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Integrating Water Resources into Computable General Equilibrium Models- A Survey

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SUMMARY 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. 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. The aim of this report is to present a literature review about the state of the art methodology regarding the study of water issues using the CGE approach at global and national scale. The analysis of the different studies confirm the economy wide consequences of changes in water allocation, irrigation policies, and climate change, among others water related issues.

Keywords: Computable General equilibrium models, water, irrigation, agricultural policy, water allocation.

JEL: C68, Q18, Q25, Q54.

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. Taking into account that water is a scarce resource, less than 1% is available for human consumption, any management strategy should consider this scarcity feature (UNESCO, 2003).

Economic theory uses two main approaches to address agricultural water related issues: partial equilibrium and general equilibrium approaches. Under the partial equilibrium approach, the main interests are the equilibrium conditions of a market for one good/sector that is part of the overall economy. This approach implies both prices fixed in other markets and the minimal price interaction across markets. Within this category it is possible to identify: hydro-economic modeling, agricultural models, and the Ricardian approach, among others.

The general equilibrium approach uses Computable general equilibrium (CGE) models as analytical tools. CGE models simulate the equilibrium theory formalized by Arrow and Debreu (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.

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. 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 review is the use of the general equilibrium approach to study agricultural water related issues.

The aim of this report is to present a literature review about the state of the art methodology regarding the study of water issues using the CGE approach. A special attention is devoted to those studies that analyze water issues using a linkage between top-down and bottom-up approaches.

The report is organized as follows: section two presents CGE studies at global scale highlighting its main research issues and contributions; section three is devoted to the studies dealing with water issues at national scale, along with studies that use CGE in combination with bottom-up approaches; finally section four presents the key issues and future research direction in CGE model addressing water issues.

2. General Equilibrium Models and Water at Global Scale

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.* (2007(a)). Based on the GTAP-E model (Burniaux & Truong, 2002), using the aggregation of the GTAP 5 database (based on 1997) authors propose 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.

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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).

[2] A previous version of GTAP-W called GTAP-EWF was published before as working paper. Berrittella, *et al* (2005).

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.

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 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.* (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.

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[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.

Berritella *et al.* (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* (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.* (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.

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.

[4] A similar study, considering only 4 scenarios, was published later on 2008 (Berrittella, *et al*.,2008).

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.* (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.* (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 et al., 1998).

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

[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.

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.* (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 et al., 2009) 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.* (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 (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.* (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 (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. CGE and Water at National Scale

The use of CGE models to address water related issues at national/regional scale precedes the analysis at the global scale. One of the first efforts in this direction was done by Lofting & McCaughey (1968), in this study they include water into an input-output model in order to analyze the requirements of water in California. Since then, CGE model has been used to analyze a broad type of issues, such as: water pricing policy (Decaluwé, Patry, & Savard, 1999; Letsoalo, *et al*., 2007), water allocation (Seung, *et al.*, 2000; Diao, Roe, & Doukkali, 2005; Lennox & Diukanova, 2011; Juana, Strzepek, & Kirsten, 2011; Diao & Roe, 2003), water markets (Gomez, Tirado, & Rey-Maquieira, 2004), irrigation policies (Roe *et al.*, 2005; Cakmak, *et al*, 2008; Strzepek, *et al*, 2008; Hassan & Thurlow, 2011), and climate change impacts (Smajgl, 2006; You & Ringler, 2010; Cakmak, Dudu, & Saracoglu, 2009), among others.

Some of the studies listed above include the integration of top-down and bottom-up models. The integrated approach seems to be a proper way to analyze water related issues, mainly because it accounts for local conditions (bottom-up) and the systemic consequences of any change at the aggregated level (top-down).

Decaluwé *et al.* (1999), present a CGE model applied to Morocco in which they analyze the impacts on water allocation of different pricing policies. The pricing scenarios analyzed are: Boiteux-Ramsey pricing (BRP), BRP and production tax decrease, BRP and income tax decrease, marginal cost pricing (MCP), and MCP with tax decrease[6].

The model presents a detailed representation for the agricultural sector through a series of nested CES functions. In this representation agricultural production uses: capital (K_{ag}), land ($Land_{ag}$), fertilizer (Fer_{ag}), water ($water_{ag}$), and Labor (Ld_{ag}), as primary inputs. The intermediate consumption is represented through a composite (Ci_{ag}).

The model considers two different technologies to produce water: water produced by dams already in use (*Eb*), and water "produced" by both more efficiency in the retrieving of surface water and water from pumping stations (*Wat*). *Eb* is produced using only capital (*K*), while *Wat* is produced using capital (K_{eua}) and labor (Ld_{eau}).

