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Title: The economic impact of irrigation water scarcity from climate change: A CGE analysis distinguishing between surface and ground water

Presenter: Jason F.L. Koopman

Authors: Jason F.L. Koopman[1], Onno Kuik[2], Richard Tol[3,2,4], Marnix van der Vat[5], Joachim Hunink[5], Roy Brouwer[6]

[1] Wageningen Economic Research, Wageningen University and Research, Alexanderveld 5
2585 DB The Hague, The Netherlands

[2] Department of Environmental Economics, Institute for Environmental Studies, VU University Amsterdam, De Boelelaan 1087, 1081HVAmsterdam, The Netherlands

[3] Department of Economics, University of Sussex, Sussex, UK

[4] Department of Spatial Economics, VU University Amsterdam, De Boelelaan 1087,
1081HV Amsterdam, The Netherlands

[5]Deltares, Boussinesqweg 1, 2629 HV Delft, The Netherlands

[6]Department of Economics, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1, Canada

Abstract

Future climate change brings with it many challenges to agriculture. The impact of climate change on agricultural production would in large part depend on the possibility of farmers to adapt by intensifying irrigation and changing cropping patterns. Depending on their location farmers may have access to surface water, ground water or both as their irrigation source. These different irrigation sources have distinctive characteristics for agricultural and non-agricultural uses that water managers need to consider in making allocation decisions while keeping in mind that the ability to increase irrigation in times of water scarcity may determine the success of agricultural adaptation to climate change.

The importance of distinguishing between various type irrigation water sources is illustrated by using the Netherlands as a case study. The majority of irrigation in Northwest-Europe is fully reliant on groundwater which has a limited supply and is slow to recover when depleted. Areas close to rivers, such as the low lying areas of the Netherlands, can however also be supplied by river water allowing for additional adaptation possibilities not enjoyed to the same extent by other countries in the region. Access to river water, mainly from the Rhine, to supplement ground water supplies for irrigation could make the Dutch agricultural producers more successful in adapting to a warmer drier climate and giving The Netherlands a competitive advantage over its neighbors in the region.

To determine the extent of the benefit of increased access to river water in times of water scarcity we employ the multi-regional computable general equilibrium model GTAP-W (Calzadilla et al., 2010), which includes water as an explicit input in agricultural production. The model has been expanded to allow for differentiation between surface and groundwater endowments within individual regions in order to quantify the importance of increased surface water in irrigation as an adaptation response to climate change and to allow for different allocation policies with respect to surface and groundwater endowments. The model has been applied to

analyze the impact of a drier climate on the agricultural sector and the economy as a whole both in The Netherlands and its upstream neighbors in the Rhine and Meuse river basin, Belgium and Germany.

We further examine the benefit of increased water irrigation infrastructure as an additional adaptation response for Dutch agricultural producers and the subsequent effect that the Dutch adaptation response might have on the agricultural markets for the upstream countries Belgium and Germany. The results show that a limited increase in surface water irrigation infrastructure increases the output of all crop sectors including rain fed sectors. However a much larger expansion of irrigated areas increases the demand and price for labor and capital to such an extent that rain fed agricultural sectors decrease as a result. The impacts on the upstream countries are limited but non-negligible.

Section 1: Introduction

Climate change could lead to an increased incidence of hot summers and intensify the reliance on irrigation water for agricultural production. This increased reliance on irrigation as an adaptation mechanism could make additional investments in irrigation infrastructure a very attractive adaptation policy option.

For the growth of the plant it does not matter if the water it receives was first pumped up from the ground, abstracted from a nearby river or falls from the sky, assuming of course similar quality. However from the perspective of farmers and water managers it can matter a great deal as different sources for irrigation water have different costs for abstraction, purification and alternative uses depending on the source. Pumping groundwater generally involves larger energy costs than abstracting surface water, on the other hand fully utilizing surface water resources for irrigation often requires large infrastructure projects such as dams, canals or pipe lines. The location of a farm may make one or both sources of water prohibitively costly and if both sources are not feasible a farm can only rely on rain to fulfil the water needs of the plant.

