Universidad del Desarrollo
Facultad de Economía y Negocios

SERIE WORKING PAPERS

Climate Change, Water Scarcity in Agriculture and the Country-Level Economic Impacts. A Multimarket Analysis.

Roberto Ponce, María Blanco, Carlo Giupponi

November 2014 Working Paper 02

Climate Change, Water Scarcity in Agriculture and the Country-Level Economic Impacts. A Multimarket Analysis.

Roberto Ponce[1], María Blanco[2], Carlo Giupponi[3]

Abstract

Agriculture could be one of the most vulnerable economic sectors to the impacts of climate change in the coming decades. Considering the critical role that water plays for agricultural production, any shock in water availability will have great implications for agricultural production, land allocation, and agricultural prices. In this paper, an Agricultural Multimarket model is developed to analyze climate change impacts in developing countries, accounting for the uncertainty associated with the impacts of climate change. The model has a structure flexible enough to represent local conditions, resource availability, and market conditions. The results suggest different economic consequences of climate change depending on the specific activity, with many distributional effects across regions.

Keywords: Agricultural Multimarket Model, Climate Change, Agriculture, Water Resources, Uncertainty.

---

[1] Facultad de Economía y Negocios. Universidad del Desarrollo. Chile. (robertoponce@udd.cl)

[2] Departamento de Economia y Ciencias Sociales Agrarias. Universidad Politécnica de Madrid, España.

[3] Department of Economics. Università Ca' Foscari Venezia, Italia

1. Introduction

The agricultural sector could be one of the most vulnerable economic sectors to the impacts of climate change in the coming decades. Climate change impacts are related to changes in the growth period, extreme weather events, and changes in temperature and precipitation patterns, among others. All of these impacts will have consequences on agricultural production (Bates, *et al.* 2008).

Regarding crop production, the impacts will be a function of the geographical location with an increase in yields in high-latitude areas with rising temperatures, and a decrease in yields in low-latitude areas. Simulation results show that the positive impacts of climate change outweigh the negative ones (Parry, *et al.* 2007).

Taking into account the key role that water plays for agricultural production, changes in water availability will have a direct impact on the agricultural sector. Simulation results show an increase in the irrigation demand at the global level throughout the 21st century, in order to cope with both climate change and population growth (Doll 2002, Fisher, *et al*. 2006, Alcamo, *et al*. 2003, Arnell, *et al*. 2011).

The magnitude of climate change impacts will demand an urgent policy response in order to cope with the consequences. Considering the high level of policy intervention that the agricultural sector already experiences (quotas, taxes, band prices), the required climate change adaptation policies could lead to undesirable outcomes if all the potential linkages within the agricultural sector are not considered as part of a single system. The welfare consequences of poor policies could be large, especially for developing countries where the agricultural sector not only has economic relevance, but is also a keystone for food security (FAO 2010).

A main issue regarding climate change impacts is related to the uncertainty associated with their occurrence. Climate change impacts, as described above, are the outcome of models based on several assumptions, among which the future emissions of greenhouse gasses are the most relevant. These emission scenarios are storylines associated with different assumptions about climate and socioeconomic conditions (Intergovernmental Panel on Climate Change 2000). Within this context, climate change impact assessment should consider this uncertainty in order to produce valuable information for policymakers.

The effectiveness of public policies will depend on local characteristics, such as: climate and socioeconomic conditions. In order to address the challenges imposed by climate change from an economic perspective, an approach that provides a detailed picture of the agricultural sector and the relationships within it is essential. In this regard, bottom-up approaches could be an effective tool to evaluate the economic impacts of climate change on the agricultural sector.

Bottom-up approaches, such as: agricultural models and hydro-economic models are characterized by the detailed description of their components. For most of them, their advantages are also their main drawbacks, principally because of the large amount of data needed to conduct this kind of research. This is relevant for the analysis of agricultural issues in developing countries.

Agricultural models simulate the agents' optimal behavior, allowing for an *ex-ante* evaluation of policy intervention. Agricultural models range from studies at farm level, to studies including the whole agricultural sector. The main difference is related to price assumptions. Considering that all the agricultural agents will be affected by climate change impacts, the most suitable agricultural model structure is that which analyzes the whole agricultural sector assuming endogenous prices, namely agricultural multimarket models. (Hazzel and Norton 1986, Sadoulet and De Janvry 1995, Howitt 2005).

Nevertheless, agricultural multimarket models fall short in relation to the complexities of computable general equilibrium (CGE) models. Their results account for direct and indirect effects restricted to the agricultural markets under analysis, in this sense the use of agricultural multimarket models is an improvement over single market models (Croppenstedt, *et al.* 2007).

Agricultural multimarket models represent the agricultural sector through a series of behavioral equations, which are optimized in order to maximize the farm income, regional income, or regional surplus, subject to technological, environmental, and institutional constraints (Howitt 2005). The core equations of a multimarket model include prices, supply, consumption, income, stock variables, and market clearance conditions. The analyses are carried out on markets that have strong links, through the demand or supply side, on issues that have sectoral relevance with differentiated impacts among model components (Croppenstedt, *et al.* 2007).

This paper presents an agricultural multimarket (AMM) model, which analyzes the economic impacts of changes in water variability due to climate change. The model's structure is designed to be used within a context of information restriction, this feature is especially valuable for use in developing countries. The multimarket model is designed specifically for the analysis of the Chilean agricultural sector, and it accounts for uncertainty through the use of Monte Carlo simulations about water availability.

The paper is structured as follows: section two presents a brief literature review about previous studies, while section three presents a full description of the new modeling approach, highlighting the new production structure, as well as the methodology used. In section four, the model is used to quantify the economic impacts of climate change on the Chilean agricultural sector. Finally in section five the main conclusions are presented.

2. Previous Studies

2.1 Agricultural Models

The study of water resources using agricultural multimarket models dates back to when the first studies of agricultural issues were carried out from an economic perspective. Since water is a key input for the agricultural sector, its analysis could not be neglected in these kinds of models. Taking into account that the agricultural sector is subject to high governmental intervention, such as: subsidies, taxes, price bands, and quotas, it is advantageous to have some idea of what the expected results of such policies could be in advance. In this regard, modeling the agricultural sector sheds some light on the consequences that specific policies may have on a defined set of markets (Croppenstedt, *et al.* 2007).

Multimarket models have been widely used for the analysis of agriculture related policies. The World Bank developed the first models, whose main purpose was to analyze the impact of price policies on production, demand, income, trade, and government revenues (Lundberg and Rich 2002a).

For developing countries, the work done by Lundberg and Rich (2002a) can be considered as a cornerstone model. Originally, the study was developed for Madagascar as a generic model that could be used as an analytical tool for other African countries. Regarding its structure, the models consider four sectors: food crops, livestock, non-agricultural products, and fertilizers. The agricultural sector is represented through a block of six equations: prices, supply quantities, consumption quantities, household income, stock (input, output), and market clearance conditions.

The simulation scenarios include an improvement in rice productivity (20% increase), subsidies for fertilizers (20% for all farmers, and 20% for poor farmers), trade liberalization (a decrease in rice tariffs), and infrastructure improvement (a 20% reduction in marketing margins).

Results show that the increase in rice productivity has wide impacts on the agricultural sector, with an increase in rice production, a reduction in coarse grain production, and an increase in the consumption of agricultural products. International trade is affected by a 60% reduction in rice imports. Regarding the fertilizer policy, results show a small increase in general agricultural production (2%), while the tariff reductions lead to a small reduction in rice production (1%).