Regarding *Eb*, capital is linked to the amount of rain needed to provide irrigation services through a linear function, while in *Wat* the specific technology used will depend on the availability of surface water. If surface water becomes

[6] Ramsey-Boiteux pricing consists in maximizing the total welfare under the condition of non-negative profit for the monopolist, that is, zero profit.

scarce, the potential improvement in efficiency will decrease and the pumping option will arise as a competitive option. The production of *Wat* is modeled using a Weibull function.

The model considers four types of agents: household, firm, government and rest of the world (ROW). Considering the uneven distribution of water resources across the country, authors consider two regions: North and South. The north zone does not face water scarcity, while the south zone is an arid region. This geographical disaggregation accounts for water production, agriculture and industry.

Results show that the BRP along with a reduction in production taxes is the most efficient pricing policy in reducing water consumption. This policy has also a positive impact on welfare. The MCP policy induces a more positive impact on welfare, but it is not as efficient in reducing water use.

Letsoalo *et al.* (2007) analyze whether the setup of water charges generates triple dividends for the South African economy. In this case the potential reduction in water use is considered the first dividend, the use of these revenues in order to stimulate economic growth is the second dividend, while the improve of income distribution due to the faster economic growth is the third dividend.

Using the South African Social Accounting Matrix (SAM) authors divide households into 12 income and 4 ethnic groups, and distinguish 27 economic sectors. After splitting energy and water intensive sectors they use 39 sectors. Originally the SAM considers only one agricultural sector but authors split this sector into seven subsectors in order to determine exactly which water policies would achieve the best results.

At policy level they simulate 3 different water charges: (1) a surcharge of 10¢ per cubic meter of water used by forestry, (2) a surcharge of 10¢ per cubic meter of water used by irrigated agriculture (field crops and horticulture), and (3) a surcharge of 10¢ per cubic meter of water used by all mining industries (gold, coal, and other mining). Besides of these policies, authors also simulates 3 different tax recycling policies: (1) a decrease in the overall level of direct taxation on capital and labor, (2) a decrease in the overall level of sales tax on household consumption, and (3) a decrease in the sales tax rate on food to households. Due that water price is higher, results show that the first dividend is always reached. Related to the double dividend, it is possible to reach it almost for all scenarios, exceptions are: forestry water surcharge (for every tax scheme), gold mining water surcharge (for every tax scheme) and coal mining water surcharge (for capital and labor tax scheme). The third dividend is reached for other mining water surcharge (for every tax scheme); for other water surcharges, the third dividend is reached depending on the tax scheme selected.

Regarding water allocation, Seung *et al.* (2000) combine a dynamic CGE model with a recreational model to analyze the economic impacts of water reallocation from agriculture to recreational use. The model considers 8 sectors, 3 of which are in agriculture. For all sectors the technology is represented through a Cob-Douglas function. Agricultural sector uses land, capital and labor as production factors, while the remaining sectors use only capital and labor. In this model, water is entitled as water rights and these rights are associated to the amount of land. So, if water is extracted from the agricultural sector it implies a reduction of land for the agricultural sector.

Recreational sector is represented through two econometric equations: hunting rate and the general recreation rate. Using in-site surveys the authors determine the total expenditure for both activities.

The authors evaluate a withdrawal of 30,000 acre-feet from the agricultural sector to the recreational one. To do this they compute the number of visitors and their expenditure before the policy implementation. Then they compute the same variable after the policy implementation. In the CGE model, they compute the change in water availability, as a decrease in land availability for the agricultural sector, and the change in recreational expenditures as a consequence of this policy.

Results show that as a consequence of the reallocation of water, agricultural production drops, while the number of visitors increases. Still, the increase in the number of visitors is not enough to compensate the decrease in agricultural production. As a consequence, the impact over the total output decreases by 0.9%, while the total employment drops by 0.2%.

Diao and Roe (2003), present a CGE model that analyzes the impact of a trade liberalization policy over water resources allocation. Authors propose a theoretical model which links trade reform with water market creation. According to this model, the combination of a trade reform with the creation of a water user-rights market generates the most efficient allocation of water.

The CGE model proposed by the authors has twenty production sectors: 12 agricultural sectors (6 irrigated and 6 rain fed), 4 agricultural related sectors and 4 non-agricultural related sectors. The model uses labor, water, land, capital and intermediate inputs as factors of production. Furthermore, the model is dynamic so that capital accumulates overtime. The model does not allow for factor substitution across sectors.