Climate change brings with it a new set of uncertainties regarding freshwater supplies further stressing the need for flexible management regimes that can at times cope with too much water and alternatively develop a policy infrastructure to allocate water in periods of scarcity.

In times of water scarcity water managers also take into account competing demands for water such as the natural ecosystem needs as well as other economic uses such as industry, energy, transport or municipal water demands. The Netherlands has developed a water needs hierarchy as a guide for water managers in times of scarcity (Ministerie van Verkeer en Waterstaat, 2009). Groundwater and surface water sources each have their own set of hydrological characteristics and alternative uses that are taken into account when deciding what restrictions should be placed on abstraction for irrigation. For example the supply of surface water reacts much more immediately to changes in precipitation, while groundwater reacts more slowly and can be used as a short term drought buffer in times of relative drought. On the other hand the health and stability of the soil in many areas of the Netherlands is critically dependent on the level of groundwater and maintaining current levels of groundwater one of the main priorities of water managers (Ministerie van Verkeer en Waterstaat, 2009).

In The Netherlands sprinkling bans are periodically issued in hot summers, the latest one issued in 2015. These sprinkling bans differ per province and vary with respect to the source of water used (groundwater or surface water), crop type (grass or arable), soil type (sandy or clay) and time period (part of the year and day) (Hellegers and van Ierland, 2003). Sprinkler bans are most frequent on higher sandy soils in the South of the Netherlands. Authorities in this region have also issued restrictions on the use of groundwater for irrigation purposes, for example the prohibition to irrigate meadowland before June and to impose restrictions during the summer (Broers and Griffioen, 2012).

The royal Dutch meteorological institute (KNMI) has sketched four scenarios as a representative sample of the many possible climate futures for the Netherlands (van den Hurk et al., 2006). The W+ scenario predicts increased summer temperatures and reduced summer rainfall. The Netherlands is a delta region and has access to a large supply of fresh water, however maintaining appropriate groundwater levels and river discharge rates is crucial for maintaining many services that the Netherlands relies on, for example for the stability of the ground in the polders or in flushing out salt water from intruding into the harbours and into the ground water. A hotter climate presents opportunities as well. For agriculture, higher temperatures in the summer growing season allow for the possibility of higher transpiration from plants which would result in a higher yield than in a cooler climate. This higher yield is only possible however if the plants have access to enough water, either from water trapped in the root zone accessible to the plant or as irrigation water.

This hotter drier climate will increase the importance of irrigation, as agriculture will need more water to maintain current yield and also possibly increase yields. At the same time water demand for other needs such as maintaining ground stability and a healthy ecosystem might limit the water available to agriculture. Recent studies have indicated the possibility to significantly increase agricultural production in the Netherlands in a warm and dry climate given an increase in the existing irrigation infrastructure, primarily through surface water irrigation projects (van Beek et al. 2008, Kleijn et al. 2012).

In this study we examine the economic pressures and feedbacks on water and land from climate change in the Netherlands making an explicit distinction between ground and surface water supplies. We include the economic links between Dutch agriculture and the global marketplace for food products specifically regarding its upstream neighbors Germany and Belgium which share the Rhine and Meuse river basin, the largest sources of river water in the Netherlands. We further explore two policy scenarios regarding expanding irrigation infrastructure to meet the potential yield targets in the new dry climate; first an increase of surface water irrigation infrastructure for farms already equipped for irrigation, and second an expansion of total irrigated area from both ground and surface water at current levels of irrigation intensity. In both policy scenarios we will estimate the value of the increased irrigation infrastructure to the agricultural sector by examining how the addition of the irrigation infrastructure changes the autonomous adaptation response of the Dutch agricultural sector to climate change. In all scenarios we will include the effects of the policy on the Dutch economy as well as the effect of the Dutch adaptation response on the agricultural sectors of the upstream countries Belgium and Germany.

