The Economic Impact of Water Scarcity from Climate Change in an International River Basin Context

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Abstract

In this paper we simulate and analyze the direct and indirect impacts of climate change on water availability for irrigation on the economy of the Netherlands and the other EU countries which share in the Rhine and Meuse river basin (France, Germany and Belgium), employing a computable general equilibrium (CGE) modeling approach. We make use of the GTAP-W model, distinguishing between rainfed and irrigated land and irrigation water as input factors in agricultural production, to simulate the economic effects of a structural decrease in water availability due to climate change in the region. We compare our results with the direct agricultural damage costs estimated using hydrological and crop growth models and find that the total economic impacts on agriculture are much lower when accounting for substitution effects and cross-sectoral and cross-country interlinkages, while the impact on the non-agricultural sectors becomes larger when these interlinkages are included.

Key words: Applied General Equilibrium, Water allocation, Water scarcity, Climate Change

1. Introduction

The Netherlands is a delta region and water is deeply interwoven with the Dutch economy and way of life. The two major rivers flowing into the Netherlands, the Rhine from Germany and the Meuse from Belgium, provide many economic services which range from allowing shipping traffic and ground water recharge, to providing irrigation water and preventing the sea water from infiltrating the groundwater which degrades the productivity of farmland. The Rhine and Meuse rivers are also a direct connection between the Netherlands and its neighbors and the actions of the upstream countries affects the quality and quantity of the water available downstream. The use of these shared rivers is coordinated and regulated by international committees on the Rhine and Meuse rivers.

Historically the Netherlands has been focused on controlling its water supply (both fresh and salt water) and on anticipating the effects of any changes in its hydrology. A reduction in the availability of fresh water on either a temporary or semi-permanent basis can have harmful effects on the economic sectors that depend on a reliable supply of water as an input for their production process. If these sectors are large enough then the impact of water scarcity might affect other aspects of the domestic and foreign economy that are not directly impacted by water scarcity through price changes as well as firm input and consumption bundle substitutions, as the economy readjust in the face of prolonged water scarcity.

The prospect of climate change brings with it a new set of uncertainties to the freshwater supply for the countries in the Rhine and Meuse river basin: the Netherlands, Belgium, Luxemburg, Germany and France. These countries' are linked economically and politically, as they are all in the Euro zone, and they draw much of their water from the same sources. The interconnection of these distinct national economies in both the economic and hydrological sense provides for a rich testing ground for assessing the wider impacts of water scarcity. This region also has experience with droughts, the most severe one in recent memory being in 2003. Sustainable management of water resources has been a priority for the EU member countries; a striking example of this is the European Water Framework Directive (Water Framework Directive 2012) which is a common treaty on integrated river basin management planning in Europe.

The objective of this paper is to examine the scale of the economic feedbacks to determine the full impact of water scarcity on both the water using sectors and the economy as a whole. To this end we employ a computable general equilibrium model GTAP-W to examine the dependence on water of the economy in the Rhine and Meuse river basin countries and to establish the wider economic consequences of water scarcity brought on by a changing climate. The fundamental question posed by this paper is the following: what is the scale of the general equilibrium effects when assessing the impacts of water scarcity from climate on the Netherlands, and are these economic feedbacks sufficiently large to alter the assessment of the impact of water scarcity?

To gain insight into this question, we examine the direct impact of water scarcity on agriculture in the Netherlands estimated in a recent study Zoetwatervoorziening in Nederland (Freshwater supplies in the Netherlands) commissioned by the Dutch Delta Committee (Klijn, ter Maat, and van Velzen 2011). We incorporate their results into our model as the direct damage to agricultural production from water scarcity and place them within a general equilibrium model to capture the larger economic feedbacks as the economy responds to the water scarcity conditions. Furthermore, noting that climate change does not respect national boundaries, we implement the same water scarcity conditions experienced by the Netherlands in the neighboring EU countries that share the Rhine and Meuse river basin as well. This is done to determine the importance including the wider regional context when assessing the impacts of water scarcity from climate change.

Although water is used for many different economic activities in the Rhine and Meuse river basin countries from drinking water to cooling towers in the energy industry, in this paper we focus on water use in agriculture. We do this for a variety of reasons, the first is that we are examining the effect of changes in water quantity not quality, and agriculture uses the largest share of the fresh water resources compared with other economic sectors like transport or energy which use water but return the same quantity to the system. Second, agriculture is also considered a low value economic sector as opposed to the other economic uses of water, i.e. the returns per liter of water used is lower than for other uses, and it can be assumed that in times of water scarcity other sectors will have priority for the available water and so any scarcity will be felt entirely by the agriculture sectors. This assumption that the effects of water scarcity exclusively affect agriculture is in keeping with the majority of CGE models that examine water scarcity (see for example (Calzadilla, Rehdanz, and Tol 2010). These assumptions are also supported by the priority use list for water use in the Netherlands (Verdringingsreeks), (ARCADIS 2012).

The remainder of the paper is structured as follows, section two reviews the relevant literature regarding general equilibrium analysis of water scarcity, section three provides an overview of the GTAP-W model and the data used in this study, section four describes the specific water scarcity scenarios examined in this paper, section five presents the results and section six provides the discussion and conclusion.

2. Literature review

There has already been much work done in applying economic principles to assess the importance of irrigation water to the economy. Traditionally questions of water distribution for economic use have been the realm of engineering models. More recently hydro-economic models which include economic principles, in the form of water demand functions, in water distribution models have been used to optimize the allocation of existing water resources. See (Harou et al. 2009) for a conceptual overview of these hydro-economic models. These models however, lack the larger economic feedbacks from agents outside the river basin.

In the past two decades computable general equilibrium (CGE) models have seen increasing wider use in the economic assessment of water allocation and policy. In their introduction article to a special issue on integrated hydro-economic modeling, Brower and Hofkes include CGE modeling as an important alternative modeling framework to assess the economic efficiency of water allocation among users alongside more traditional holistic and modular hydro-economic models (Brouwer and Hofkes 2008). The authors consider CGE models of water allocation unique among hydro-economic models in that they start from the perspective of the economic system and inherently include the economic feedbacks.

The use of Computable General Equilibrium (CGE) models to examine water policy dates back at least to (Berck, Robinson, and Goldman 1990) who examined the economic costs resulting from transferring water from agricultural to recreational use in California. Berck and co authors only include water as an economic input into agriculture and so the transfer of water to recreation takes water out of productive use and benefits to recreation are not measured. Most other CGE models of agricultural water use examine a similar principle i.e. the economic costs and benefits of transferring water away agriculture to other uses. (Seung et al. 2000) examines a similar situation of transferring water from agricultural to recreational use, however Seung and co-authors include a recreational demand model in their analysis to capture the benefits of increased tourism resulting from the transfer. (Goodman 2000) uses a dynamic CGE to model a situation where urban water users are able to purchase water from rural users during dry years.

The above papers have focused on alternative uses, or reductions in use, of a single water source within a single region. Later papers have added increasing levels of water heterogeneity in their models. (Diao, Roe, and Doukkali 2005) have modeled multiple water sources within Morocco. Each water source was however restricted to serving their local area and water trading between regions was not allowed. (Gomez, Tirado, and Rey-Maquieira 2004) examined the benefits of adding water desalinization plants to supplement ground water extraction on Balearic Islands where both agriculture and tourism compete for water; and (Diao et al. 2008) modeled the Moroccan economy where a distinction was made between ground and surface water.