Results show a close linkage between changes in the sectoral shadow price of water and the rates of trade protection. When tariff, non-tariff trade barriers, and producer subsidies are removed, a country's comparative advantage in the production of non-protected crops increases. Additionally, due to the trade liberalization both income and welfare increase for the whole economy. Nevertheless, there are differences across sectors: farmers producing protected crops are worse off, in the short and medium term, while the returns from irrigated land (associated to protected crops) decrease. Finally, when the water market is permitted, the reallocation of water toward more productive uses confirms the assumptions of the theoretical model.

Diao *et al.* (2005), present a CGE model in which they analyze the economy-wide effects of water reallocation to its most productive use. The model accounts for spatial heterogeneity within the country among seven major irrigation zones, the model differentiates also between irrigated and rainfed crops.

The agricultural sector is modeled using a series of nested CES functions for the primary inputs, while the intermediate consumption is assumed to be Leontief. Agricultural production uses labor, capital, land and water. Labor could be rural or urban. Rural labor is mobile only among agricultural sectors (including primary and processing agriculture). Capital and land are mobile within irrigation zones. Land could be irrigated or rainfed, and the supply of irrigated land is fixed. Finally, water is mobile within each region but not across regions.

Results suggest that trade liberalization in the water market will increase agricultural output in each region (8%). According to their results, irrigated agriculture will be better off, while rainfed crops will be worse off.

Diao *et al.* (2008) present an extension of the model presented by Diao *et al.* (2005). The new version of the model includes explicitly a difference between surface (SW) and groundwater (GW).

Authors simulate tree scenarios: increase in groundwater pumping costs (20%), decrease in surface water (one standard deviation) and re-allocation between rural and urban water (one third).

Simulations confirm the direction of the expected changes associated to each scenario simulation, but more interesting is the fact that the tree scenarios have similar impacts over economy-wide variables. “Especially the drought impact on the SW supply and the increase in cost of extraction of GW shocks, affect most of the economy’s sectors in a similar way, with regions that have better access to GW, facing a less dramatic effect”.

Lennox and Diukanova (2011), present a regional CGE model suitable for the analysis of water policies. They analyze agricultural water issues in Canterbury, NZ.

The modeling approach represents the agricultural sector through a series of nested CES functions for the primary inputs, in which the agricultural production uses labor and a composite land and capital. The composite land and capital is further disaggregated into the demand of land and the demand of capital. At the bottom of the productive structure, water is linked in fixed proportions with the land endowment.

The authors simulate three different scenarios: decrease in irrigated land (10%), increase in availability of labor and capital (10%), and increase in the world agricultural prices (5%).

For the first scenario, the results show negative impacts on the water-intensive agricultural sectors, with a decrease in production and increase in prices. In general terms, those impacts do not affect the performance of other economic sectors. Scenarios two and three show the expected results on production, prices and total welfare.

Juana *et al.* (2011) analyze the economic impacts of the reallocation of water from the agricultural sector to other sectors on the South African economy. Using information from 19 water management areas, authors define the amount of water used by each sector, while using the municipal water tariff schedule they assign the monetary value of the water used by sector.

The model considers water as a new primary factor, along with capital and labor. The production structure is modeled using CES functions with the exception of capital that it is modeled through fixed proportions. Water and labor are freely mobile across sectors, while capital is sector specific.

Authors simulate four water reallocation scenarios of 30%, 20%, 10, and 5%. Results show that the reallocation of water increases the sectoral output, but reduce the output of agriculture, beverages, and the services sector.

Gomez *et al.* (2004) present a CGE model for the Balearic Islands in which they analyze the welfare gains associated with trade liberalization in water markets. They divide the economy in 10 sectors, two of them in the agricultural sector: irrigated agriculture and rainfed agriculture. They also consider two sectors producing drinking water: the traditional and the desalination sector. Both sectors produce the same product (water) but under different cost structures.

This model considers five production factors: labor, capital, land, water and seawater. Water is distributed among farmers and water supply firms, and they cannot trade water between each other (in the benchmark).

Both agricultural sectors are modeled using a series of nested CES functions. For the irrigated sector, water enters in the production structure at the bottom level through a Leontief function of groundwater and energy. The production structure also considers a Capital-Land CES composite. The rainfed sector follows the same approach, but in this case the groundwater-energy Leontief composite does not apply.

The water and distribution sector produces water using two technologies: groundwater extraction and desalination. In the first case, water is produced using capital, labor and intermediate inputs in fixed proportions. In the second case, water is produced using the same inputs under a Leontief formulation. The total drinking water produced is the sum of both sectors. Desalination water operates only when the amount of groundwater is below a threshold that is defined exogenously. In the benchmark scenario the model assumes that the desalination sector is not active.