In order to capture the full economic feedbacks from the climate impacts and the direct irrigation adaptation policies, we employ GTAP-W a global CGE model with water as an explicit input in agriculture (GTAP-W, Calzadilla et al. 2010). We extend GTAP-W by explicitly distinguishing between surface and groundwater used for irrigation, as well as allowing for a direct substitution between rain fed and irrigated land.

Computable general equilibrium models have been applied to examine the economic efficiency of water use since at least Berck et al. (1990). Some recent reviews of the literature of this growing field include Ponce et al. (2012) and Griffith (2012). Berck and most of the studies since focus exclusively on the value water use in agriculture while a few others examine the efficiency of allocation of water between agriculture and other uses, some examples of these are Goodman (2000), Gomez et al. (2004) and Koopman et al. (2015a), which examine the efficiency of markets to allocate water between agriculture municipal and industrial uses. Most of the work in this area has focused on water quantity, with some notable exceptions Delink et al. (2011) and Brouwer et al. (2008) which focus on water quality. Recently the global CGE model GTAP (Hertel, 1999) has been applied to water use in agriculture in various itterations starting with Berriatella et al. (2007) which included water as an intermediate input in all water using sectors of the economy including, but not limited to agriculture. Calzadilla et al. (2010), included water as an endowment exclusive to agriculture that can be directly substituted for land use in production. A recent development has been the work of Taheripour et al. 2013 and Liu et al. (2014,2016) and Haqiqi et al. (2016) who have further distinguished water supply by river basin. Distinguishing water supply by geopgraphical location in a CGE model was first done at the national level by Diao and Roe (2005) for Morroco. In later work Diao and Roe (2008) distinghished between ground and surface water in Morroco to examine the impact of increased groundwater extraction costs as well as rural-urban water tranfers.

By distinguishing between the unique characteristics of surface and ground water in a trans-national shared river basin context we hope to further integrate the conditions of the agricultural sector within a CGE framework as well as further clarify the options of policy makers and water managers with regards to ground and surface water management and infrastructure investment.

Section 2: Methods

2.1 Model

In this study we extend the GTAP-W model (Calzadilla, 2010), which is itself an extension of the GTAP model (Hertel, 1999). The Global Trade Analysis Project (GTAP) is a comparative static computable general equilibrium (CGE) model with global coverage and national level resolution, with small countries represented by regional aggregates. All consumption, production, trade and taxes are covered in the model as well as the reactions of producers and consumers to changes in prices. All income including taxes in each region (i.e. nation or aggregate) is collected by a regional household. Expenditure is then distributed into private, government and savings expenditures according to a Cobb-Douglas function. Private and government expenditure purchases are allocated over consumption goods according to a CDE function and Cobb-Douglas function respectively to maximize the regional households' utility function. Savings (which represent he demand for future consumption) are purchased from a global bank which in turn purchases investments from a capital goods sector in each region. The regional consumption (both household and firms) are assumed to have heterogeneous preferences for products from the same sector distinguished by origin (either domestic or imports distinguished by source country) according to the Armington assumption (Armington 1969).

Firms purchase intermediate inputs and endowments (labor, land and capital) to maximize their profits according to a constant elasticity of substitution (CES) function. The assumption of perfect competition (zero profit condition) assures that prices adjust such that income always equals expenditure for each firm. The endowments owned by the regional household are labor, capital and land. Labor and capital perfectly mobile across sectors while land is imperfectly mobile (i.e. a small price difference is allowed for land between sectors). All endowments are immobile between regions.

GTAP-W extends the GTAP model by splitting the land endowment into pasture land, rain fed land, and irrigated land, and then further splitting the irrigated land into a land component and a water component. The value of pasture land is the value of land used by the animals sector. The rain fed land endowment is split from the irrigated land composite based on the value share of production in each region. Irrigated land is split from irrigation water by comparing the ratio of irrigated yields to rain fed yields, where the value of the additional yields from irrigated production is attributed to water. The equation for splitting the value of irrigation water from irrigated land for each crop in each region is shown in equation 1 and 2 below (modified from Calzadilla et al., 2011a). For more detail on GTAP-W see Calzadilla et al. (2011a, 2011b).