Finally, the decreasing of the marketing margin drives an increase of between 8% and 33% in the producer's price for rice and livestock, respectively.

Lundberg and Rich (2002b) applied the same model to Malawi. Using the same structure, authors simulated an increase in maize productivity (20%), fertilizer subsidy (20%), and infrastructure improvements (a decrease of 20% in the marketing margin). The Results are similar to those reported for Madagascar.

Using the same model, Stifel and Randrianarisoa (2004), analyzed the impact of agricultural reforms in Madagascar. The authors looked into the impacts of tariff changes, infrastructure improvements, and yield increases.

FAO used these models in order to develop multi-market models for Egypt, Indonesia and Paraguay. These models aim to analyze the impact of agricultural policies on poverty and food security.

Siam and Croppenstedt (2007) analyzed the impact of wheat market liberalization in Egypt; their model is based on Stifel and Randrianarisoa's model (2004). The production side includes nine agricultural products and two inputs. It does not include seasonality, an aggregate for all other food, or non-food commodities. Authors simulated 4 scenarios: complete liberalization, an import price increase, increases in stock, and increases in yield. Results show that wheat market liberalization implies a large cost for both consumers and producers, with producers facing the most serious impact.

Multi-market models use mathematical programming (MP) to compute their solutions. The wide use of this method is underpinned in the limited amount of data required for their development. This feature is well appreciated, especially by researchers conducting studies in developing countries. (Howitt 1995, Hazzel and Norton 1986).

Despite the wide use of MP, the method has a series of caveats, among which the calibration process is the most important (Howitt 1995). To solve this critical issue, Howitt (1995) presented the Positive Mathematical Programming approach (PMP). Using the PMP approach it is possible to achieve a perfect calibration on: area planted, products, and prices, avoiding the dependency between parameters and constraints.

Since the first study using PMP was published, the PMP approach has been widely used for the analysis of agricultural issues. The application of this method includes exercises at farm, basin, and regional scales (for reviews of PMP applications see (Heckelei and Britz 2005).

Despite PMP's widespread use, it has several drawbacks. According to de Frahan, *et al.* (2007) the main limitations of PMP are related to the unequal treatment of marginal and preferred activities, the lack of representation of economic activities with zero level of supply during the reference period, and the integration of risk, among others. Efforts to overcome these flaws are presented in studies by Rohm and Dabbert (2003), and Paris and Arfini, (2000).

Models using PMP in their multiple versions have been applied to several agricultural models, like models analyzing the expected impacts of the Common Agricultural Policy (CAP) in regions like Belgium, UK, Greece, Germany, and Sweden. (Mattas, *et al.* 2011, de Frahan, *et al.* 2007, Blanco, *et al*. 2008). Other applications include the estimation of the economic value of water and land (Medellín-Azuara, *et al*. 2009, Howitt, *et al.* 2001, Cortigiani and Severini 2009, Kan, *et al.* 2009), climate change impacts (Howitt, *et al.* 2009, Henseler, *et al.* 2009) and water allocation in a holistic model at the basin scale (Cai and Wang 2006).

Blanco, *et al.* (2008) used an agricultural model to evaluate the predictive capacity of three PMP approaches: standard PMP, Rohm and Dabbert, and Maximum Entropy. None of these methods is able to simulate farmers' behavior for activities that are not represented in the base year. To overcome this problem, the authors proposed a wide-scope PMP approach. The new approach is based on farmers' preferences and local conditions that are represented through a new cost parameter on the average cost function. The capacity of these methods was tested in an irrigated region in central Italy.

Results show that when the wide-scope approach is included, two out of the three methods show a better match between the predicted and the real crop area when no pre-existent activities are included. The efficiency gains are around 5%. The opposite is the case with the Rhom and Debbert method, which shows a better performance when pre-existent activities are not included.

Medellin, *et al.* (2009) analyzed the economic value of water for irrigated agriculture. To do so, the authors used a CES production function and a quadratic cost function, both of which are calibrated using the standard PMP approach. The authors analyzed the impact of four scenarios on the value of irrigation water: technological change, warm-dry climate, irrigation costs, and crop prices. The model was tested in the Rio Bravo basin, with both a farm and regional analysis.

Results show that the impact on the value of water is different depending not only on the scenario, but also on the regional scale. For example, for a warm-dry climate around 44% of farms have no change in the value of water, while at the regional level, this proportion is 15%. The authors show the impact on farmers' revenues; in this case the higher impacts are related to technological change, while climate change has a higher variability.

Regarding climate change impacts, Howitt, *et al.* (2009), analyzed the economic impacts for California using the SWAP model. The SWAP model includes 21 regions and 12 crops and considers the expected impacts in 2050. The model uses a CES production function and an exponential cost function, both of which are calibrated using PMP. The authors simulated a reduction in agricultural land (5%), an increase in crop yield (0.9% to 1.57% per year), an increase in the demand for Californian crops (3% to 45% in 2050), a change in crop yields because of climate change (-11% to 5%), and a reduction in water availability (15% to 25%).

Results show that the main impact expected is an increase in the economic value of water due to the water shortage. This shortage drives a reduction in the area of irrigated crops that is greater than the area needed for urban expansion.

2.2 Climate Change Impacts on the Chilean Agricultural Sector

Climate change impacts on the Chilean agricultural sector have been widely analyzed from different perspectives in recent years. The first study on this subject was conducted by the University of Chile’s AGRIMED center in 2008 (Santibáñez, *et al.* 2008). In this study, authors analyzed the productive impacts that climate change could produce within the Chilean agricultural sector. In order to analyze the expected impacts new climate conditions would have on different agricultural activities, they used the SIMPROC model. The SIMPROC model simulates both the growth and the productivity of a crop by integrating the crop’s ecophysiological processes and its climatic regulation. Crop growth is simulated from emergence to harvest. The input data used includes climatic data and ecophysiological data. On the other hand, the output information includes: dry matter production, grain/fruit yield, optimal sowing and harvesting dates, and water consumption, among other information. The model considers the following activities: wheat, maize, potatoes, sugar beets, common beans, peaches, apples, oranges, grapes, and forestry. The results are computed at the commune level (340 communes), while the scenarios modeled are the IPCC A2 and B2 for two periods: 2040 and 2070 (Intergovernmental Panel on Climate Change 2000). According to the results, the most affected activities due to the impacts of climate change are located in the northern region.

In 2009, the Economic Commission for Latin America and the Caribbean (CEPAL) conducted a study analyzing the economic impacts of climate change in Chile (CEPAL 2009). Although the study does not focus on the agricultural sector, this sector is analyzed as part of the Chilean economy. Using an econometric model (assuming exogenous prices), the authors simulated the expected changes in land allocation due to climate change. The analyzed crop yield changes and activities are those used by Santibáñez, *et al.* (2008).

Their results suggest that net incomes will increase from the Biobío region to the south, while in the northern region the net incomes will decrease. This is because climate scenarios predict a large decrease in precipitation in the northern region. In the worst-case scenario, the agricultural sector will loose 15% of its income (A2 scenario), while in the best scenario the incomes will increase by 1% (B2 scenario).