Water use in agriculture is the focus of the above mentioned models and indeed the majority of CGE models of water use. For overviews of CGE models of water use see (Ponce, Bosello, and Giupponi 2012), and see (Dudu and Chumi 2008) for an overview of the general and partial equilibrium models that have explicit water use in agriculture and see (Johansson et al. 2002) for a review of economic models of irrigation water in general. See (Dixon 1990) and (Horridge, Dixon, and Rimmer 1993) for some notable exceptions to the above trend that focus municipal water use in a general equilibrium context.

All of the above mentioned CGE models are national in scope and do not include water use outside of the national boundaries in their analysis; recently however there have also been efforts to examine the economy’s dependence on water in an international context. This has been done by integrating water resources into the GTAP model, which is a global CGE with a focus on world trade, (see (Hertel 1999) for a complete description of the GTAP model). The first to do this was Berrittella and co-authors (Berrittella et al. 2007) who examined the global response to a restricted water supply, Berrittella and co-authors model water as a produced good and make a distinction between the agricultural and non-agricultural sectors. Calzadilla and co-authors used a different version of the same model, but this time with water modeled as an endowment restricted to agriculture, to similarly examine the global response to less water (Calzadilla, Rehdanz, and Tol 2010) and more water available for irrigation (Calzadilla, Rehdanz, and Tol 2011b). This paper builds on their work.

3. Methods and Data

The model

The GTAP-W model was first introduced in (Calzadilla, Rehdanz, and Tol 2010) and is an extension of the GTAP model (Hertel 1999) which is a static computable general equilibrium model of the world economy with a focus on global trade. In particular GTAP-W extends GTAP version 6 which uses the year 2001 as its benchmark data (Dimaranan 2006) . GTAP-W extends the GTAP model by splitting the value added input “Land” into several production factors relevant to agriculture; pasture land, rainfed land, irrigated land and irrigation water. Pasture land is exclusively used by the animals sector, which is included in the Rest of the Economy in the aggregation used in this paper.

In GTAP the production function is modeled using a nested Constant Elasticity of Substitution function (CES). Irrigable land and irrigation water are combined on the lowest level of the CES nest using a separate elasticity of substitution, see (Calzadilla, Rehdanz, and Tol 2011a). The appendix to this paper provides a brief discussion of the derivation of the substitution elasticity between land and water for the Rhine and Meuse river basin countries. The specific form of the CES function determining the production structure for GTAP-W is shown in equation 3.

EQ 3 Sector Output =

$$((((\alpha_{IL} IL^{\rho LW} + \alpha_W W^{\rho LW})^{1/\rho LW})^{\rho VA} + \sum_{VA-\{IR,W\}} \alpha_{VA} VA^{\rho VA})^{1/\rho VA})^{\rho Int} + \sum_{Int} \alpha_{Int} Int^{\rho Int})^{1/\rho Int}$$

In equation 3 the α coefficients are parameters of technical change and represent the importance of the different inputs in the production function. Further equation 3 shows that irrigation water W can only be directly exchanged for irrigated land IL with a particular elasticity of substitution σ_{LW} where $\sigma_{LW} = \frac{1}{1-\rho LW}$. The irrigated land and irrigation water combination is then combined with the remaining elements of value added VA, rainfed land, pasture land, labor, capital-energy composite and natural resources.

The optimal mix of value added is then combined in the value added nest and the combination of value added is further combined with intermediate inputs Int. In GTAP-W σ_{Int} the elasticity of substitution within intermediate inputs and between intermediate inputs and value added is zero (Leontief production technology), so no substitution is permitted. See (Gohin and Hertel 2001) for a discussion of the CES function and its implementation in the GTAP model.

Next to the production function itself another attribute characterizes water in GTAP-W. It is the partially mobile nature of the endowment. While some endowments in GTAP-W have a common price between all sectors (perfectly mobile endowments), such as labor and capital water in the GTAP-W model is a partially mobile endowment i.e. it can move between sectors but with an additional penalty. All endowments are immobile between regions in GTAP-W, any endowment in a particular region in the initial equilibrium must also be in that region in the final equilibrium.

The GTAP database, as in all other CGE models, is in the form of a social accounting matrix (SAM), which contains information on payments made between economic sectors, regional governments (national in our case) and households within a single year. The regional households own the factors of production and rent them out to domestic firms. The regional household spends all of the rewards of the factors on private consumption, government consumption and savings for future consumption. The domestic firms use the factors purchased from the regional household and combine them with intermediate inputs purchased from other firms to create a product which is then sold to firms, to the private household and the government for consumption or as exports. As static computable general equilibrium models do not explicitly model future consumption, all demand for future consumption is incorporated into savings. The SAM is said to be balanced when payments plus investment minus savings are equal to the receipts.

The modeling construction of the regional household in each country as the point from where all consumption (both private and government) is allocated and where all payments for endowment factors are collected allows GTAP to institute national measure of welfare. The welfare changes for any country can be assessed by the equivalent variation, a money metric, to determine what the region as a whole would be willing to pay to avoid the change to the new equilibrium.

The GTAP 6 data base describes the world economy in 2001 and contains 87 regions and 57 sectors. Our focus is on the Rhine and Meuse river basin countries so we used the GTAP 6 Data Base GTAPAgg software package (GTAP 2012) , a GTAP supplied aggregation program, to combine the original regions and sectors into 6 regions and 7 sectors. Table 1 gives the distinction between regions, sectors and endowments used in this study.

INSERT TABLE 1 HERE

DATA

In the Netherlands, about 90 percent of the agricultural land is used for arable farming and 10 percent for open-air horticulture. Although the area of arable land has decreased over time, these shares have stayed more or less the same over the past decade since 2000 (Statistics Netherlands and LEI 2011). Cereals are the most important crop, grown on approximately 35 percent of the agricultural land, of which 60 percent is wheat. This is followed by green fodder (33 percent of all crop land) and potatoes (28 percent of all cropland), and sugar beets (18 percent of all cropland). Fruit and vegetables are grown on about 12 percent of all agricultural land in the Netherlands. The share of oil seeds is relatively low, i.e. less than 1 percent of all cropland (LEI 2012). Hence, other agricultural activities in Table 1 consist primarily of potatoes and green fodder.

The original GTAP endowments that remained after the aggregation and re-organization were labor, land, human made capital and natural resources (used only in the energy industries, which are aggregated into the nonagricultural sectors). Following (Calzadilla, Rehdanz, and Tol 2011b) and (Calzadilla, Rehdanz, and Tol 2011a) we used the IFPRI IMPACT database (IFPRI 2010) on world crop yields from 2000 to split the value of the original land factor used in agriculture into irrigated land, rainfed land and irrigation water. The IMPACT database and model are fully described in (Rosegrant, Cai, and Cline 2002).

The value of irrigation water in the GTAP-W model is calculated using the difference in yield between rainfed and irrigated land. Irrigation water is then a composite for everything involved in creating additional yields in irrigated land as compared to rainfed land. The value attributed to irrigation water defined in this way is then not simply the water itself but everything involved in irrigation, including equipment.

As shown in Table 1, the agricultural sector in the GTAP-W aggregation used in this study consists of 6 main activities. In the Netherlands the most important agricultural activity in output value terms is other agriculture (which includes mainly potatoes), followed by vegetables and fruits. The other activities are comparatively much smaller. Hence, any analysis of the effects of water scarcity on agriculture as a whole in the Netherlands will most likely be driven by the vegetables and fruits and the other agriculture activities. Figure 1 shows the output value in 2001 U.S. dollars of the agricultural activities included in the model in the Netherlands.