$$Lnd_{j,r} = LndWatC_{j,r} * (\frac{YRF_{j,r}}{YIRG_{j,r}}) \quad \text{Eq 1}$$

$$Wat_{j,r} = LndWatC_{j,r} * (1 - \frac{YRF_{j,r}}{YIRG_{j,r}}) \quad \text{Eq 2}$$

Where:

$LndWatC_{j,r}$ = The value of the Land-Water composite

$Wat_{j,r}$ = The value of the Water endowment

$Lnd_{j,r}$ = The value of the Irrigated Land endowment

$YRF_{j,r}$ = The rain fed yield

$YIR_{j,j}$ = The irrigated yield

For all crops j and for all regions r

In this study we further extend and adjust the GTAP-W model to distinguish between crops irrigated by ground and surface water. The irrigation water and irrigable land endowments from GTAP-W have been replaced by the four endowments: irrigation from ground water, land irrigated by groundwater, irrigation from surface water, and land irrigated by surface water. Further, the structure of the CES function has been adjusted such that, all land endowments related to crop agriculture are placed in a single nest "crop land" at the same level as labor, capital and pasture land. The crop land aggregate is then further split into rain fed land and the irrigated land composite. The irrigated land composite is further split into a surface water composite and a ground water composite, which are then each split into an irrigable land and irrigation water component respectively. The new production structure is shown in figure 2.1.

The value of the rain fed land and the irrigated land composite, as well as the value of the surface water and ground water composite are all derived from the value share of production using the same methodology as Calzadilla et al. (2011, 2011b). The value of land irrigated by groundwater is split from the value of groundwater irrigation by comparing the yield ratio between groundwater irrigated agriculture to rain fed agriculture, and applying equations 1 and 2. The surface water aggregate is split in the same way.

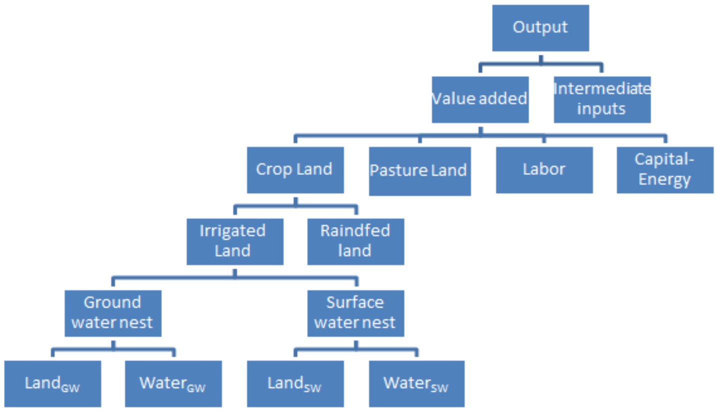

Figure 2.1: The production structure used in this study

The elasticities of substitution among the elements of the Crop Land nest and sub-nests were calibrated to the scenarios described in section 3. We assumed that irrigated and rain fed agriculture produce the same (or very similar) crops and therefore an increase in irrigated agriculture would not necessitate a similar increase in the production of the rain fed product, (this would not be the case for example if within the aggregated vegetables and fruits sector irrigated agriculture was primarily apples and rain fed agriculture was primarily carrots). Therefore it was assumed that irrigated land and rain fed land are nearly perfect substitutes and consumers were indifferent between the two. The same assumption was made for the ground water and surface water aggregates. Therefore the elements of the Crop land nest and in the irrigated land nest have a very high substitution elasticity of 3. The elements of the ground water nest and the surface water nest were calibrated such that a 1 percent increase in the productivity of irrigation water (surface or ground) would result in a higher not lower demand for the irrigation water endowment. This resulted in each having an elasticity of 1. The elasticities of substitution among the elements of the value added nest differ per sector and were taken from the standard GTAP model. It was assumed that it is not possible to substitute between intermediate inputs and value added.

2.2 Data

We use version 6 of the GTAP database (Dimaranan, 2006). This database has 87 regions each with 57 sectors, which together describe the global economy in 2001. We aggregate these to 5 regions and 12 sectors focusing on the aspects of the economy relevant to agriculture in the Netherlands and its neighbours in the Rhine and Meuse river basin. The regions, sectors and endowments used in this study are shown in table 2.1.