Using the yield changes computed by Santibáñez, *et al.* (2008), the Agricultural National Research Center (INIA) conducted a study in 2009 analyzing both vulnerability and adaptation options to climate change in two agro-ecological zones in central Chile (Gonzalez 2009). Using yield changes, the author computed the net income at a farm level (current and simulated). With this information, and using primary information collected through surveys, the author defined the vulnerability level using indexes such as: ratio of irrigated to rainfed land, a farm's use of capital, and the link with foreign trade.

Results show that under the A2-2020 scenario, the economic impacts due to yield changes are within the range -USD11 million to -US20 million. The negative impacts are associated with decreases in the central valley's fruit productivity, while the positive impacts are related to increases in the sub-Andean region's crop productivity.

Finally, in 2010 the Agricultural Agency conducted a study at the national level in order to account for the magnitude of the economic impacts climate change could have on the Chilean agricultural sector (ODEPA 2010). The study updates the information generated by Santibáñez, *et al*. (2008), increasing the number of activities analyzed, from 17 to 25. In this study, the authors used an econometric model (assuming exogenous prices) in order to account for the land allocation change due to expected yield changes, and expected changes in the labor demand.

The main conclusions of the study show that climate change will have uneven impacts across the country, with the northern region being the most affected. Results also show a southward movement of the land allocated to annual crops and cereals. In general terms, a 7% decrease in the land devoted to cereal and fruit production is expected under the A2-2040 and B2-2040 scenarios. While the forestry sector shows an increase of 3% in all scenarios. The net income decreases by 5% under the A2-2040 and B2-2040 scenarios.

In general, the use of agricultural multimarket models has been restricted to policy analysis, with few studies addressing climate change impacts in general, and water issues in particular. On the other hand, climate change impacts on the Chilean agricultural sector have mainly been analyzed through the use of econometric techniques, or using simple accounting methods. In each case, the exogenous price assumption is used. The model presented in the next section assumes endogenous prices, which is a major improvement in relation to the previous studies in Chile and Latin America. Furthermore, the use of mathematical programming methods is more suitable to analyze agricultural issues than the econometric techniques. This is mainly because these techniques make it possible to analyze *ex-ante* policy consequences, and answer "*what if…*" questions, which are especially relevant in order to analyze the consequences of policies addressing climate change issues.

3. The Agricultural Multimarket Model

3.1 Model Description

The Agricultural Multimarket model (AMM) is a mathematical programming model designed to analyze the agricultural sector with high geographical disaggregation. It includes the major agricultural activities within the area, and differentiates between water provision systems (rainfed and irrigated), among other features.

The core of the AMM includes two sets of equations. The first set describes the behavior of the agricultural producers (supply), while the second set describes the behavior of the consumers (demand). Within this framework, the model maximizes the total surplus of the agricultural sector: producer surplus plus consumer surplus (*CPS*).

The supply side is characterized by detailed information at the producer level in order to represent a system of outputs supply and inputs demand, which is the result of the assumed profit maximization behavior. The information is differentiated by activity and geographical area, including: area planted, yield, variable costs, and labor demand, which is used to compute total costs, gross margin, and net revenues. The information presented above is complemented with supply elasticities for each activity.

The demand side of the agricultural multimarket model is composed of a matrix of own-price elasticities for agricultural products, which are used to calibrate a linear demand system. These parameters indicate which changes are expected in the demand when supply prices change as a result of a certain policy, or in this specific case, as a consequence of climate change.

The last section of the model includes a set of equations representing the market clearing conditions. The clearing conditions are imposed on each activity and its associated product, implying that production should be equal to consumption.

The core model is optimized considering a series of endowment restrictions, such as: total land, irrigated land, and water. These restrictions imply that the use of a certain resource cannot be larger than its initial endowment.

Using Positive Mathematical Programming (PMP), the model is calibrated to the base year. Using the PMP method it is possible to achieve a perfect calibration for: area planted, products and prices, avoiding the dependency between parameters and constraints (Howitt 1995).

3.2 Model Structure

The model's development involves a three-step procedure. In the first step, a mathematical programming model is built in order to maximize the region's farm net income by allocating land and irrigation water to crops. This model takes all relevant data and farming conditions into account, and includes: 1) the objective function describing the farmers' behavior as rational agents; 2) the set of explicit constraints related to resource availability (land, irrigated land, water) and institutional conditions (policy and environmental).

The main decision variables are cropland allocation and irrigation technology choice. $X_{r,a,s}$ denotes the area (ha) allocated to crop *a* with farming system *s* in region *r*. The model can be compactly written as (subscript *i* denotes the resource type):

$$Z = \sum_{r}\sum_{a}\sum_{s}\left(p_a * y_{r,a,s} - AC_{r,a,s}\right) * X_{r,a,s} \qquad [1]$$

$$AC_{r,a,s} = v\cos t_{r,a,s} \qquad [2]$$

$$\sum_{a}\sum_{s} r_{i,r,a,s} * X_{r,a,s} \le b_{i,r} \qquad [3]$$

$$X_{r,a,s} \ge 0 \qquad [4]$$

In equation [1], *Z* denotes the objective function value (profit function), $AC_{r,a,s}$ is the vector of average costs per unit of activity, $v\cos t_{r,a,s}$ represents the observed variable costs per unit of activity. In equation [1] p_a is the price of crop *a*, $y_{r,a,s}$ is the yield per hectare of crop *a*, in region *r,* using system *s*. In equation [3] $r_{i,r,a,s}$ represents the matrix of coefficients in resource/policy constraints, and $b_{i,r}$ is the vector of available resource quantities. Finally, equation [4] represents the non-negativity constraints on land allocation.

The resource constraints depicted in equation [3] include: total land, irrigated land, and water availability. The model considers that climate change will modify the water availability in each region.

In the second step, a non-linear objective function is calibrated using PMP based on observed activity levels for the base situation. The model assumes constant average revenues (regardless of the level of activity) and increasing average costs, as well as non-linear cost function, which captures all production conditions not explicitly modeled. The average cost function of activity *a* can be written:

$$AC_{r,a,s} = \alpha_{r,a,s} * \left(X_{r,a,s}\right)^{\beta_{r,a,s}} \qquad [6]$$

The cost function parameters $\alpha_{r,a,s}$ and $\beta_{r,a,s}$ are derived from a profit-maximizing equilibrium that maximizes equation [1] subject to [3], [4], and [6].

Additional conditions are: 1) In the base-run, the estimated average cost equals the observed average cost for each activity; 2) supply elasticities are exogenous; 3) The assumption of optimal farmers' behavior can be extended to new activities, and cost function parameters can then be approximated by means of optimality conditions.

On the other hand, the model demand core includes a set of lineal demand equations as presented below:

$$P_p^d = \varphi_p + \lambda_p * q_p^d \qquad [7]$$

Where P_p^d is the demand price of product *p*, φ_p is the constant term of the demand function, λ_p is the slope term of the demand function, and q_p^d is the quantity demanded of product *p*.