INSERT FIGURE 1 HERE

To help determine the extent to which market forces, as opposed to the direct crop growth response, contribute to the overall economic response to irrigation water scarcity it is instructive to note which agricultural activities use the most water relative to other inputs. An assessment of the direct crop response to water scarcity would assume that the activities or crops that use relatively more water compared to other inputs would have a larger loss in output than an activity which is less dependent on water. Figure 2 shows the percentage of irrigation water that a cropping activity uses relative to other input endowments (irrigable land, rainfed land, labor and capital). The shares are based on the relative value added of water in U.S. dollars compared to the total value added of all input factor endowments taken together. The value added of water is estimated as explained above.

INSERT FIGURE 2 HERE

Figure 2 shows that the wheat, sugar beets and other agriculture activities, use the most irrigation water relative to the other value added inputs, followed by vegetables and fruits, with cereal crops and oil seeds using the least irrigation water. If the crop response to water scarcity was purely based on the lack of irrigation water, then the damage to output should follow the order displayed in Figure 2, i.e. with highest losses in wheat, sugar beets and other agriculture activities.

The Netherlands has a different share of agricultural endowments than its neighbors in the river basin as shown in Figure 3. Agriculture in the Netherlands is much more dependent on irrigable land and irrigation water then the other regions in the basin, which have a much larger share of rainfed land. This large difference in the share of irrigated agricultural endowments to agricultural endowments creates the expectation that the Netherlands will be affected differently than its neighbors by the same water scarcity conditions.

INSERT FIGURE 3 HERE

4. Future climate change drought scenarios

For the climate change scenarios and their effect on the fresh water resources for the regions in the Rhine-Meuse river basin we relied on the existing studies from the Dutch Delta program on the impacts of the Dutch national climate change scenarios (Klijn, ter Maat, and van Velzen 2011)**.** . These scenarios are based on the same source material as the existing IPPC climate change scenarios, which describe average changes in the rainfall patterns, temperature, and water in and outflows. Of particular interest is the W+ scenario which predicts an average global temperature increase of 4 degrees by 2050, an average summer temperature increase as well as an average rainfall decrease in the summer (Van Den Hurk et al. 2006). For both the climate change scenarios and the current climate, the Delta program studies characterize the water supply for an average, dry and extremely dry year. For each of these benchmark years the direct effects of water scarcity are described for several water dependent industries. The studies chose the climate of 1967 as a benchmark average year which has a 50 percent chance of occurring and chose the climate of 1976 as an extremely dry year where the water inflow from rivers was reduced by 37 percent and the rainfall deficit more than doubled compared to the benchmark year. An extremely dry year has approximately a 1 percent chance of occurring.

The Delta program studies used a combination of existing hydrological and crop growth models to determine the direct damage costs to agriculture if the climate conditions that occurred in the benchmark year and in the extremely dry year were to occur today, affecting the present day agricultural sector. The damage estimates are calculated as the difference between crop growth under optimal conditions and crop growth under the modeled climate conditions given the current irrigation infrastructure. Modeled in this way, there is also a significant damage to agriculture from the climate in the benchmark year with respect to the optimal growth conditions.

In our study we used the extremely dry scenario from Klijn and co-authors and used their results on the reduction in direct agricultural output in the Netherlands from as a consequence of lack of irrigation water and rainfall. The additional direct damage from the climate of the extremely dry scenario (the climate of 1976), as compared to the climate of the average scenario (the climate of

1967), amounts to 19 percent of total agricultural output in the Netherlands or approximately \$1.6 billion. From Klijn and co-authors it is also established that the inflow from the Rhine is 37 percent less in an extremely dry year than in an average year.

To implement the climate conditions of the extremely dry scenario in GTAP-W we assumed that agriculture would suffer all the effects of water scarcity from the reduced water inflow and that all other water demanding activities from shipping to nature conservation would be their usual quantities of water. Further we assumed that a reduction in rainfall would affect the productivity of both irrigable and rainfed land, in line with for example (Calzadilla et al. 2010)

To implement the climate conditions of the extremely dry scenario in GTAP-W reduced the irrigation water endowment in the Netherlands by 37 percent and further reduced the productivity of rainfed and irrigation land by 25.3 percent so that the agricultural output of the Netherlands was reduced by 19 percent. As we did not have sufficient information on the loss of land productivity as a result of the extremely dry scenario we calibrated the losses of land productivity by using the estimates of direct damage in the Netherlands from Klijn and co authors to achieve the 25.3 percent reduction. We then imposed the same irrigation water and agricultural land productivity shocks on the neighboring countries in the river basin as well, as we do not have similar studies on the direct losses to the Germany, France, Belgium and Luxemburg as a result of the 1976 climate on the current economic conditions land productivity losses for these countries separately. However, assuming that these countries face the same climate conditions and share the same river basin it can be assumed that they face the same loss irrigation water and land productivity.

To examine the scale of the general equilibrium effects as compared to the direct effects of water scarcity we make a distinction between two scenarios. First we implement water scarcity in the Netherlands is the only, and second we implement water scarcity in all countries within the Rhine-Meuse river basin, the Netherlands, Germany, France and Belgium-Luxemburg. As by nature any direct assessment of the damage to agriculture assumes that other countries affected by water scarcity have a negligible effect on the economy of the country being studied, our approach of examining these scenarios separately gives insight into the consequences of this assumption. This will also help to determine the extent to which the economic impact of water scarcity in the Netherlands depends on the water scarcity conditions facing the other countries sharing the same river basin.

Implementing the additional water scarcity conditions on the neighboring countries also allows for a comparison of the shadow price of water across different countries; a large difference in the shadow price of water would indicate that allowing countries to purchase the right to use more irrigation water from each other would reduce the impact of the drought.

Although the scale of the loss of irrigation water and land productivity for an extremely dry year are quite dramatic, this situation occurred in 1976 while in subsequent years the rainfall and water inflows returned to normal. In the scenarios used in this paper we are not examining the effect of a one-off event but the effect of a several year period of water scarcity, which takes place within the frame-work of a climate changing in the direction of hotter and drier summers. Furthermore in this study we are using 2001 economic data. Therefore, the goal is not to make a prediction about the economy of some future date, but rather to explore the response to water scarcity by the economy as a whole, and to determine the importance of that response in diagnosing the overall effect on agriculture and also those aspects of the economy that are outside of the local agriculture that is directly affected by water scarcity. In keeping with a period of increased water scarcity of several years, the labor and capital endowments are classified as perfectly mobile between all sectors, but immobile between regions. Irrigable land, rainfed land, pasture land and water are all classified as imperfectly mobile with the same elasticity of transformation. All endowments levels in the scenarios are fixed, i.e. new sources of labor, capital or water are not introduced and there are no possibilities for rainfed land to become irrigated land or pasture land. These restrictions are consistent with a drought length of approximately 2 to 5 years.