Regional Aggregation	**Sector Aggregation**
The Netherlands	Wheat
Belgium	Cereal Crops

Germany	Vegetables and Fruits
Rest of Europe	Sugar Beets
Rest of the World	Other Agriculture
	Animals
Endowments	Meat
Surface water (SW)	Food Products
Land Irrigated by Surface Water (SW Land)	Manufacturing
Ground Water (GW)	Services
Land Irrigated by Ground Water (GW Land)	Transport
Rain fed land	Capital Goods
Labor	
Capital	

Table 2.1: Regions, sectors, and endowment, in this study

For the value of the production of rain fed agriculture, and agriculture irrigated by ground water and surface water in the Netherlands we used data from the NHI hydrology and crop model (Hoogewoud et al., 2013)**.** The NHI model also provided data on how yields would change in the Warm+ scenario (van den Hurk et al., 2006). The NHI model includes detailed information on river flows as well as the needs of nature and other demands on water use. It therefore assumes restrictions on the surface water available for irrigation. There are assumed to be no policy restrictions on ground water however, and the NHI model assumes that the only restriction on the volume of abstracted ground water is the capacity of the current irrigation infrastructure. This assumption on the availability of ground water for irrigation differs from the assumptions made in the Delta Program Phase 3 data (Deltares 2013) which used in Koopman et al. (2015a, 2015b). The more conservative assumptions regarding policy restrictions on ground water abstraction in DPP3, resulted in yield losses in the warmer climates studied in Koopman et al. (2015a, 2015b), while the assumed ground water availability in the NHI data allows for an increase in yields in the warmer climate of Warm+ scenario. The models used in the construction of the Delta Program Phase 3 database are simplifications of the NHI models and are calibrated to the NHI database, therefore it was decided to use the NHI data for this study as it was considered more reliable.

The value of rain fed and irrigated production and yields for the remaining regions in the model were taken from the IFPRI IMPACT data (IFPRI 2010). While the fraction of agriculture irrigated from ground and surface water in Belgium and Germany was taken from the Water-Gap model (Water-Gap, 2017).

Because of constraints on data availability it was assumed that the yields for ground and surface water were the same in all regions except for the Netherlands. It was also assumed that the fraction of agriculture irrigated from ground and surface water in the regions Rest of Europe and Rest of the World were the average of those of The Netherlands, Belgium and Germany.

2.3 Water in the Netherlands and the interpretation of the water endowment

The Netherlands is a delta country where water is plentiful; it has relatively high or low levels of irrigation depending on how it's defined. The tightly controlled capital intensive nature of Dutch farming means that the Netherlands has installed a relatively high amount of irrigation equipment but they are only activated on unusually hot days, and there is comparatively less total water volumes used in farming compared with other countries.

The Netherlands has a heavily developed infrastructure system for controlling and directing river water, it also has significant shallow groundwater resources. Most days irrigation water will not be restricted and there is excess supply but on certain hot dry days of the summer the demand for water will either exceed the pump capacity or their will be an irrigation reduction or stop placed on farmers by the water manager to insure that other water demands are met such as regulating water levels in the polders, or preventing salt intrusion into the fresh water systems. In both cases, water restrictions due to policy or pump capacity results in a water demand that exceeds supply. This is what leads to the reduction in potential growth for the crop.

The water endowment in this study is then defined as the value of the ability to irrigate when needed, under the current infrastructure. The value of the endowment is reflected in the value of the additional yield (see equations 1 and 2). When we examine an increase in the quantity of the endowment we mean an increase in infrastructure that either increases the pump capacity or by building storage or water management infrastructure so we can move water from a time/place where it exceeds supply to a time/place where it is needed. If other circumstances change, such as water policy or climate, such that the existing irrigation infrastructure produces higher or lower yields then this is interpreted as a change in the productivity of the existing water endowment.