In the third step, once the cost function parameters have been derived, the calibrated non-linear model is specified. The AMM maximizes the *CPS* [8] subject to [3], [4], [6], and [7]. Following McCarl and Spreen (2011), the final model is presented below.

$$Max : cps = \sum_p \left(\varphi * q_p^d + \frac{1}{2} * \lambda_p * \left(q_p^d\right)^2 \right) - TTC \qquad [8]$$

$$\sum_a \sum_s r_{i,r,a,s} * X_{r,a,s} \le b_{i,r}$$

$$X_{r,a,s} \ge 0$$

$$AC_{r,a,s} = \alpha_{r,a,s} * \left(X_{r,a,s}\right)^{\beta_{r,a,s}}$$

$$P_p^d = \varphi_p + \lambda_p * q_p^d$$

Where *TTC* represents the total costs:

$$TTC = \sum\sum\sum\left(AC_{r,a,s} * X_{r,a,s}\right) \qquad [9]$$

The model as presented above reproduces the activity levels observed for the base-run and allows us to simulate hypothetical climate change scenarios. The model structure is flexible enough to incorporate all relevant environmental constraints and policy instruments.

Uncertainty is included in the modeling framework using the Monte Carlo method. The Monte Carlo method allows us to simulate the behavior of a random variable according to its distribution. In this specific case, the model assumes that the water availability is random variables. Considering that it is uncertain how climate change impacts will affect water availability, it is necessary to assume a probability distribution to represent its behavior. Based on expert opinions, it is assumed that water availability follows a Gamma distribution. Thus, several sets of water availability scenarios are simulated using both uniform pseudo-random numbers and the inverse probability distribution function (Hardaker, Huirne and Anderson 1997). The Gamma probability distribution function (PDF) and its key parameters are shown in equations [10] to [12].

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\exp\left(-\frac{x}{\beta}\right)x^{\alpha-1} \qquad [10]$$

$$\alpha = \frac{\left[E(x)\right]^2}{\sigma^2} \qquad [11]$$

$$\beta = \frac{\sigma^2}{E(x)} \qquad [4.12]$$

Where, α is the shape parameter, and β the inverse scale parameter. With $\alpha,\beta > 0$. *E(x)* is the mean of the distribution, and σ^2 the variance.

4. The Economic Impacts of Climate Change on the Chilean Agricultural Sector.

Chile is a long, narrow country located in the southeast corner of South America. It covers 756,000 km^2, with a coastline of 4,300 km, and a population of 17.4 million inhabitants.

Due to its geographical characteristics, Chile has diverse climatic conditions throughout its diverse regions. The climate ranges from desert in the north, to alpine tundra and glaciers in the eastern and southeastern areas. At the administrative scale, northern Chile, characterized by an arid and semiarid climate, includes regions [XV-III]. Central Chile, characterized by a Mediterranean climate, includes regions [IV-VIII]. Southern Chile, characterized by an oceanic climate, includes regions [IX-IX], while the austral area, characterized by a sub-polar climate, includes the XII region.

Chile has a large endowment of water resources in both surface and groundwater. However, the water resources are characterized by a high variability in water supply, as well as an uneven distribution of water across the country. Water availability throughout the year is characterized by seasonal behavior, with high precipitation in the winter, and water shortages in the summer.

Across regions, the mean annual rainfall varies between 0-10 millimeters in the northern desert, to more than 3,000 millimeters in the southern region. This uneven distribution has serious impacts on the water available for human consumption, as well as for the agricultural sector.

Within the climatic context presented above, the total agricultural land (18.4 million ha) is divided as follows: 1.7 million ha of cultivated land, 14.03 million ha of grassland, and 2.7 million ha of forested land. Considering only the cultivated land (1.7 million ha), 76% is devoted to annual and permanent crops, while 23.5% is devoted to fodder (INE 2007).

The main annual and permanent crops are: fodder (29.9%), cereals (28%), fruits (18%), industrial crops (8.3%), vineyards (7.6%), and vegetables (5.5%), among other agricultural activities. Regarding farm size, more than 90% of farms have an area within the range of 1 ha to 20 ha (INE 2007).

Irrigation is a widely spread practice across the country. Chile has 1.1 million ha under some irrigation scheme, representing 64.7% of the total cultivated land. The main activities under irrigation are: industrial crops, fruits, and vineyards (INE 2007). At the macroeconomic level, the agricultural sector represents 4% of the Chilean GDP, and it employs 13.6% of the total labor force (The World Bank 2007).

4.1 Model Specification

The application of the multimarket model includes a smaller area than those considered in previous studies. The area being analyzed here includes regions from Atacama in the north to Los Lagos in the south. This area includes 265 communes, grouped into 36 provinces, and 10 regions. The agricultural sector is represented by 21 activities, aggregated according to the following categories: Crops (9), Fruits (10), and Forestry (2); the model considers irrigated and rainfed activities, accounting for 3.3 million ha.

The crops considered are: rice (irrigated), oats (rainfed), common beans (irrigated), maize (irrigated), potatoes (irrigated and rainfed), alfalfa (irrigated), and wheat (irrigated and rainfed). The fruits considered are: cherries, plums, peaches, apples, oranges, walnuts, olives, avocadoes, pears, grapes, and vine grapes. Finally, the model also includes the area devoted to forestry, including: pine and eucalyptus, both rainfed activities. The agricultural sector depicted above represents 95.5% of the agricultural activities developed within the study area.

The core information used in the model (area, production, yield) is from the year 2007, and comes from the National Agricultural Census (INE 2007), considering a disaggregation at communal level. The information about costs per commune, activities and watering systems (irrigated, rainfed), as well as labor intensity is the same information that was used in the ODEPA study (ODEPA 2010). Prices were taken from the Agricultural Agency's website (ODEPA 2010), while the elasticities used to calibrate the model were collected from previous studies (Quiroz, *et al*. 1995, Foster, *et al.* 2011, CAPRI Model 2008).

The current water availability per commune was computed using the crop irrigation requirements simulated by Santibáñez *et al.* (2008). In order to include climate change impacts, a 25% decrease in water availability was assumed for the Atacama region (Zone 1), -35% for the Coquimbo and Valparaiso regions (Zone 2), and -25% for the Metropolitana region to the south (Zone 3), according to the expected changes in precipitation for the A2-2040 climate change scenario. (CEPAL 2009)

4.2. Results

At the national level, the expected changes in water availability have a minor impact on the total land allocation, with total agricultural land decreasing by 8,300 ha. However, the expected impact across regions is uneven, with the largest impacts in the northern region. For instance, the Atacama region decreases its agricultural land by 13%, equivalent to 412 ha, while for both the Coquimbo and the Valparaiso regions the decrease is only 7.6% (on average), with a decrease of

2,800 ha and 4,800 ha, respectively. On the other hand, from the Metropolitana region to the south, the decrease in agricultural land is negligible (0.04%). Due to the decrease in water availability, the total rainfed land decreases by 40,200 ha, while the irrigated land increases by 31,900 h. (Table 1).

Table 1. Land Allocation (ha)

	Rainfed Land		Irrigated Land	
Region	Baseline	Climate Change	Baseline	Climate Change
Atacama	0	0	3,151.8	2,738.8
Coquimbo	342.3	423.7	28,770	25,811
Valparaiso	46,094.8	47,698.7	45,222	38,744.4
Metropolitana	7,847.2	5,992.8	68,945.4	70,743.1
Ohiggins	133,900	124,229.6	140,042.5	149,705
Maule	489,754.8	467,521.3	145,586.9	167,820.4
Biobio	1,019,463.9	1,010,598.7	66,250.6	75,115.9
Araucania	702,407.2	703,015.1	9,865.3	9,201.2
Los Rios	253,127	253,266.2	939.6	800.4
Los Lagos	110,027.4	110,017.7	413.9	423.6

Although the change in total land allocation is minor, the impact this has on agricultural production is quite relevant, with fruit production increasing by 15% (700,000 ton) and forest production decreasing by 2% (12,000 ton). On the other hand, crop production decreases by 3% (133,000 ton). These figures imply that the expected impact of climate change will have serious distributional effects with significant differences across sectors and regions. At the regional level, the O'Higgins region represents 29% of the total crop production reduction; and the Maule region represents 63% of the increase in fruit production, as well as 42% of the increase in forest production. Detailed results are presented in Table 2.