5. Results and Analysis

The results showed that Dutch agricultural producers will have their losses partially, although quite significantly compensated by rising prices for their products, and that these price rise even further when the other regions in the Rhine-Meuse river basin are affected as well. Figure 4 shows the importance of the larger economic feedbacks on Dutch agriculture as a whole. The left column is the direct effect of the extremely dry climate on Dutch agriculture, a loss of $1582 million U.S. a loss of 19 percent of agricultural production. Rising prices for Dutch agricultural products partially compensate producers such that total loss of value from the sale of their products is now $1179 million U.S. which is $400 million less than the damage estimate without taking the general equilibrium effects into account. The economic feedbacks have an even larger effect on the market faced by Dutch agricultural producers if the water scarcity conditions affect the other in the river basin countries as well, as even more supply is removed from the market and other consumers and firms have less possibilities of substituting Dutch products for products made elsewhere. The rightmost column in figure 4 shows that the value losses to Dutch agriculture will be $889 million about 10.7 percent of original value, when all regions in the river basin are affected by scarcity and accounting for price rises. This is nearly half of the damage estimate when only direct damages to Dutch agriculture are accounted for assuming to general equilibrium effects.

INSERT FIGURE 4 HERE

Changes to agricultural production shown in figure 4 also has an effect on the non-agricultural sectors of the Dutch economy, even though in this model there is no explicit dependence on water for any non-agricultural sector. As the agricultural sector shrinks in output it uses less capital and labor, reducing the price of these value-added inputs for the non-agricultural sectors. However, the non-agricultural sectors are also paying higher prices for the agricultural products used as intermediate inputs, and consumers spending more on food have less to spend on other products, which reduces demand and thus prices for the non-agricultural products. Figure 5 shows the impact on the total sector output in the Netherlands from the extremely dry climate. In figure 5 all but the right most column show that the total loss of Dutch economic output at either original prices or final prices is less than the agricultural losses for both the situation where the Netherlands is the only country affected by water scarcity and when all countries in the basin are affected. This shows that while the situation in the new equilibrium is a loss for total economic output in the Netherlands, it is a gain for the non-agricultural sectors. It is only the right most column where water scarcity affects all regions in the river basin and changing prices are taken into account where there is a loss of value for the non-agricultural sectors as well.

Notice in figure 4 that as one moves from left to right in the figure (one allows for more economic feedbacks in the analysis) the situation improves for the agricultural sectors, as other regions are effects by water scarcity higher demand for Dutch agricultural products contributes to rising prices. However, in figure 5 the situation is reversed, a loss of agricultural production in the whole region decreases available incomes, which depresses demand and prices for Dutch products. So as the agricultural producers do better when the effects of water scarcity increase in scope, it is the rest of the economy however that absorbs the impact. Finally note that agricultural output is only 1 percent of total economic output in the Netherlands, and while the economic impact of water scarcity has a real effect on the non-agricultural sectors in the Netherlands as shown in Figure 5, these changes are very small when compared with the total economic output of the Netherlands.

INSERT FIGURE 5 HERE

Although the same water scarcity conditions are implemented in all four regions of the Rhine Meuse river basin, the impact on agriculture differs between regions. Figure 6 gives the losses to agriculture for all regions in the river basin in both output (value at original prices) and value (output at final prices) terms. Figure 3 in section 2 gives an explanation for the different direct effects between regions, namely that the Netherlands has a much higher dependence on irrigated agriculture then it neighbors, and the specific water scarcity conditions implemented in the extremely dry scenario, 37 percent loss of irrigation water and 25.3 percent productivity loss for both rain fed and irrigated land, effect irrigated agriculture to a higher degree than rain fed agriculture. As the scale of the drought was calibrated for the Netherlands only in this study it is difficult to judge the accuracy of the scale of the impact on agriculture for the other regions in the river basin. However, it is important to note that the losses to agricultural output are less in, Germany, France and Belgium-Luxemburg than in the Netherlands, if the damage to agriculture were at a similar level to that of the Netherlands than then prices increase for Dutch agriculture would be even higher as more product is removed from the market.

INSERT FIGURE 6 HERE

Figure 7 shows the percent change in agricultural output and value in the Netherlands per cropping activity as a response to the imposed water scarcity shock in the Netherlands only. As described in Section 3, the scale of the shock was calibrated such that the total reduction agricultural output would be 19 percent. Figure 7 shows that in the new equilibrium, agricultural activities react differently to the same water shock. Wheat and the other agriculture activities have the highest percent loss of output while cereal crops, oilseeds and sugar beet have output losses of well below 19 percent.

INSERT FIGURE 7 HERE

Figure 7 demonstrates that changing (rising) prices partially compensate agricultural producers for a reduction in their output. We see that for all activities the relative loss in value is less than the loss in output. The general trend in figure 7 shows that the loss in value follows the loss in output with the highest percent loss in value felt by the producers of wheat and other agriculture, followed by vegetable and fruits. Some results however are surprising at first glance. Sugar beets actually increase in value, so the rise in prices more than offsets the loss in production, while the oil seeds producers have a larger percent loss in value than the producers of cereal crops even though cereal crops have a larger percent loss in output.

Comparing Figures 2 and **7** we see the importance of the demand component in the economic response to water scarcity. Figure 2 shows that in the simplified representation of agriculture in the GTAP-W model several crops use the same percentage of irrigation water as compared to other inputs. Similarly the parameter which governs the ability of a crop sector to substitute land for water is the same for all crops in the Netherlands, as is the ability to substitute between irrigated land (the land water combination) and other value added inputs. Consequently if only the supply mechanisms were taken into account in assessing the different crop activity response to water scarcity one would expect that the change in output would be the same for all crops with the same dependence on water. Figure 7 shows that this is not necessarily the case; while wheat and other agriculture have a similar drop in output, sugar beets have only a marginal decline. Similarly the percent decline in cereal crops is nearly double that of oil seeds even though they are identical in their dependence in water, so demand considerations must be influencing the different crop responses to the drought.

Figures 7, shows that the sugar beet sector is the only agricultural sector positively affected by the water shock. The reason behind the positive results for the sugar beets is that almost all of the sugar beet consumption in the Netherlands is domestically produced, whereas the consumption of the other cropping activities are a mix of domestically produced goods and foreign imports. GTAP-W uses the Armington assumption to regulate the ability to switch between domestic and foreign goods, and so the ability to switch from domestic to foreign consumption, while feasible, not unlimited. In percentage terms Dutch imports of sugar beets rise dramatically (20%) relative to the rise in imports of all of the other crops (all of which rise less than 3%). However in the initial equilibrium imports of sugar beets into the Netherlands were so small that even a very large percentage increase in imports results in only a slight physical increase, most of Dutch consumption of sugar beets therefore must rely on domestic supply, the supply shock then results in a large increase in price. In contrast to sugar beets, oil seeds are compensated for its loss of output only slightly by rising prices. This can be explained by the fact that oil seeds production in the Netherlands is very small and a reduction in output of Dutch oil seeds would therefore not translate into a large increase in price.

Figure 8 shows the percentage changes in output and value in the agricultural activities of the Netherlands as a result of the water quantity and crop land productivity shocks in all regions of the Rhine-Meuse river basin. Comparing Figure 8 with Figure 7 we see that all crop activities fare better when drought affects the neighboring countries than in the scenario where only the Netherlands is affected by drought. The largest change is in the Cereal Crops sector which gains almost 6 percent in value terms as a result of the shock, this is a very large improvement compared to the scenario where only the Netherlands is affected by water scarcity where Cereal

Crops lost 2 percent of its value. The wheat sector also gains disproportionately when all four regions are affected by drought as compared to the scenario where the Netherlands is the only country affected. In Figure 7 we see that wheat, together with other agriculture, has the largest losses; however when other regions are affected as well we see that the wheat sector is relatively better off than the vegetables and fruits sector, and the value losses of wheat are only a third of value losses to other agriculture. Comparing Figure 8 and 7 with figure 2 we see that Figure 2 is an even worse predictor of the sector outcome as a response to the water scarcity conditions when all regions are affected than when the Netherlands only is affected. The economic feedbacks have a much larger impact on the final equilibrium in the latter case.