Section 3: Scenarios

In this study the following, three climate change and adaptation scenarios will be explored. All three scenarios take place within the context of the Warm+ climate change scenario. This climate change scenario is one of four equally likely future climate change scenarios for the year 2050 from the Royal

Dutch Meteorological Institute (KNMI), (van den Hurk et al. 2006). The Warm+ climate change scenario assumes a 2.8°C increase in average summer temperatures, and a 19 percent reduced summer precipitation. We apply the Warm+ climate conditions to the current economy to assess the importance of irrigation in the new drier climate. To simplify the analysis it is assumed that the agriculture in the Netherlands is the only country to experience the new climate impact leaving the global market for agricultural products the same as in the current climate.

3.1 Climate change with autonomous adaptation

This scenario explores the market reaction of Dutch farmers to the climate shock of the Warm+ climate scenario. The direct climate impact on agricultural yields from the Warm+ climate is shown in table 3.1 and is derived from the NHI data (Hoogewoud et al., 2013).

		Wheat	Cereal Crops	Vegetables and Fruits	Sugar Beets	Other Agriculture
Actual output	Rain fed	6.8	6.8	-4.7	-0.5	-4.3
	Surface water Irrigated			8.4	13.4	11.1
	Ground water Irrigated			5.7	11.5	8.7
Potential output	Rain fed	15.7	15.7	15.7	18.2	22.6
	Surface water Irrigated			12.6	15.0	29.2
	Ground water Irrigated			10.8	14.4	11.9

Table 3.1: Percent change in output for Dutch agriculture between the current climate and the Warm+ climate. The potential output refers to the output if the plant were to receive the necessary water to achieve maximum growth. Source NHI data and own calculations.

From the change in output shown in table 3.1 we derived the corresponding changes in productivity to the endowments rain fed land, ground water, and surface water. Equations 3.1 and 3.2 link the changes in production to the changes in the endowments. The derivation of equation 3.1 and 3.2 follows the derivation described in Appendix B of Koopman et al. (2017b).

$$RFL\_prod_j = RFA\_qo_j \qquad \text{Eq 3.1}$$

$$Wat\_prod_{j,k} = \left(1 + \frac{\theta IL_{j,k}}{\theta Wat_{j,k}}\right) * IR\_qo_{j,k} \qquad \text{Eq 3.2}$$

Where:

RFL_prod = % change in the productivity of the rainfed land endowment

RFA_qo = % change in the quantity of output for rain fed agriculture

Wat_prod = % change in the productivity of the irrigation water

θIL = The ratio of the value or irrigated land over the value of the Irrigated land-Irrigation water composite.

θWat = The ratio of the value or irrigation water over the value of the Irrigated land-Irrigation water composite.

IR_qo = % change in the quantity of output for irrigated agriculture

For crop j and k is either surface water or ground water.

Equation 3.1 shows that the percent change in rain fed land productivity is the same as the percent change in output of the rain fed crop, while the percent change in the surface (ground) water irrigation productivity is a function of the percent change of the output of the surface (ground) water irrigated crop and the share of water in the water-land composite. Table 3.2 shows the changes in endowment productivity as a result of the Warm+ climate using table 3.1 and equations 3.1 and 3.2.

	Climate shock for all scenarios, % change in productivity					SW-adaptation	IR Land Adaptation
	Wheat	Cereal Crops	Vegetables and Fruits	Sugar Beets	Other Agriculture	Total quantity % change	Total quantity %change
Surface Water			49	79	50	65	56
Ground Water			45	77	54		35
SW-Land							56
GW-Land							35
Rain fed Land	6.8	6.8	-4.7	-0.5	-4.3		-24
Labor							
Capital							

Table 3.2: The impact of climate and the planned adaptation responses on the endowments from the three scenarios. Source, own calculations.