Detailed results show that land allocated to plums decreases by 76%, followed by walnuts (-53%), pears (-41%), and olives (-29%). On the other hand, vineyards increase by 43%, followed by oranges (34%), and apples (30%). Details are shown in Table 3.

Table 2. Agricultural Production (ton)

Region	Crops		Fruits		Forest	
	Baseline	Climate Change	Baseline	Climate Change	Baseline	Climate Change
Atacama	3,226	3,976	31,546	27,153	0	0
Coquimbo	69,799	61,088	330,008	328,453	0	0
Valparaiso	175,855	178,131	400,038	363,314	5,561	5,769
Metropolitana	425,425	445,401	545,950	532,821	684	497
Ohiggins	766,499	727,789	1,402,048	1,608,156	30,190	28,392
Maule	601,308	582,089	1,313,670	1,753,406	123,887	118,657
Biobio	696,142	751,222	268,899	358,119	269,530	266,041
Araucania	887,860	925,987	98,943	120,962	150,553	148,977
Los Rios	175,261	194,844	20,040	17,905	64,830	64,694
Los Lagos	297,205	361,754	9,176	10,230	12,301	11,924

Table 3. Land Allocation by Activity (ha)

Activity	Baseline	Climate Change
Alfalfa	42,520	43,292
Apple	35,642	46,478
Avocado	35,857	34,737
Cherry	8,483	5,792
Common Bean	7,617	9,025
Eucalyptus	878,268	860,535
Grapes	8,544	9,288
Maize	95,275	91,375
Oat	61,520	61,760
Olive	12,365	8,694
Orange	6,186	8,290
Peach	15,366	15,759
Pear	5,887	3,456
Pine	1,631,131	1,593,414
Plum	16,207	3,919
Potato Rainfed	28,653	37,250
Potato Irrigated	19,309	20,006
Rice	21,193	25,507
Vineyard	118,880	169,636
Walnut	12,702	5,929
Wheat Rainfed	163,393	169,805
Wheat Irrigated	47,157	39,921

Results by area and activity show that there is a direct relationship between the expected change in water availability and the final change in land allocation. As was established above, the total agricultural land decreases by 8,300 ha, out of which the area most affected by climate change, Zone 2, accounts for 95% (7,751 ha).

Detailed results by zone show that in relative terms, Zone 1 is the most affected by climate change, with a 13% (413 ha) decrease in agricultural land. Within Zone 1, the land allocated to pears, plums, and walnuts is zero under the climate change scenario. On the other hand, common beans, vineyards, and oranges show the largest increase in land allocation, 83%, 49% and 41%, respectively.

The largest decrease in land allocation within Zone 2 is related to avocadoes (5,824 ha), walnuts (3,756 ha), and olives (2,300 ha). On the other hand, the activities that increase their land are vineyards (2,787 ha), eucalyptus (930 ha), and oranges (642 ha).

In general, land allocation in Zone 3 remains almost unchanged under the climate change scenario, with a decrease of 121 ha. However, this zone shows great differences across activities, with a large reallocation of land from forest to crops and fruits. Among crops, the largest increase is reported for rainfed potatoes (8,597 ha), followed by rainfed wheat (6,239 ha), and rice (4,314 ha). Regarding fruits, the most extreme values are those representing the increase in land devoted to vineyards (47,700 ha), and the decrease in land devoted to plums (12,000 ha), these figures represent a change of 46% and -75%, respectively. Details are shown in Table 4.

The total agricultural production increases by 9%, despite the decrease of 8,300 ha due to climate change. The largest decreases are reported for plums (-76%), walnuts (-55%) and pears (38%), these fruits reduce their production by 330,000 ton. On the other hand, vineyards, oranges and apples increase their production by more than 1,000,000 tons. In general, the total agricultural production changes from 9.1 million tons to 9.9 million tons (Table 5).

Table 4 Land Allocation by Activity and Zone.

	Zone 1		Zone 2		Zone 3	
Activity	Baseline	A240	Baseline	A240	Baseline	A240
Crops	235	292	17,585	17,151	468,817	480,498
Alfalfa	0	0	7,887	7,347	34,633	35,945
Common Bean	5	9	314	334	7,298	8,683
Maize	0	0	1,502	1,558	93,773	89,816
Oat	0	0	402	411	61,118	61,349
Rainfed Potato	0	0	0	0	28,653	37,250
Irrigated Potato	230	283	4,538	4,408	14,541	15,314
Rice	0	0	0	0	21,193	25,507
Sugar Beet	0	0	2,001	2,174	161,393	167,632
Rainfed Wheat	0	0	942	918	46,215	39,003
Irrigated Wheat	2,917	2,447	58,809	49,989	214,391	259,542
Fruits	0	1	259	303	35,382	46,175
Apple	380	410	25,482	19,657	9,995	14,669
Avocado	0	0	172	20	8,311	5,772
Cherry	0	0	5,268	5,422	3,276	3,865
Grapes	1,977	1,257	2,787	485	7,601	6,953
Olive	100	141	1,731	2,374	4,354	5,775
Orange	15	15	4,610	4,796	10,741	10,948
Peach	4	0	309	1	5,574	3,455
Pear	0	0	292	0	15,915	3,919
Plum	417	624	13,616	16,404	104,846	152,609
Vineyard	23	0	4,283	528	8,396	5,402
Walnut	0	0	44,035	45,538	2,465,364	2,408,411
Forest	0	0	7,279	7,853	1,623,852	1,585,561
Pine	0	0	36,756	37,685	841,512	822,850
Eucalyptus	235	292	17,585	17,151	468,817	480,498

Table 5. Agricultural Production (ton).

Activity	Baseline	Climate Change
Alfalfa	785,503	802,623
Apple	1,247,859	1,628,683
Avocado	308,622	310,624
Cherry	45,749	31,723
Common Bean	14,179	16,882
Eucalyptus	166,155	163,568
Grapes	219,126	238,168
Maize	1,075,610	1,030,975
Oat	281,075	282,663
Olive	162,053	122,838
Orange	136,355	183,357
Peach	365,244	375,072
Pear	90,841	56,019
Pine	491,382	481,383
Plum	357,640	83,653
Potato	773,605	911,366
Rice	108,323	129,438
Vineyard	1,449,213	2,073,711
Walnut	37,615	16,673
Wheat	1,060,285	1,058,336

Results by zone and activity show that the impact on crop production is unevenly distributed across the country, with crop production increasing by 23% in Zone 1 and by 4% in Zone 3, while in Zone 2 it decreases by 3%. Fruit production decreases by 10% on average in Zone 1 and 2. Forestry production remains unchanged in Zone 1, increases by 4% in Zone 2, and decreases by 2% in Zone 3.

Potato production is the only crop that increases its production within Zone 1, by approximately 750 tons (23%). Regarding fruits, the largest decrease is reported in olive production (7,800 tons - 43%). On the other hand, vineyards increase their production by approximately 2,000 tons, representing an increase of 48%.