Results show that the trade liberalization in the water market has benefits for the whole economy. Through water markets it is possible to reduce the negative impact of droughts over urban water consumption. Even though under the water markets scheme the output of irrigated agriculture decreases, this profit loss is compensated with the income generated in the water market.

Roe *et al.* (2005) analyze the macro-micro feedback links between economy wide and irrigation policies in Morocco[7]. They analyze the impact of trade reforms over the farm level economy, and the impact of new irrigation policies over the whole economy. In order to do that, the authors build a soft link between a CGE model and a farm model. The farm model developed by the authors considers only irrigated crops.

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[7] A previous version of this study was published as a Policy Research Paper of the World Bank (Roe *et al*. 2005).

Authors identify three macro-micro links (1) prices of inputs and outputs that are determined at macro level, prices that are exogenous for the farmers, (2) trade policies which can affect the prices of inputs and outputs faced by the farmers, and (3) water projects which have impacts over the water supply faced at micro level. Regarding micro-macro links, authors identify any policy that could affect the allocation of inputs at farm level, examples of these policies are: the water pricing method, water institution, and water allocation rules. The implementation of these policies will affect the demand of inputs at micro level, and when all the farmers change their demands, the impacts will reach the whole economy.

Assuming an optimal behavior at the both macro and micro scale, authors link both models through prices. Output and input prices are established at macro scale, those prices are taken as given by farmers. When a shock is applied to the macro model, the prices faced by the farmers change modifying their optimal behavior.

The empirical model is applied to the Morocco economy, which is regionalized according to irrigation districts. The model includes 88 activities, 49 commodities and 9 irrigation zones. The model differentiates between agricultural (rain fed and irrigated) and non-agricultural activities/commodities.

Authors link both models using prices for both output and inputs, and as a consequence of this interaction, they identify two effects: direct and indirect. The former is the effect of a trade policy over the output prices faced by the farmers, while the latter is the effect of this change in output prices on rental rates (input prices) and domestic prices.

Authors show that the indirect effects, represented by the economy-wide impacts, modify and in some cases reverse direct effects. They also found that micro and macro policies have different impacts: trade reforms have a higher impact than the micro reform.

Cakmak *et al.* (2008) analyze the macro-micro feedback of irrigation management in Turkey. Authors analyze the economy wide impacts of an increase in agricultural prices and climate change, through a soft link between a CGE model and a farm model.

The CGE model includes 20 agricultural and 9 non-agricultural activities and it divides Turkey in 5 zones. The model accounts specifically for water, which is used in agricultural activities. The farm model is formulated as a programming problem, which assumes that water is supplied free of charge but the supply is limited to certain amount. This approach tries to estimate the shadow water price by asking the farmers how much are they willing to pay for relaxing the water constraint. The derived demand of water estimated is then used to compute the water rent, which is added to the irrigation payments made by the farmers.

Results show that the major effect on macroeconomic level occurs for the climate change simulations. In this case the nominal GDP declines drastically, nevertheless the real impact is limited. The increase in agricultural prices reduces all the macroeconomic indicators, except for the agricultural exports.

Strzepek *et al.* (2008) present a CGE model for the Egyptian economy, in which they analyze the economic impact of the construction of the Aswan Dam. Considering that the Aswan dam was built in 1952, the authors compare the Egyptian economy in 1997 to the 1997 economy as it would have been without the Dam, which implies high flow variability in the Nile River.

The model assumes that farmers use land and water in fixed proportions. The choice of land-water combination by crop is a maximization problem in which a farmer chooses the combination of land-water based on the price of both inputs. The model distinguishes two types of land and water: summer land/water, winter land/water. The scenario with the dam considers an even distribution of water within a year, while the scenario without the dam considers floods during the winter and drought during the summer. The last implies different water prices for each season.

The solution of the maximization problem generates the land-water aggregate for each agricultural sector, and then this land-water aggregate goes into the production function along with capital and labor.

The agricultural sector is modeled using a Leontief demand for intermediate inputs, a CES function for the value added, and a linear programming model for land and water use.

According to the results, the construction of the dam has had negative impacts over the agricultural production, specifically over summer crops. Simulations show that by removing the dam, the summer agricultural output would be higher than that actually recorded. The contrary impact is reported for the electrical sector, transportation, and tourism. Nevertheless, the dam presents a positive net impact over the Egyptian economy.