3.2 Climate change with increased surface water infrastructure investment as planned adaptation

From the data of the NHI model, in the Warm+ climate scenario if the crops irrigated by surface water were to receive the optimal amount of water for growth then the output would increase by over 14 percent compared to the Warm+ scenario under current irrigation infrastructure. In this scenario we explore this possibility by increasing the quantity of the surface water endowment such that the output of agriculture irrigated by surface water would increase 10 percent. Equation 3.3 shows the link between the percent change in the quantity of the surface water irrigation endowment and the percent change in the output of the crop irrigated by surface water. The derivation of the 3.3 follows the same reasoning as Eq 3.2.

$$Wat\_qo = \left(1 + \frac{\theta IL}{\theta Wat}\right) * IR\_qo \qquad \text{Eq 3.3}$$

Where:

Wat_qo = % change in the total quantity of endowment of surface water

θIL = The ratio of the total value or irrigated land over the total value of the Irrigated land-Irrigation water composite for the Netherlands.

θWat = The ratio of the total value or irrigation water over the total value of the Irrigated land-Irrigation water composite for the Netherlands.

IR_qo = % change in the quantity of output of agriculture irrigated by surface water

3.3 Climate change with increased irrigation area as planned adaptation

As a final scenario of planned adaptation in the Warm+ climate scenario we explore the impacts of doubling the amount of irrigated area. Assuming these newly irrigated areas had an average rain fed yield and now have an average irrigated yield for each of the crop sectors, the changes irrigated areas results in the changes to the value of the land and water endowments shown in table 3.2.

4 Results

4.1 Climate shock

The Warm+ climate scenario increases the production of all crop types in the Netherlands as shown in Table 4.1. The increase of supply naturally leads to a drop in price also shown in table 4.1. This drop in price benefits consumers and all other economic sectors that rely on agricultural products for their inputs. The Wheat activity increases the most and has a lower drop in price as compared to cereal crops even through both activities have the same increase in land productivity as shown in table 3.2. Wheat is very homogeneous product with a very high Armington elasticity which allows the sector to increase its exports and sell the additional supply. Sugar beets is mostly rain fed so even through it has a high increase in irrigation water productivity, the small productivity loss from rain fed land keeps the total increase of output near zero.

The decline in the price of the output products has an effect on the endowments. This is shown in table 4.2. The marginal value product of surface water and land irrigation decrease slightly, while the marginal value product of the direct substitute ground water and land irrigation slightly increases. The marginal value product of rain fed land decreases substantially. Most of the rain fed land endowment is used by Vegetables and Fruits and by Other Agriculture so even though the productivity of rain fed land increases for Wheat and Cereal Crops the average total productivity of rain fed land in the Netherlands decreases. The price of labor and capital increase as the demand for these endowments increases when the agricultural production increases. The increase in the crop production in the Netherlands increases exports to Belgium and Germany and has a small but noticeable effect on the crop prices of the upstream neighbors in river basin, shown in table 4.3

	Climate Shock	Climate Shock	SW-adaptation	SW-adaptation	IR-Land Adaptation	IR-Land Adaptation
	Quantity	Price	Quantity	Price	Quantity	Price
Wheat	4.03	-0.83	4.69	-0.96	-1.93	0.36
Cereal Crops	1.72	-1.10	1.99	-1.28	-0.85	0.48
Vegetables - Fruits	0.72	-0.29	1.60	-0.63	5.84	-2.23
Sugar Beets	0.01	-0.31	0.01	-0.45	-0.13	0.58
Other agriculture	1.86	-0.39	3.31	-0.69	9.44	-1.91

Table 4.1: Percent price and quantity change of Dutch agricultural activities in the three future scenarios as compared to the baseline.

4.2 Climate change with increased surface water infrastructure investment as planned adaptation

The increase in surface water infrastructure increases the production of all agricultural activities. It increases the production of Vegetable and Fruits and of Other Agriculture directly through an increase in the surface water endowment and it induces these two large agricultural activities to use less rain fed land which further reduces the price of rain fed land, shown in table 4.2. Table 4.2 also shows that the reduction in the shadow price of the surface water endowment (due to the increase in supply) reduces the shadow price of ground water and land as well, as this is the substitute production mechanism of surface water irrigated agriculture. The price of labor and capital increase even further than in the Climate shock only scenario however this increase is not enough to offset the decrease in rain fed land rents and so Wheat and Cereal Crops can increase their output even further as their input endowments are on the whole less expensive.