Zone 2 reports a decrease of 44,500 tons (-5%) in agricultural production, out of which avocadoes, olives, and walnuts account for the largest share. On the other hand, vineyards, oranges, and grapes increase their production by 48,000 tons.

The largest increase in production in Zone 3 is reported for vineyards (590,000 tons), representing an increase in production of 46%. In relative terms, avocadoes show an increase in production of 58%, equivalent to 47,000 tons. Wheat and maize decrease their production by 47,000 tons, making maize the most affected crop (-45,000 tons). This decrease in production is compensated by the increase reported for potatoes (140,00 tons). Due to this figure, the final crop production increases by 139,000 tons (4%). Details are presented in Table 6.

Table 6. Agricultural Production by Activity and Zone

	Zone 1		Zone 2		Zone 3	
Activity	Baseline	Climate Change	Baseline	Climate Change	Baseline	Climate Change
Crops	3,226	3,976	245,654	239,220	3,849,699	3,989,087
Alfalfa	0	0	145,376	140,337	640,127	662,286
Common Bean	7	14	526	568	13,646	16,300
Maize	0	0	15,797	16,516	1,059,813	1,014,459
Oat	0	0	1,592	1,626	279,483	281,037
Potato	3,219	3,962	71,142	68,600	699,244	838,804
Rice	0	0	0	0	108,323	129,438
Wheat	0	0	11,222	11,573	1,049,063	1,046,763
Fruits	31,546	27,153	730,046	691,767	3,658,726	4,401,600
Apple	9	12	9,523	11,104	1,238,327	1,617,566
Avocado	5,519	5,802	221,692	176,340	81,411	128,482
Cherry	0	0	1,061	110	44,688	31,613
Grapes	0	0	135,325	139,291	83,801	98,876
Olive	18,366	10,533	29,972	6,596	113,716	105,708
Orange	3,150	4,443	38,972	53,217	94,234	125,698
Peach	266	266	122,137	127,140	242,841	247,665
Pear	47	0	3,983	14	86,811	56,004
Plum	9	0	6,811	0	350,819	83,653
Vineyard	4,132	6,096	146,637	176,591	1,298,445	1,891,023
Walnut	48	0	13,934	1,363	23,633	15,310
Forest	0	0	5,561	5,769	651,975	639,183
Pine	0	0	1,474	1,576	489,908	479,807
Eucalyptus	0	0	4,087	4,193	162,068	159,375

Along with the agricultural supply impacts described above, the AMM model also accounts for impacts on agricultural demand. As is shown in Table 5, the impacts of climate change affect the agricultural supply differently, with some products increasing their supply (for instance: alfalfa, apples, and avocadoes), while others decrease their supply (for instance: cherries, maize, and olives). Table 7 shows the associated demand prices for each activity. As is shown in this table, the inverse relationship between demand and supply holds for the agricultural sector.

Table 7. Demand Prices (USD/ton)

Product	Baseline	Climate Change	% Change
Alfalfa	174.3	164.8	-5.4%
Apple	692.3	340.2	-50.9%
Avocado	8,487.7	8,418.8	-0.8%
Cherry	1,444.8	2,183.0	51.1%
Common Bean	2,279.6	1,410.6	-38.1%
Eucalyptus	2,193.4	2,278.8	3.9%
Grapes	534.0	476.0	-10.9%
Maize	217.3	239.8	10.4%
Oat	195.8	194.7	-0.6%
Olive	1,128.1	1,469.3	30.2%
Orange	1,331.3	413.5	-68.9%
Peach	446.5	429.3	-3.8%
Pear	428.4	633.7	47.9%
Pine	1,265.2	1,329.5	5.1%
Plum	202.0	395.5	95.8%
Potato	636.3	258.6	-59.4%
Rice	1,272.6	652.4	-48.7%
Wine	1,568.7	817.6	-47.9%
Walnut	2,604.0	4,416.2	69.6%
Wheat	286.5	288.2	0.6%

According to Table 7, crop prices decrease by 20%; this change is driven by the large decrease in the price of potatoes and rice, 59% and 49%, respectively. On the other hand, fruit prices increase by 16%, with plums (96%), walnuts (69%), and oranges (69%) being the most affected products.

All the changes described above drive a 16% decrease in the agricultural net income, equivalent to USD344 million (171,8 billion Chilean Pesos). At the regional level, the Metropolitana, O'Higgins and Maule regions account for 67% of the total decrease in income (USD 248 million).

The Metropolitana region loses the largest proportion of its net income: -54%, followed by the Valparaiso region (-27%), and the Atacama region (15%). On the other hand, the Los Rios, Araucania, and Los Lagos regions experience the smallest losses due to climate change (1%-3%). Results by Zone show that losses in Zone 3 are the smallest across the country (-14%), followed by Zone 1(-23%), and Zone 2 (-21%). Details are presented in Table 8.

Table 8. Net Income by Region (Million USD)

Region	Baseline	Climate Change	Change (%)
Atacama	13	10	-23%
Coquimbo	112	95	-15%
Valparaiso	202	147	-27%
Metropolitana	186	89	-52%
Ohiggins	388	308	-21%
Maule	425	359	-16%
Biobio	437	418	-4%
Araucania	296	291	-2%
Los Rios	104	103	-1%
Los Lagos	50	48	-3%
Total	2,212	1,868	-16%

As is shown in Table 8, the zone most affected by climate change (Zone 2) is not the most affected in economic terms. This is because land distribution across zones is uneven, with Zone 1 accounting for 0.1% of the total agricultural land, Zone 2 (3.7%), and Zone 3 (96.2%). Thus, to have a better picture of the economic impacts by Zone, it is necessary to adjust the net income according to the agricultural land that exists in each zone.

By adjusting the net income by zone, the results are consistent with the simulated climate change scenarios, with Zone 2 showing the largest decrease in its income per hectare (-18%), followed by Zone 3 (-14%), and Zone 1 (-12%). Table 9 shows details at the regional level.

Table 9. Net Income by Hectare (USD)

Region	Baseline	Climate Change
Atacama	4,120	3,642
Coquimbo	3,836	3,612
Valparaiso	2,215	1,704
Metropolitana	2,420	1,165
Ohiggins	1,415	1,124
Maule	668	565
Biobio	403	385
Araucania	415	409
Los Rios	410	407
Los Lagos	450	434

This figure should be considered carefully, mainly because the land allocation computed by the AMM model is not the result of a profit maximization problem, instead the model maximized the total welfare associated with the Chilean agricultural sector, using the Consumer plus Producer Surplus (CPS) as the measurement unit. By using the *CPS*, the impact of climate change on the agricultural welfare is USD 757 million, changing from USD15.6 billion to USD14.8 billion (-4.8%), approximately 378 billion Chilean Pesos.

Considering that the agricultural model presented here accounts for climate change impacts on water availability, the welfare implications should be considered as a lower bound because the model does not account for climate change impacts on rainfed agriculture. In order to have an approximation about the consequences of this approach, a new version of the model was running. The new version includes the expected changes on rainfed yields (reported by Santibáñez, *et al*. 2008), along with changes in water availability.

Results suggest that the differences on welfare are quite small, with loses in the *CPS* equivalent to 3.9%, versus the 4.8% computed in the original version. However, the net income increases 3.7% (USD 71 million), versus the decrease showed in the original version (-3.9%). This income difference is explained by the increase reported for oat, potatoes, and wheat producers.