INSERT FIGURE 8 HERE

The agricultural producers have a limited ability to substitute between valued added inputs as a response to a reduction in irrigation water. Figure 9 shows the change in the mix of value added inputs used by the agricultural producers in the Netherlands as a response to water scarcity affecting all regions in the river basin. Figure 9 shows that the reaction to the water scarcity shock is not shared equally among cropping activities. Examining Figure 9 in light of Figure 8 we see that the activities with the greatest reduction in output have the greatest reduction in water use and the activities with the least reduction in output have the least reduction in water use. However the reduction in water use is much more similar between activities than the reduction in output from Figure 8. Figure 9 shows that other value added inputs, such as irrigable land make up for that difference.

INSERT FIGURE 9 HERE

Sugar beets has the least drop in output, has the highest percent increase in irrigated land and is also the only activity to have an increase in its use of labor and capital.
Labor and capital are assumed to be perfectly mobile between all sectors in the Dutch economy and so the agricultural activities have to compete with the other sectors in the economy for labor and capital. As a result every Dutch agricultural activity that reduces its output as a response to the shock also uses less labor and capital, with the exception of sugar beets. In contrast, the other value added inputs are only shared within the agricultural sectors. So, for example, an increase in irrigated land by one agricultural activity implies a decrease in the use of irrigated land in another. Rainfed land is reallocated across three agricultural activities. Its use is reduced by the vegetables and fruits producers and its use is increased by the producers, cereal crops and oilseeds.

As mentioned in section 3, the total quantity of the available endowments is fixed in this scenario, with the exception of irrigation water which is reduced by 37 percent. Therefore the price of the endowment is the only response variable to the change in endowment demand. The relative shadow price of irrigation water increases enormously in the Netherlands by 412 percent of its pre-shock price level. The rental price of irrigable land rises by 13 percent and the rent of rainfed land rises as well by 90 percent. The price of labor and capital also decline but only marginally by 0.33 percent and 0.26 percent respectively.

The large rise in the rental price of rainfed land is initially counterintuitive due to the fact that its productive capacity is decreased due to the climate conditions of the extremely dry scenario. This can be explained from the fact that a reduction in the productive capacity of rainfed land means that more land is necessary to produce the same yields, demand for agricultural products remains high, as evidenced by rising prices for agricultural products, however more land is needed to produce the same yields, as the supply of land remains the same the rent rises as a response to the increased demand. The same phenomenon happens to irrigated land, however irrigated land must be combined with irrigation water in the production process, less water available implies that there is less irrigation land necessary for production, this trend partially balances out the need for more irrigation land as it is less productive. This results in only a relatively modest increase in the rantal price of irrigated land compared with rainfed land.

Figure 10 below shows the percent change in the shadow price of water for all four regions in the basin as a result of the shock.

INSERT FIGURE 10 HERE

From Figure 10 we see that the change in the shadow price of water in the Netherlands is the lowest of all four regions, even though from Figure 6 we see that it has by far the largest percentage reduction in agricultural output as a result of the shock. This raises the counterintuitive notion that even though the Netherlands suffers the largest percentage loss to its irrigation water using activities as a result of the shock, implementation of a water trading scheme would result in the Netherlands selling water to its neighbors. An explanation for figure

10 can be found in the ratio of irrigation water to irrigable land in the four regions that share the river basin. The Netherlands has the highest ratio, i.e. the most units of irrigation water per unit of irrigated land, followed by France, then Germany and finally Belgium-Luxemburg. Therefore even though irrigated agriculture is only a small share of total agriculture in the other regions in the river basin, the producers of irrigated agriculture place a higher value on water at the margins than producers of irrigated agriculture in the Netherlands.

Welfare falls for all regions in the river basin as a result of the shock and household income shrinks for all regions as well. Household income shrinks the most in the Netherlands .19 percent followed by .13 percent in Germany and .1 percent in Belgium-Luxemburg and France. Consumers are also directly affected by the change in the prices that they face for agricultural goods at the market. In the Netherlands the price of cereal crops rises 10.5 percent, while the price of vegetables and fruits rise 8.8 percent and wheat rises, 8.5 percent. Consumers in the other regions in the river basin face similar price rises for agricultural products.

6. Discussion, Conclusions and Summary

In this article we have used GTAP-W a computable general equilibrium model to examine the importance of economic feedbacks in assessing the impact of a structural water scarcity brought on by a changing climate. By comparing our results to (Klijn, ter Maat, and van Velzen 2011), a study that calculated the impact of the 1976 drought conditions on Dutch agriculture using hydrological and crop growth models with no economic feedbacks, we were able to gain insight into the added value of including these economic feedbacks in an assessment of the damage to

Dutch agriculture and the economy as a whole. Recognizing that changes in hydrology and rainfall patterns do not respect international borders we examined how the results would change when agriculture in neighboring regions sharing the same river basin were also affected by water scarcity and drought. As we did not have results from hydrological and crop growth models on how the 1976 drought conditions would affect the other regions sharing the Rhine Meuse river basin, Germany, France and Belgium-Luxemburg, these results should not be seen as a prediction of the economic consequences of the 1976 climate conditions effecting the current economy Rhine and Meuse river basin region but should rather be seen as an exploration of how an economic damage assessment of climate change in one country depends on what happens outside its borders.

Our results show the importance of incorporating price changes in agricultural products when assessing the impact of climate change on agriculture. A 19 percent loss of output at pre shock prices becomes a 14 percent loss of value when price changes are taken into account; this becomes 11 percent if it is assumed that neighboring regions are affected by the drought as well.

Examining the impact of the shock on individual agricultural activities when drought affects all regions in the Rhine-Meuse river basin shows that the economic impact of water scarcity varies widely per activity, with other agriculture and vegetables and fruits as the two largest losers from this shock, while sugar beets and cereal crops actually gaining in value terms as a result of water scarcity. These sector results show a different picture than when water scarcity affects the Netherlands only, which further emphasizes the importance of including the larger economic feedbacks in the analysis. GTAP-W has a very simplified model of crop production and thus most of the differences in crop response to the drought can be attributed to the economic feedbacks rather than differences in production conditions.

The results of this analysis also suggest opportunities for inter-regional cooperation on water sharing during times of scarcity. Figure 10 shows that the change in the shadow price of irrigation water in the Netherlands will be much lower than in the other countries in the basin. This indicates that even though Dutch agriculture as a whole was worse off from the shock than the other regions in the basin (see Figure 6) the agricultural producers in the neighboring countries in the basin using irrigated agriculture have a greater need for water, even though they make up a smaller percentage of the total agricultural production in their region.

It is important to note that in this study we assumed that the direct loss to Dutch agriculture from irrigation water scarcity was 19 percent of total production. However in a general equilibrium model the output losses are determined by a process that already includes the economic feedbacks (agricultural activities and other sector change their input mix, consumers change their consumption bundle etc…), this can be seen in Figure 6 where the shocks were calibrated such that the total loss to Dutch agricultural output was 19 percent when the Netherlands was the only country affected, but when the neighboring countries in the river basin were shocked as well the output loss of agriculture in the Netherlands dipped to 17 percent. An ideal approach would be to translate the hydrological and land productivity changes from the crop growth models directly to the shocks in the CGE model; however the simplified production structure of GTAP-W and indeed all CGE models would make that a very difficult task indeed.

