0.89735	3.192066	4.139784	1.907943	9.788619	-0.347794
13 EU_27	-2.613226	-0.787259	-0.242367	-3.751709	-1.986391	-3.312321	-0.296356
14 MENA	2.839145	-15.260517	-6.510617	-10.433815	-14.573466	-8.783178	-1.388994
15 SSA	-14.017425	-4.557262	0.926054	-1.356449	-1.297058	-2.345357	-0.441315
16 RestofWorld	-12.136111	4.020606	2.425158	2.043202	2.691861	4.367559	8.404867