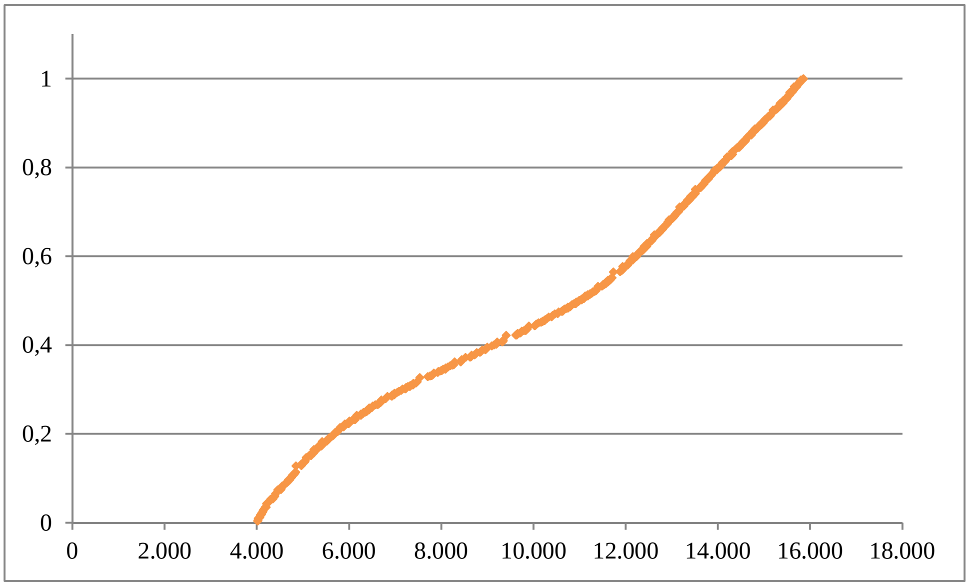
In order to account for the uncertainty associated with the change in water availability, a series of Monte Carlo simulations were developed. The objective is to determine the probability of a certain *CPS* level's occurrence, depending on the water scenario analyzed. As was established before, the model assumes that the water availability follows a Gamma distribution.

For simplicity, the Gamma distribution parameters are computed per activity and Zone, using the mean and the variance of the water availability sample. Using these parameters, a series of 400 water scenarios were computed. The cumulative distribution function for the Consumer plus Producer Surplus at the country level is presented in Figure 1.

Figure 1 shows that the cumulative distribution function does not start in zero, this is because the impacts of climate change are associated to the irrigated agriculture. Thus, even with zero water availability for irrigation the *CPS* is positive due to the demand and supply interaction within the rainfed sector.

The analysis of the distribution shows that the 25th percentile is USD6.347 billion, the 50th percentile is USD11 billion, and the 75th percentile is USD13.5 billion. Considering these figures, the welfare impact reported for the climate change scenario (USD14.8 billion) is above the 75th percentile implying a likely result.

Figure 1. Cumulative Distribution Function: Consumer plus Producer Surplus (USD).



In general, the results reported here are consistent with those reported by previous studies with large impacts on the northern zone. However, the AMM does not predict negative impacts on fruits production, or cereals, as previous studies did (Gonzalez, 2009; ODEPA, 2010). This is because in the model structure the demand prices play a key role on the final land allocation, by changing the relative profits.

IV.5. Conclusions

Climate change will have vast and diverse impacts on the agricultural sector across the world, with developing countries presenting the most vulnerable regions. Considering the high level of policy intervention that the agricultural sector already has, a modeling approach that considers all the connections within it is essential; and the model presented in this study fulfills this requirement. In addition, the model presents a very detailed picture of the agricultural sector, with a high level of geographical detail aiming to identify local conditions that could influence the final economic consequences of climate change.

The model depicted here is a tool flexible enough to be applied in several situations in which information access is a constraint. As was shown, the main source of information is the Agricultural Census, which is complemented with secondary data that should be easy to collect if the objective is to use this model in other countries.

Climate change impacts on the Chilean Agricultural sector are vast, with considerable economic consequences across regions. At the regional level, there is a complete re-allocation of land, with the northern zone showing large changes. However, this land reallocation does not seriously impact the total agricultural production. On the other hand, the results do not show a clear southward movement, as previous studies have. This is because the AMM considers feedback effects that moderate the impacts of the expected water availability changes, mainly through prices.

According to the results, climate change will not have significant absolute consequences. However, climate change will have large distributional consequences, with plum, walnut, and avocado producers being worse-off compared to vineyard, orange, and apple producers. This could worsen the inequity that already exists in Chile, presenting additional challenges for coping with climate change.

Regarding demand prices, the average decrease of 1% within agricultural products hides large differences across sectors. For instance, the 16% increase in fruits could have serious impacts on the family budget, since fruits are a typical component of the basic diet in Chile.

However, despite the high level of detail in which the agricultural sector is modeled, some drawbacks remain. These limitations are related to the demand system, input substitution, and irrigation facilities.

The way in which the demand system is modeled, does not allow for the analysis of poverty issues, that could be a consequence of changes in the agricultural sector’s production structure.

Nevertheless the model includes uncertainty the predicted prices do not consider critical issues for agricultural prices, such as the impact of the storage capacity, or international markets.

Due to a lack of information, the model does not account for substitution options between water and other inputs, nor does it consider the use of irrigation deficits as an adaptation option to climate change. On the other hand, the model assumes that the expansion of the irrigated area is costless, underestimating the costs associated to the change in the crop pattern. Finally, climate change impacts on the rainfed sector are modeled as a productivity shock, without an explicit functional form relating water and agricultural yields. Nevertheless, the structure of the model allows us to include these topics once the data becomes available.

The re-allocation of land across the country implies several impacts that are not modeled here, such as: environmental impacts due to land use changes, as well as social impacts. Regarding the latter, the use of these types of models should be part of a more complete analysis of climate change in the agricultural sector, these analyses should explicitly include the social component. This is very important considering the social consequences of changes in farming practices that are deeply rooted within the farmers' communities.