Hassan and Thurlow (2011) developed a CGE model following the approach proposed by Roe *et al.* (2005), with South Africa as a case study. In this new study the authors include water within the CGE model, while the previous report considered water through a farm model[8]. The objective of the study is to account for the economy-wide effects of: (1) water market within districts, (2) water markets within and across districts, (3) water competition between agricultural and non-agricultural uses (without water markets), the same than (3) but including water markets.

The SAM used in this study accounts specifically for water, it includes 40 sectors (17 of which in the agricultural sector). The agricultural sector includes: field crops, horticultural crops, livestock, fishing and forestry. Field crops are further disaggregated into rainfed and irrigated. Production and consumption activities are modeled at water district scale, in this sense the SAM is disaggregated in 19 districts.

Using experimental data, the authors estimated the shadow price of water through econometric quadratic functions that relate crop yield and water use. The coefficients estimated were applied to the crop yield reported in the agricultural census in order to estimate the current water use by crop. Using the crop prices, the marginal value of water was computed. Finally, subtracting non-water irrigation costs from the marginal value of water leads to the water shadow price. The water shadow price is then multiplied by crop yield in order to account for the total shadow value for every crop, which is then subtracted from the capital value-added account of the SAM. Using information recorder in the SAM, the model also accounts for non-agricultural water (heavy industry, and light industry and household).

The results show the usual benefits of water markets, in which the economy is better off when market liberalization policies are implemented.

Smajgl (2006) analyzes climate change impacts on the Great Barrier Reef (GBR) region in Australia. The author presents an integrated analysis at a catchment level using a CGE, which includes non market values for water use. Within this framework the CGE model is coupled with two different models: hydrologic and ecological. The non-market values are quantified using multi criteria analysis (MCA) and a food-web model. The model considers 8 regions and 34 economic sectors. The model analyzes the economic impacts of a decrease in water quality and quantity. The former is due to an increase on fertilizer use, wile the latter is due to climate change.

[8] A previus version of this study was published as a Policy Research Paper of The World Bank (Hassan *et al.*, 2008).

The production sector is specified using a series of nested CES functions. The production inputs are: capital (*K*), labor (*L*), fertilizer (*N*), irrigation water (*W*), and tourist attractions (*TA*). The model differentiates among five geographical zones.

According to the model, irrigation could be offered using surface or groundwater. The use of groundwater reduces the water table, while the use of surface water increases the water table. If farmers have access to both types of water, they can substitute between them, and the amount of unused water goes to the non-market side of the model.

Tourist attractions are sector specific for the tourism sector. This sector uses as inputs 7 different species and it assumes that a decrease in the number of species will have a negative impact on the tourism sector. Finally, a representative consumer demands market goods, as well as non-market goods.

This model focuses on water quality and water quantity. In the first case, the model assumes that the use of fertilizers consumes environmental quality, modeled as a virtual good. This virtual good is used by both sea-grass and environmental quality. An increase in the use of fertilizers will decrease the habitat suitability for sea-grass, which at the same time is consumed by certain species (*i.e* dolphins). As dolphins are inputs for the tourism sector, this sector will be affected. In the second case, the model assumes a decrease in rainfall, due to climate change. This decrease of water availability will have effects over the whole economy affecting both market and non-market goods.

Simulations show that a decrease in rainfall drives an increase in groundwater use, affecting both agriculture and tourism. The impact over the agricultural sector depends on the geographical zone, but as a general result the total agricultural output increases. Regarding tourism, simulations show the existence of autonomous adaptation in this sector.

Cackmak *et al.* (2009) present a CGE model for Turkey, which analyzes climate change impacts. The model differentiates among agricultural and non-agricultural sectors, regions, and irrigated and rainfed agriculture. At institutional level, authors differentiate among government, households and Water User Associations (WUA). Households are further desegregated in 5 regions.

Regarding the production structure, it is defined as a series of nested CES functions for each activity. The model considers 5 production factors: labor, capital, irrigated land, rainfed land, and water. The derived water demand is computed as a linear programming model at farm level. The shadow water price computed under this approach is then added to the current payment made for irrigation.

The authors analyze three different scenarios: increase in agricultural prices, water re-allocation from rural to urban (irrigation water), and the impact of climate change over agriculture (reduction in agricultural yield). Results show a negative impact over GDP for almost all the simulated scenarios, and the major impact is reported for climate change. The exception is the urbanization scenario that implies a reduction in water for the irrigated agricultural sector. Under this scenario, the irrigated agricultural output decreases, while the rainfed output increases. As a consequence, there is an increase in the total GDP.