It is also important to note that standard assumption of CGEs in general and GTAP in particular of perfectly mobile capital and labor tend to overestimate the ability of the economy to adapt to the a shock and in this sense the Figure 5 which shows the losses to total economic output might overestimate the gains to the non-agricultural sectors (underestimate the losses to total sector output). Exacerbating that affect, water scarcity from climate change would most likely have an even greater impact than just the river basin, further diminishing supplies and driving up prices. This would further benefit Dutch agriculture, at the expense of the non-agricultural sectors, further contributing to the notion that Figure 5 is an overestimation.

Acknowledgements

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Figure 1: The economic output value of the agricultural activities in the Netherlands included in the GTAP-W model

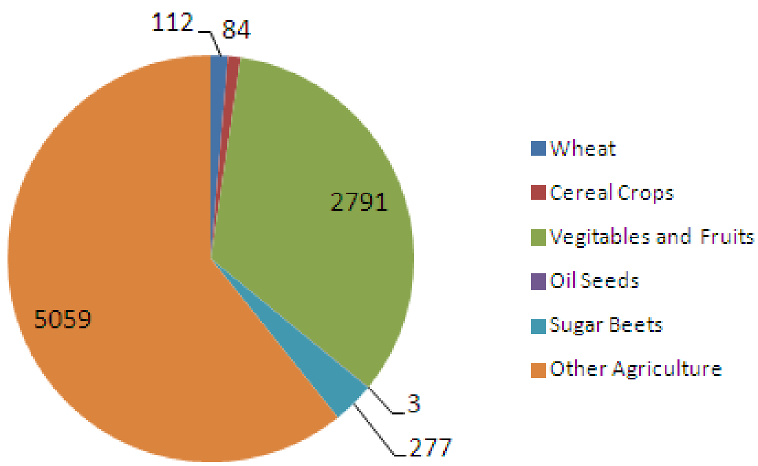

Figure 2: Share of value added of irrigation water compared to the total endowment value for all agricultural activities in the Netherlands

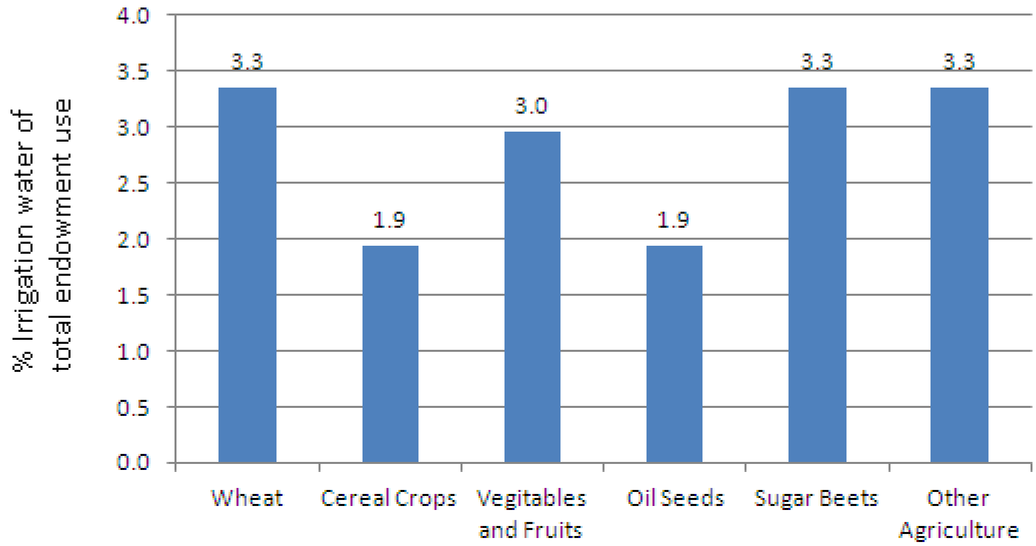

Figure 3: Initial agricultural endowments for the four regions in the Rhine-Meuse river basin, in millions of U.S. dollars

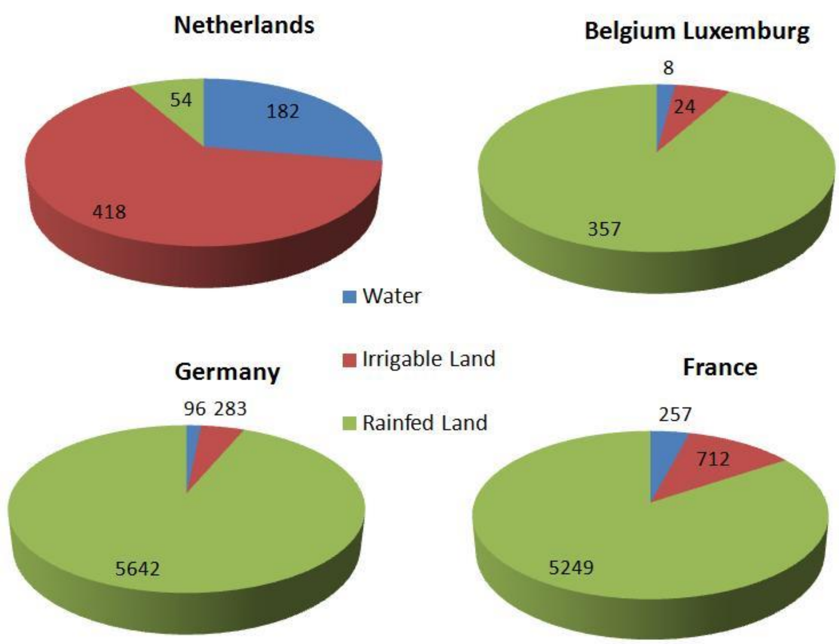

Figure 4: The losses in 2001 U.S. dollars in both original and final prices to Dutch agriculture. The Blue columns correspond to the scenario where only the Netherlands is affected by the extremely dry scenario and the red columns to the scenario where all regions in the Rhine-Meuse river basin are affected. The left most column (-1582 million U.S. dollars) is equal to 19 percent of Dutch agricultural output.

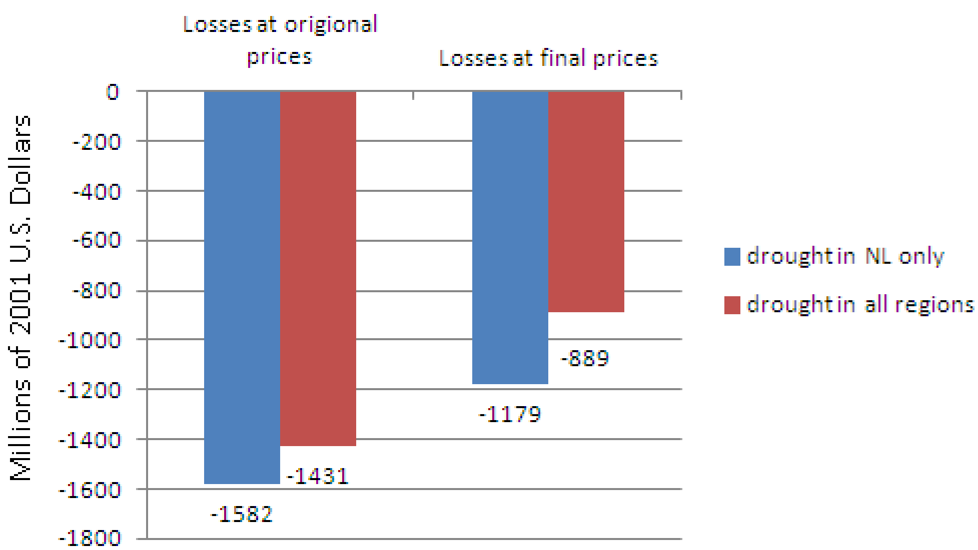

Figure 5: The losses in 2001 U.S. dollars in both original and final prices to total Dutch economic output. The blue columns correspond to the scenario where only the Netherlands is affected by the extremely dry scenario and the red columns to the scenario where all regions in the Rhine-Meuse river basin are affected.