IV.6. References

1. Aksoy, M, and F Ng. “The Evolution of Agricultural Trade Flows.” *Policy Research Working Paper 5308* (The World Bank), 2010.
2. Alcamo, J, and T Henrichs. “Critical regions: A Model-Based Estimation of World Water Resources Sensitive to Global Changes.” *Aquatic Sciences*, no. 64 (2002): 352–362.
3. Alcamo, J., Doll, P., Henrichs, T., Kaspar, F., Lehner, B., Rosch, T., *et al.* (2003). Global Estimates of Water Withdrawals and Availability Under Current and Future “business-as-usual” Conditions. Hydrological Sciences Journal , 48, 339-348.
4. Arnell, N, D van Vuuren, and M Isaac. “The Implications of Climate Policy for the Impacts of Climate Change on Global Water Resources.” *Global Environmental Change* 21 (2011): 592–603.
5. Bates, B., Z. Kundzewicz, S. Wu, and J Palutikof. *Climate Change and Water.* Technical Paper, Intergovernmental Panel on Climate Change., Geneva: IPCC Secretariat, 2008.
6. Blanco, M, R Cortignani, and S Severini. “Evaluating Changes in Cropping Patterns due to the 2003 CAP Reform. An Ex-post Analysis of Different PMP Approaches Considering New Activities.” *Modelling of Agricultural and Rural Development Policies.* Sevilla: EAAE, 2008.
7. Cai, X, and D Wang. “Calibrating Holistic Water Resources–Economic Models.” *Journal of Water Resources Planning and Management*, 2006: 414-424.
8. CAPRI Model. “CAPRI Model Documentation.” 2008.
9. CEPAL. *Economía del cambio climático en Chile. Síntesis.* CEPAL, 2009.
10. Cortigiani, R, and S Severini. “Modeling Farm-level Adoption of Deficit Irrigation Using Positive Mathematical Programming.” *Agricultural Water Management*, 2009: 1785–1791.
11. Croppenstedt, A, L Bellu, F Bresciani, and DiGiuseppe S. “Agricultural Policy Impact Analysis with Multi-Market Models: A Primer.” *ESA Working Paper No. 07-26* (Food and Agricultural Organiztion), 2007.
12. de Frahan, B., Buysse, J., Polomé, P., Fernagut, B., Harmignie, O., Lauwers, L., et al. (2007). Positive Mathematical Programming for Agricultural and Environmental Policy Analysis: Review and Practice. In A. Weintraub, C. Romero, T. Bjornda, & R. Epstein, Handbook Of Operations Research In Natural Resources. Springer.

13. Doll, P. “Impact of Climate Change and Variability on Irrigation Requirements: a Global Perspective.” *Climatic Change* 54 (2002): 269-293.
14. FAO. *FAO Statistical Yearbook 2010.* Food and Agriculture Organization, Rome: Food and Agriculture Organization, 2010.
15. Fisher, G, F Tubiello, H van Velthuizen, and D Wiberg. “Climatechange impacts on irrigation water requirements: Effects of mitigation, 1990–2080.” *Technological Forecasting and Social Change* 74 (2006): 1083–1107.
16. Foster, W, J Lopez, and A Valdes. “Impacto del Nivel de Distorsiones en el Sector Agrícola Nacional.” Subsecretaria de Agricultura, 2011.
17. Gonzalez, J. “Estudios sobre Impacto, Vulnerabilidad y Adaptación al Cambio Climático en dos Zonas Agroclimaticas del Sector Silvoagropecuario de Chile.” Instituto Nacional de Investigacion Agropecuaria, 2009.
18. Hardaker, J., R. Huirne, and J. Anderson. *Coping with Risk in Agriculture.* Oxon: CAB International, 1997.
19. Hazzel, P, and R Norton. *Mathematical Programming For Economic Analysis in Agriculture.* New York: Collier Macmillan, 1986.
20. Heckelei, T, and W. Britz. “Models Based on Positive Mathematical Programming: State of the Art and Further Extensions.” *Modelling Agricultural Policies: State of the Art and New Challenges.* Parma: European Association of Agricultural Economics, 2005. 48-73.
21. Henseler, M, A Wirsig, S Herrmann, T Krimly, and S Dabbert. “Modeling the Impact of Global Change on Regional Agricultural Land use Through an Activity-based non-linear Programming Approach.” *Agricultural Systems*, 2009: 31-42.
22. Howitt, R. “Agricultural and Environmental Policy Models: Calibration, Estimation and Optimization.” University of Carlifornia. UCDavis, 2005.
23. Howitt, R. “Positive Mathematical Programming.” *American Journal of Agricultural Economics*, 1995: 329-342.
24. Howitt, R, J Medellin-Azuara, and D Macewan. “Estimating the Economi Impacts of Agricultural Yield Related Changes for California.” California Energy Comission, 2009.
25. Howitt, R, K Ward, and S Msangi. “Statewide Water and Agricultural Production Model. Apendix A.” 2001.
26. INE. “Censo Agropecuario.” 2007.

27. Intergovernmental Panel on Climate Change. *Special Report on Emisison Scenarios.* IPCC, IPCC, 2000.
28. Kan, I, D Haim, M Rapaport-Rom, and M Shechter. "Environmental amenities and optimal agricultural land use: The case of Israel." *Ecological Economics*, 2009: 1893-1898.
29. Lundber, M, and K Rich. *Multimarket Models and Policy Analysis: An Application to Malawi.* Development Economics Research Group/Poverty Reduction Group, Environment and Infrastructure Team, mimeo, The World Bank Group, The World Bank Group, 2002b.
30. Lundberg, M, and K Rich. *Multimarket Models and Policy Analysis: An Application to Madagascar.* Development Economics Research Group/Poverty Reduction Group, Environment and Infrastructure Team, mimeo, The World Bank Group, The World Bank Group, 2002a.
31. Mattas, K, F Arfini, P Midmore, M Schmitz, and Y Schmitz. "CAP's Impacts on Regional Employment: A Multi-Modelling Cross Country Approach." In *Dissagregated Impacts of CAP Reforms: Proceeding of an OECD Workshop*, by OECD. Paris: OECD, 2011.
32. McCarl, B., and T Spreen. *Applied Mathematical Programming Using Algebraic Systems.* Texas: Texas A&M University, 2011.
33. Medellín-Azuara, J, J Harou, and R Howitt. "Estimating Economic Value of Agricultural Water Under Changing Conditions and the Effects of Spatial Aggregation." *Science of the Total Environment*, 2009.
34. ODEPA. *Estimación del impacto Socioeconómico del Cambio Climático en el Sector Silvoagropecuario de Chile.* ODEPA, ODEPA, 2010.
35. —. "Oficina de Politicas Agrarias." 2010. www.odepa.cl (accessed 2012, 09-July).
36. Paris, Q, and F Arfini. *Frontier Cost Functions, Self-Selection, Price Risk, PMP and Agenda 2000.* Eurotools Working Papers Series, No. 20, 2000.
37. Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. Van-der-Linden, and C.E Hanson. *Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by M.L. Parry, O.F. Canziani, J.P.

Palutikof, P.J. Van-der-Linden and C.E Hanson. Cambridge University Press, Cambridge, UK, 2007.

38. Quiroz, J, R Labán, and F Larraín. “El sector agrícola y agroindustrial frente a Nafta y Mercosur.” Sociedad Nacional de Agricultura, 1995.
39. Rohm, O, and S Dabbert. “Integrating Agri-Environmental Programs into Regional Production Models: An Extension of Positive Mathematical Programming.” *American Journal of Agricultural Economics*, 2003: 254-265.
40. Sadoulet, E, and A De Janvry. *Quantitative Development Policy Analysis.* Baltimore and London: The Johns Hopkins University Press, 1995.
41. Santibáñez, F, P Santibáñez, R Cabrera, L Solis, M Quiroz, and J Hernandez. *mpactos productivos en el sector silvoagropecuario de Chile frente a escenarios de Cambio Climático.* AGRIMED, AGRIMED, 2008.
42. Siam, G, and A Croppenstedt. *An Assessment of the Impact of Wheat Market Liberalization in Egypt: A Multi- Market Model Approach.* FAO, ESA Working Paper No. 07-15, 2007.
43. Stifel, C, and J Randrianarisoa. *Rice prices, Agricultural Input Subsidies, Transactions Costs and Seasonality: A Multi-Market Model Approach to Poverty and Social Impact Analysis for Madagascar.* Lafayette College, Easton, PA., 2004.
44. The World Bank “Open Data.” *Data Catalog.* 2007. data.worldbank.org (accessed 2012 on 24-01).