Smjgl *et al.* (2009) present a methodological approach that integrates a CGE model at catchment level with an Agent Based Model (ABM) for the GBR in Australia. Through the integration of both models, the CGE results could show spatially differentiated results. The aim o the study is to improve the water policy assessment in the area.

The CGE model used in this study is the PIA model proposed by Smjgl (2006). This model includes market and non-market values for the GBR region, and it is intended to analyze scenarios related to water trading systems, fertilizers use, and precipitations changes, while the agent-based model used is the SEPIA model. The model simulates both land use and water use decisions at micro scale. The SEPIA model is not an optimization model, instead of that the model assumes agents' behavior as a consequence of global dynamics. This type of models assumes that agent decisions are driven by market and non-market conditions, within an uncertain framework. The rules governing the model should be defined through a deep involvement of the catchment stakeholders. The result of the SEPIA model is the land allocation of the catchment users, and this allocation is spatially explicit through a geographical information system (GIS) system. This land allocation is included within the PIA CGE model.

You and Ringler (2010) analyze the impacts of climate change over the Ethiopian economy. The impacts under analysis are: water availability, floods, and the impact of CO_2 over agriculture. The authors expand the existing multimarket model used by Diao and Nin-Pratt (2005) and its further modifications.

This model includes only benefits and it has a huge desegregation of the Ethiopian agricultural sector (34 activities), the remaining economic activities are analyzed through two aggregated non-agricultural sectors. The last version of the model also includes a module that accounts for water stress, as well as a module that accounts for extreme events (floods and droughts). The authors extend the model including the impact of CO_2 concentration over agricultural production.

The impact of water stress is included through the Climate Yield Factor (CYF). This factor considers several climate variables and it determines the suitability of the growing of a certain crop. Depending on the value of CYF, the yields will be constrained by the water availability, and this information about yields is then included as an input for the multimarket model. Regarding extreme events, the model uses the Flood Factor (FF) to determine the probability of occurrence of monthly precipitation. Based on the flood losses estimated by the FF, as reduction in both agricultural and nonagricultural commodities, the multimarket model estimates the economic impact of the extreme event.

The impact of the CO2 concentration over agricultural production is analyzed using the concept of potential yield, which is result of the interaction of climate, CO_2, and crop type. In this case the authors use a logarithmical relationship among these variables. The impact of CO_2 over agricultural production is then included as an input into the multimarket model.

The simulation show that the major impact of climate change over the Ethiopian economy are the consequences of the more frequent occurrence of extreme weather events that could cause losses in both the agricultural and nonagricultural sectors.

4. Key Issues and Future Research Directions

At global level, although great improvements have been made since the first model proposed by Berritella *et al.* (2007(a)), some caveats remain. These limitations are related to lack of reliable data, as well as model specification.

Regarding data, there are two major issues. The first one is related to the industrial water demand, all the economic models presented above consider only one industrial sector, and thus there is no option to reallocate water across subsectors according to differences in water productivity. The second one is related to the water price elasticities used, the parameters used in the GTAP-W models were collected by Rosegrant *et al.* (2002), most of them are based on 1997/2000. Within the last decade several studies have been published in this regard, thus it is necessary to use the new evidence to update this vital information.

Regarding model specification, the way in which some models analyze water issues does not allow accounting for water itself. The main point regarding these approaches is that all the simulated changes are consequence of exogenous shocks in productivity, instead of changes in water availability. Considering that water productivity is not considered, these approaches exclude substitution options between water and other inputs.

Although the model proposed by Calzadilla *et al.* (2008) is a major improvement regarding the previous work, the crop approach used in order to differentiate between rainfed and irrigation land, is not the best approach to analyze substitution options between water and other inputs, such as capital in the irrigation composite.

Studies at the national scale look for a detailed representation of the market under analysis. In this regard, the main issue with the studies presented above is related to the lack of representation of other economic sectors, beside the agricultural one, in more detail. With the data available at country level, it is possible to build a model that accounts for water competition among sectors: urban, industrial, environmental, and agricultural. The assumption of *ceteris paribus* for other markets does not seem realistic.

Finally, the integration of top-down and bottom-up models takes advantage of the best of both approaches by integrating the geographical scale dimension. This approach is suitable for the analysis of water related issues considering that water decisions are taken at the local scale, and it can be affected by national (or even global) policies.

Future research directions should be oriented towards improving the data used for the global models, as well as their specification. In this regard, the main issues of interest are the potential substitutions of inputs across sectors, with special focus on the agricultural sector. Considering the expected impacts of climate change on water resources, substitution among inputs arises as an adaptation strategy. On the other hand, considering that the irrigation sector is a large consumer of capital, models should go further on the disaggregation of the agricultural sector in order to account for the impact of capital movements across regions and sectors. Regarding national CGE models and bottom-up/top-down integration, the research should be focused on improving the representation of the national economy. One step in this direction is the inclusion of other economic sectors, either implicitly or explicitly.