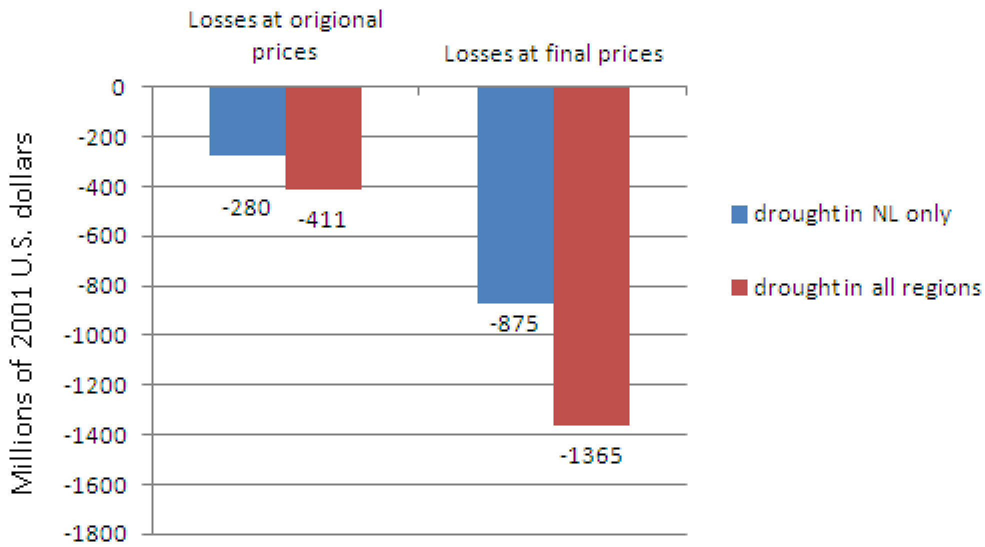

Figure 6: The percent losses in both original and final prices to agriculture for all regions in the river basin, when all regions are affected by the same water scarcity conditions.

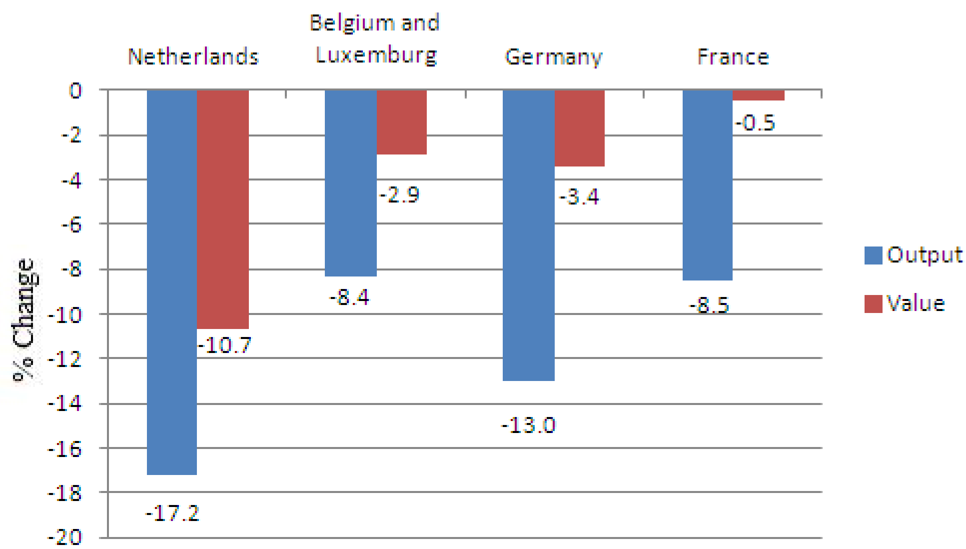

Figure 7: Percent change in agricultural output and value per cropping activity in the Netherlands, when only the Netherlands is affected by the extremely dry scenario.

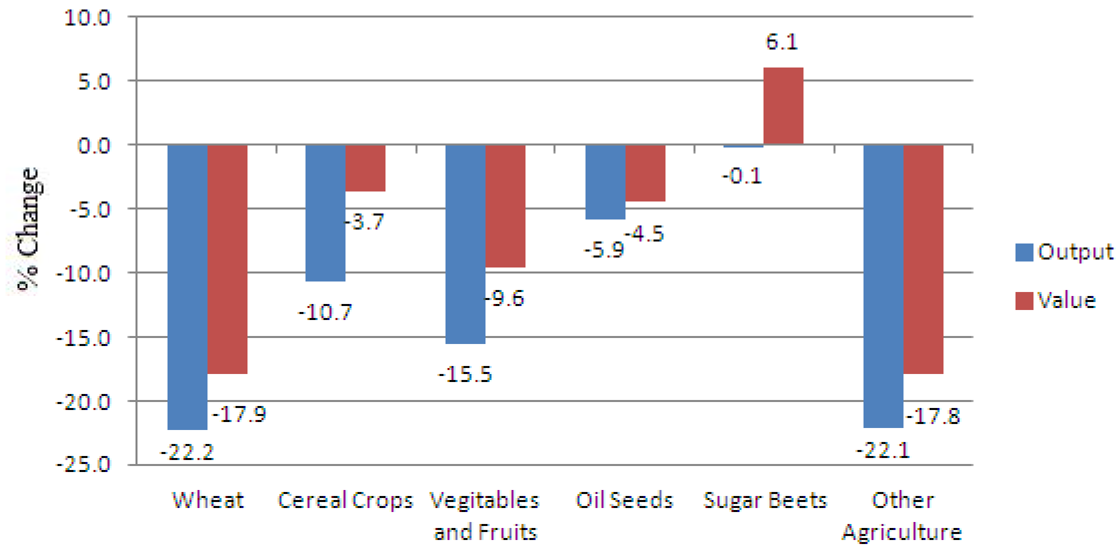

Figure 8: Percent change in agricultural output and value per cropping activity in the Netherlands, when all regions in the river basin are affected by the extremely dry scenario.