	Climate Shock	SW-adaptation	IR-Land Adaptation
Surface Water	-0.88	-39.49	-33.86
Ground Water	0.59	-4.65	-30.21
SW-Land	-0.83	-0.60	-34.33
GW-Land	0.61	-4.63	-30.19
Rain fed Land	-9.00	-12.75	-6.38
Labor	0.03	0.05	0.15
Capital	0.02	0.04	0.11

Table 4.2: Percent change in the (shadow) price for Dutch agricultural endowments for the three future scenarios as compared to the baseline.

4.3 Climate change with increased irrigation area as planned adaptation

Doubling irrigated areas in scenario 3 results in a further increase in the production of the Vegetables and Fruits activity and the Other Agriculture activities which increase 5.8 and 9.4 percent respectively compared with the base data, shown in table 4.1. The increase in these two large agricultural activities further drives up the price of labor and capital which now more than offsets the gains from the reduced price of rain fed land for the activities Wheat, Cereal Crops. These two rain fed crops now have an increase in output price and decrease in production compared to the base data. The same is true for Sugar Beets which are primarily rain fed. Prices for agricultural products drop even further in the upstream countries compared to the other two scenarios.

	Climate Shock	Climate Shock	SW-adaptation	SW-adaptation	IR-Land Adaptation	IR-Land Adaptation
	Belgium	Germany	Belgium	Germany	Belgium	Germany
Wheat	-0.02	-0.01	-0.02	-0.02	-0.04	-0.03
Cereal Crops	-0.02	-0.01	-0.03	-0.02	-0.05	-0.03
Vegetables - Fruits	-0.01	-0.01	-0.02	-0.02	-0.05	-0.06
Sugar Beets	-0.01	-0.01	-0.02	-0.02	-0.04	-0.04
Other agriculture	-0.02	-0.03	-0.03	-0.04	-0.07	-0.11

Table 4.3: Percent change in the price of the agricultural products in the upstream countries for the three future scenarios as compared to the baseline.

Section 5: Discussion Conclusions

In this study we explored one of the possible impacts of climate change on the Netherlands, extending the GTAP-W CGE model to distinguish between ground and surface water irrigation endowments. The Warm+ climate change scenario (the most hot and dry of the four climate change scenarios for the Netherlands) had the effect of increasing the productivity of irrigated agriculture, and even the rain fed agriculture for some activities where there was enough water in the root zone of the plant to increase growth. Overall rain fed land decreased in productivity but agricultural output increased due to increase in irrigation productivity. Increasing surface water infrastructure further increased the growth of all crop activities. Irrigated agriculture increased because of easily accessible irrigation while rain fed agriculture (wheat and cereal crops) profited from the reduced price of rain fed land which was the result of reduced demand for rain fed land from Vegetables and Fruits and Other agriculture that switched to irrigated land. Doubling the irrigated area however increased the production of irrigated agriculture to such an extent that the resulting increase in the demand, and therefore price, of labor and capital caused a decrease in the production of agricultural activities that were primarily rain fed.

The increase in productivity of irrigated agriculture in all scenarios resulted in a decrease in the price of all types of land, with the exception of land irrigated by groundwater in the climate shock only scenario. The gains of the productivity increase went to the owners of labor and capital. In this study it is assumed that labor and capital are perfectly mobile throughout the Dutch economy, if we were to assume a more segmented factor market (i.e. that agricultural labor and capital must stay within agriculture) then the gains to the owners of these agricultural endowments would be even larger.

The impact of the Dutch irrigation infrastructure increases had a small but noticeable effect on the agricultural prices upstream countries Belgium and Germany. In this study we did not examine the effect of the climate shock on the productivity of agriculture in these countries. If the Warm+ climate were to decrease their productivity of agriculture then the further increase in production of Dutch agriculture from large irrigation infrastructure projects might very well encourage the upstream countries to engage in large infrastructure projects of their own which might negatively impact downstream water supply in the Netherlands.

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