References

1. Arrow, K., & Debrau, G. (1954). The Existence of an Equilibrium for a Competitive Economy. *Econometrica , XII*, 265-90.
2. Bates et al. (2008). *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change.* Geneva: IPCC Secretariat.
3. Berrittella, M., Hoekstra, Y., Rehdanz, K., Roson, R., & Tol, R. (2007(a)). The Economic Impact of Restricted Water Supply: A Computable General Equilibrium Analysis. *Water Research* , 1799 – 1813.
4. Berrittella, M., Hoekstra, Y., Rehdanz, K., Roson, R., & Tol, R. (2005). Virtual Water Trade in General Equilibrium Analysis. *GTAP Conference Paper 1715* .
5. Berrittella, M., Rehdanz, K., & Tol, R. (2007(b)). The Economic Impact of the South-North Water Transfer Project in China: A CGE Analysis. *Fondazione Eni Enrico Mattei, Working Paper 72* .
6. Berrittella, M., Rehdanz, K., Roson, R., & Tol, R. (2006). The Economic Impact of Water Pricing: A Computable General Equilibrium Analysis. *Research Unit Sustainability and Global Change, FNU-96. Hamburg University.*
7. Berrittella, M., Rehdanz, K., Roson, R., & Tol, R. (2008). The Economic Impact Water Taxes: a Computable General Equilibrium Analysis with an International Data Set. *Working Paper 05. Department of Economics, Ca' Foscari University of Venice. Italy* .
8. Berrittella, M., Rehdanz, K., Tol, R., & Zhang, J. (2007(c)). The Impact of Trade Liberalization on Water Use: A Computable General Equilibrium Analysis. *Research Unit Sustainability and Global Change, FNU-142. Hamburg University.*
9. Burniaux, J., & Truong, T. (2002). GTAP-E: An Energy-Environmental Version of the GTAP Model. *GTAP Technical Paper* .
10. Cakmak, E., Dudu, H., & Saracoglu, S. (2009). Climate Change And Agriculture In Turkey: A Cge Modeling Approach. *EconAnadolu 2009: Anadolu International Conference in Economics.*
11. Cakmak, E., Dudu, H., Saracoglu, S., Diao, X., Roe, T., & Tsur, Y. (2008). Macro-Micro Feedback Links of Irrigation Water Management in Turkey. *Policy Research Working Paper 4781. The World Bank* .
12. Calzadilla, A., Rehdanz, K., & Tol, R. (2010). The Economic Impact of More Sustainable Water Use in Agriculture: A CGE Analysis. *Journal of Hydrology* , 292–305.
13. Calzadilla, A., Rehdanz, K., & Tol, R. (2008). Water Scarcity and the Impact of Improved Irrigation Management: A CGE Analysis. *Kiel Institute of the World Economy, Working Paper 1436, Kiel University* .
14. Calzadilla, A., Rehdaz, K., & Tol, R. (2010). Climate Change Impacts on Global Agriculture. (H. University, Ed.) *Research Unit Sustainability and Global Change* (FNU-185).
15. Calzadilla, A., Zhu, T., Rehdaz, K., Tol, R., & Ringler, C. (2009). Economy Wide Impacts of Climate Change on Agriculture in Sub Saharan Africa. *Research Unit Sustainability and Global Change, FNU-170.* .
16. Decaluwé, B., Patry, A., & Savard, L. (1999). When Water is No Longer Heaven Sent : Comparative Pricing Analysis in an AGE Model. *Working Paper 9908. Département d'économique. Université Laval.*
17. Diao, X., & Nin-Pratt, A. (2005). *Growth Options and Poverty Reduction in Ethiopia:A Spatial, Economy-wide Model Analysis for 2004–15.* Washington, DC: DSGD Discussion paper 20.
18. Diao, X., & Roe, T. (2003). Can a Water Market Avert the ''double-whammy'' of Trade Reform and Lead to a ''win–win'' Outcome? *Journal of Environmental Economics and Management* , 708–723.
19. Diao, X., Dinar, A., Roe, T., & Tsur, Y. (2008). A General Equilibrium Analysis of Conjunctive Ground and Surface Water Use with an Application to Morocco. *Journal of Agricultural Economics* , 117-135.
20. Diao, X., Roe, T., & Doukkali, R. (2005). Economy-Wide Gains from Decentralized Water Allocation In A Spatially Heterogeneous Agricultural Economy. *Environment and Development Economics* , 249–269.
21. Dimaranan, B., & McDougall, R. (2002). *Global Trade, Assistance, and Production: The GTAP 5 Data Base.* Center for Global Trade Analysis, Purdue University.
22. Gomez, C., Tirado, D., & Rey-Maquieira, J. (2004). Water Exchanges Versus Water Works: Insights from a Computable General Equilibrium Model for the Balearic Islands. *Water Resources Research* .
23. Hassan, R., & Thurlow, J. (2011). Macro–Micro Feedback Links of Water Management in South Africa: CGE Analyses of Selected Policy Regimes. *Agricultural Economics , 42* (2), 235-247.
24. Hassan, R., Thurlow, J., Roe, T., Diao, X., Chumi, S., & Tsur, Y. (2008). *Macro-Micro Feedback Links of Water Management in South Africa.* Washington, DC: Policy Research Working Paper 4768. The World Bank.