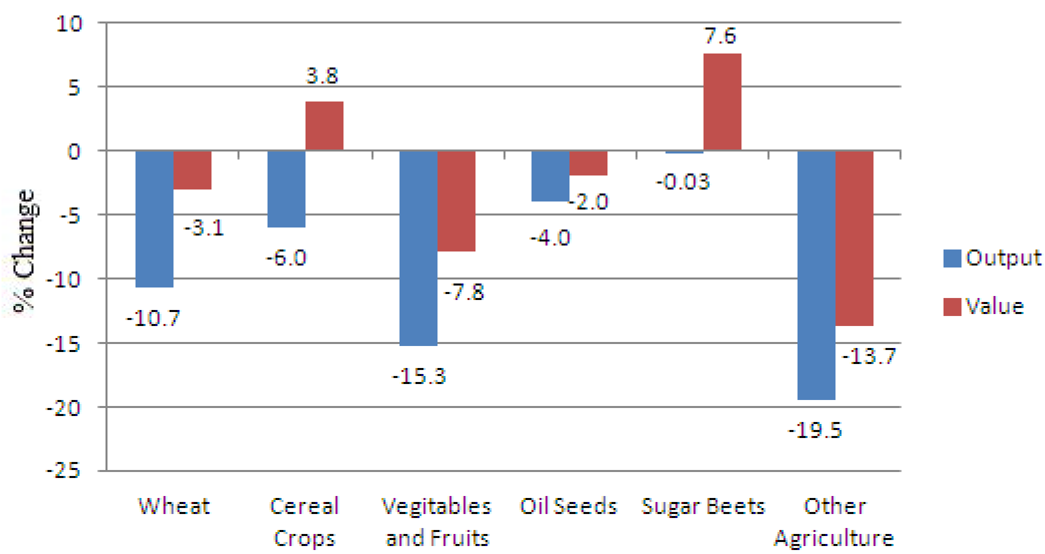

Figure 9: Percent change in value added of inputs per activity in Dutch agriculture due to structural water shortage in for all regions in the river basin.

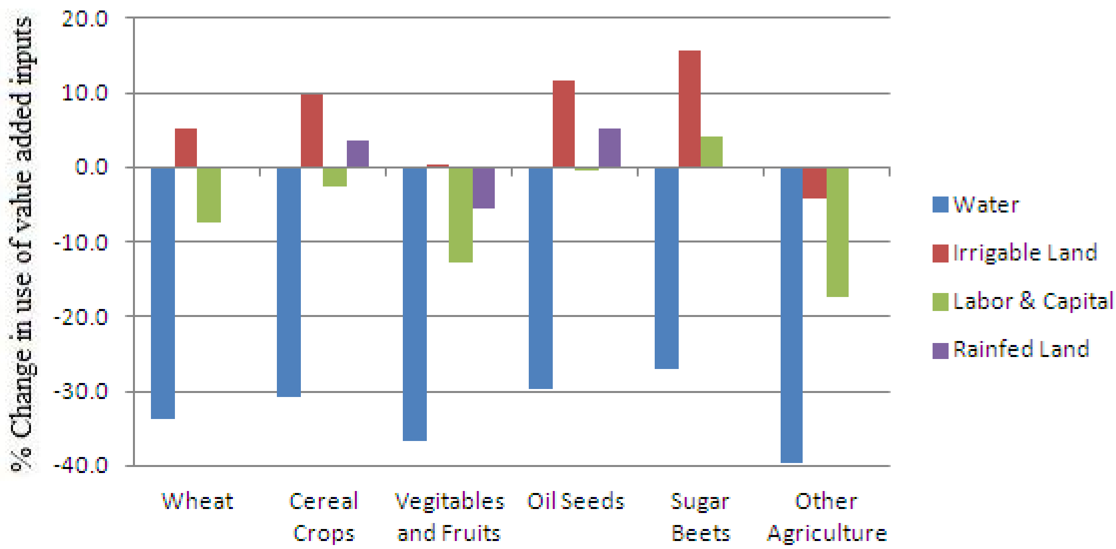

Figure 10: Percent change in the relative shadow price of water in the all four regions of the Rhine-Meuse river basin, when all four regions receive a 37 percent irrigation water shock and a 25.3 percent crop land productivity shock.

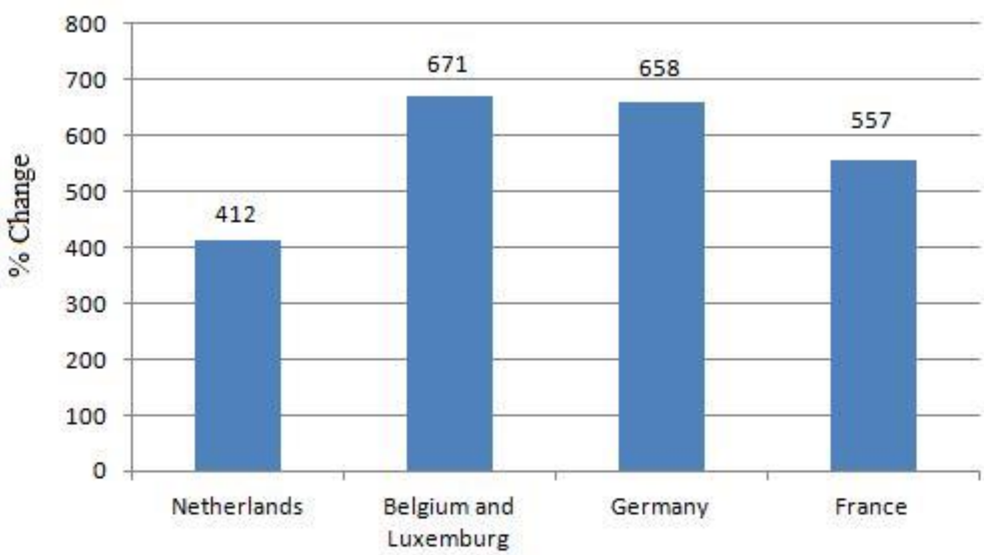

Table 1: Regions, sectors and endowments distinguished in the model. All non-agricultural crop sectors are combined into the Rest of the Economy. The contents of the other agriculture sector differ per country but in the Netherlands (the focus of this document) it is primarily potatoes and green fodder.

Regions Aggregation	**Sectors Aggregation**	**Endowments used in agriculture**
1. Netherlands	1. Wheat	1. Irrigation Water
2. Belgium and Luxemburg	2. Cereal Crops	2. Irrigable Land
3. Germany	3. Vegetables and Fruits	3. Rainfed Land
4. France	4. Oil Seeds	5. Labor
5. Rest of Europe	5. Sugar Beets	6. Capital
6. Rest of the World	6. Other Agriculture	
	7. Rest of the Economy	

Appendix

From Calzadilla et al. (Calzadilla, Rehdanz, and Tol 2011a) we have the formula [1] below for the calculation of the land-water substitution elasticities.

$$\rho = -\frac{\ln(1+\delta)}{\ln(1+\eta\delta)} - 1 \qquad [1]$$

Where:

ρ is the elasticity of substitution between land and water

η is the water price elasticity

δ is a change in the price of water

Then taking the limit $\delta \to 0$ we have [2]

$$\rho = -\frac{(1+\eta)}{\eta} \qquad [2]$$

In their article on world water scarcity (Rosegrant, Cai, and Cline 2002) provided price elasticities for various regions around the world . These regions were then matched to the regions in the GTAP-W version of Calzadilla and co-authors (Calzadilla, Rehdanz, and Tol 2011a), the regions in GTAP-W include Western Europe (WEU) and Central and Eastern Europe (CEE). In our study we use the price water elasticity for Western Europe for calculating the land water substitution elasticities of The Netherlands, Belgium-Luxemburg, Germany and France. To calculate the price water elasticity for the region Rest of Europe we took the average price water elasticity for WEU and CEE regions weighted by the value of irrigable land in those regions (as given in the GTAP-W aggregation of (Calzadilla, Rehdanz, and Tol 2011a)). We used the weighted average, by irrigable land, of all the other regions for our calculation of the land-water substitution elasticity for the Rest of the World region in our model.

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