25. Intergovernmental Panel on Climate Change. (2000). Special Report on Emisison Scenarios. IPCC. IPCC.
26. Juana, J., Strzepek, K., & Kirsten, F. (2011). Market efficiency and Welfare Effects of Inter-Sectoral Water Allocation in South Africa. *Water Policy , 13* (2), 220-231.
27. Lennox, J., & Diukanova, O. (2011). Modelling Regional General Equilibrium Effects and Irrigation in Canterbury. *Water Policy , 13* (2), 250-264.
28. Letsoalo, A., Blignaut, J., de Wet, T., de Wit, M., Hess, S., Tol, R., et al. (2007). Triple Dividends Of Water Consumption Charges In South Africa. *Water Resources Research , 43* (5), 1-32.
29. Lofting, E., & Mcgauhey, P. (1968). Economic Valuation of Water. An input-output Analysis of California Water Requirements. *Contribution nº116. Water Resources Center* .
30. Roe, T., Dinar, A., Tsur, Y., & Diao, X. (2005). Feedback Links Between Economy-wide and Farm-level Policies: With Application to Irrigation Water Management in Morocco. *Journal of Policy Modeling , 27* (8), 905–928.
31. Roe, T., Dinar, A., Tsur, Y., & Diao, X. (2005). Feedback Links Between Economy-wide and Farm-level Policies: With Application to Irrigation Water Management in Morocco. *World Bank Policy Research Working Paper 3550* .
32. Rosegrant, M., Cai, X., & Cline, S. (2002). *World Water and Food to 2025: Dealing with Scarcity.* Washington Dc: International Food Policy Research Institute.
33. Rosegrant, M., Ringler, C., Msangi, S., Sulser, T., Zhu, T., & Cline. (1998). *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description.* International Food Policy Research Institute. Washington, D.C.: International Food Policy Research Institute (IFPRI).
34. Roson, R., & Sartori, M. (2010). Water Scarcity and Virtual Water Trade in The Mediterranean. *Working Paper 08. Department of Economics, Ca' Foscari University of Venice. Italy* .
35. Roson, R., & Van der Mensbrugghe, D. (2010). Climate Change and Economic Growth: Impacts and Interactions. *Working Paper 07. Department of Economics, Ca' Foscari University of Venice. Italy* .
36. Seung, C., Harris, T., Englin, J., & Netusil, N. (2000). Impacts of Water Reallocation: A combined Computable General Equilibrium and Recreation Demand Model Approach. *The Annals of Regional Science* , 473-487.
37. Smajgl, A. (2006). Quantitative Evaluation of Water Use Benefits An Integrative Modeling Approach For The Great Barrier Reef Region. *Natural Resource Modeling* , 511-538.
38. Smajgl, S., Morris, S., & Heckbert, S. (2009). Water Policy Impact Assessment – Combining Modelling Techniques in the Great Barrier Reef Region. *Water Policy , 11* (2), 191-202.
39. Strzepek, K., Yohe, G., Tol, R., & Rosegrant, M. (2008). The Value of the High Aswan Dam to the Egyptian Economy. *Ecological Economics* , 117-126.
40. UNESCO. (2003). *Water Facts. Encyclopedia of Life Support Systems. World Water Development Report (WWDR).* . UNESCO.
41. van der Mensbrugghe, D. (2009). *The ENVironmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model.* The World Bank. Washington, DC. : The World Bank.
42. You, G., & Ringler, C. (2010). *Hydro-Economic Modeling of Climate Change Impacts in Ethiopia.* Washington, DC: IFPRI Discussion Paper 00960.

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