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Introducing water by river basin into the GTAP-BIO model:

GTAP-BIO-W

By

Farzad Taheripour**

Thomas W. Hertel

Jing Liu

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**Corresponding Author: Farzad Taheripour, Department of Agricultural Economics, Purdue University, 403 West State St., West Lafayette, IN 47907-2056, Phone: 765-494-4612, E-mail: tfarzad@purdue.edu. Farzad Taheripour is Research Assistant Professor, Thomas W. Hertel is Distinguished Professor, and Jing Liu is Ph.D. student in the Department of Agricultural Economics at Purdue University.

Introducing Water by river basin into the GTAP Model: GTAP-BIO-W

Farzad Taheripour, Thomas W. Hertel, and Jing Liu

Abstract

This paper introduces water into the GTAP modeling framework at a river basin level. The new model: 1) distinguishes between irrigated and rainfed agriculture using different production functions; 2) takes into account heterogeneity in land quality across agro-ecological zones; 3) traces supply of water at the river basin level within each country/region; 4) fully captures competition for land among crop, livestock and forestry industries; 5) and, most importantly, offers the potential to extend the competition for managed water among agricultural and non-agricultural activities.

Key words: Water, Irrigation, Computable general equilibrium, River basin, Land, Agro ecological zone.

JEL classification: C68, Q15, Q24, Q25.

1. Introduction

GTAP is a global Computable General Equilibrium (CGE) model which traces production, consumption, and trade of a wide range of goods and service across the world while takes into account market clearing conditions and resource constraints. In recent years, the land-use augmented versions of this model (GTAP-AEZ, GTAP-BIO-AEZ, GTAP-BIO-ADV) have been extensively used to address trade, development, energy, environment, climate, welfare, poverty, land, agriculture, and food security issues and their interactions with land resources.

While the GTAP model has been frequently used to address the land use related topics, only a few attempts have been made to extend its application in the areas of research on water. To the best of our knowledge so far only two major attempts have been made to introduce water into the GTAP modeling framework. In the first trial, Berritella et al. (2007) have introduced managed water as an exogenous endowment into the GTAP standard model. Henceforth, we refer to this model as GTAP-W1. In this model crop and livestock industries only use water and the price of water is zero when there is no water scarcity. However, if water is scarce, then the economic rents associated with water resources drive a wedge between the market and agent prices of each commodity. This model assumed no substitution between water and other primary intermediate inputs.

In the second trial Calzadilla et al. (2010) have used a different approach to introduce managed water as an exogenous endowment into the GTAP standard model. Henceforth we refer to the model developed by these authors as GTAP-W2. In this model only crop industries use water. This model divided the standard value added of cropland into three categories of *rained land*, *irrigated land*, and *irrigation*. The first two components represent value added of rained and irrigated croplands, respectively. The latter component (*irrigation*) shows payments for water and has been calculated from the difference between the irrigated and rained yields.

Unlike the first model, the GTAP-W2 allows substitution between water and other primary inputs. It first combines water (*irrigation*) and irrigated land with a non-zero elasticity of substitution. Then it combines the composite of land-water with other primary inputs including rained land, labor, and capital with a non-zero elasticity of substitution in the value added nests of the production functions of crop industries. Thus there are two margins along which irrigation water can be conserved: by using more irrigated land, and by using more sophisticated irrigation techniques (labor and capital substitution) or by using more rained land. The former margin does not appear very realistic, while the latter component seems to mix a variety of important substitution possibilities.

Perhaps most importantly, these earlier approaches to incorporating irrigation into the GTAP model do not distinguish between the irrigated and rained production functions. GTAP-W1 only included water as an aggregated input into the national production functions of crop and livestock industries which subsequently produced output from both rained and irrigated farming. GTAP-W2 distinguishes between the irrigated land and rained land inputs, but does not differentiate between the irrigated and rained production functions themselves. This obscures the fact that rained and irrigated crop producers may behave differently in response to economic and climate shocks. On the other hand, the climate variables may affect the rained and irrigated crops in different ways. Indeed, in the case of extreme water scarcity, irrigation in a given region may

be eliminated altogether. Hence, it is important to define separate production functions for rainfed and irrigated crops to capture these responses and impacts more accurately.

In addition to the first limitation, these pioneering modeling frameworks ignored the fact that the quality of land varies significantly within the boundaries of a country/region and that water scarcity may vary across River Basins (RBs) of a country/region. Within the border of a country/region productivity of land varies across Agro Ecological Zones (AEZs) and intensity of water scarcity alters from one basin to another one. Finally, in these two models crop and livestock industries are the only active industries in the market for land. Therefore, these models do not fully capture the competition for land among crop, livestock, and forestry industries.

In this paper we develop a new modeling framework which: 1) distinguishes between irrigated and rainfed agriculture using different production functions; 2) takes into account heterogeneity in land quality across AEZs; 3) traces supply of water at the RB level within each country/region; 4) fully captures competition for land among crop, livestock and forestry industries; 5) and, most importantly, offers the potential to extend the competition for managed water among agricultural and non-agricultural activities. The rest of this paper describes the configurations of the new modeling framework and its data base.

2. Modeling Framework

To build the new model we begin with the model developed by Taheripour, Hertel, and Liu (2013: Henceforth THL). These authors have extended the GTAP-BIO¹ model by splitting the crop industries into irrigated and rainfed activities. Their model considers water as an implicit input imbedded in the irrigated land and traces demand for, and supply of, land by AEZ in each region, while defines distinct production functions for irrigated and rainfed crops. The GTAP-BIO model fully captures the competition for land among crop, livestock and forestry industries in each AEZ. In this paper, we extend this earlier model by introducing water as an explicit input into irrigated crop production.

The structure of the new model (henceforth: *GTAP-BIO-W*) is presented in Figure 1. In this model there is a national competition among industries for labor, capital, and resources other than land and water. Water resources are available at a RB level, each country may have several RBs, and a RB may serve several AEZs. Supply of managed water in each RB is exogenously specified and agricultural and non-agricultural industries compete for managed water at the basin level. Water does not move across RBs but it can move across AEZs within a given basin. Following the earlier versions of the GTAP-BIO model, the new model also considers accessible land as an endowment with fixed supply at the AEZ level by region. The accessible land is divided into three groups of pasture, cropland, and forest. The crop, livestock, and forestry industries compete for land and crop industries compete for cropland. Irrigated crops use irrigated land and rainfed crops use rainfed land. Land can move from rainfed to irrigated agriculture and vice versa, if biophysical and economic factors allow such a conversion. At the national level, the irrigated and rainfed

¹ This model is an advanced and improved version of the GTAP-E model which has been designed and frequently used to examine the economic and environmental consequences of biofuel production and policies. Examples are: Hertel et al. (2010), Taheripour et al. (2010), Taheripour et al. (2011), Beckman et al. (2011), Diffenbaugh (2012), and Taheripour and Tyner (2013).

farmers supply a homogenous crop (but region-specific) product to domestic and foreign consumers.

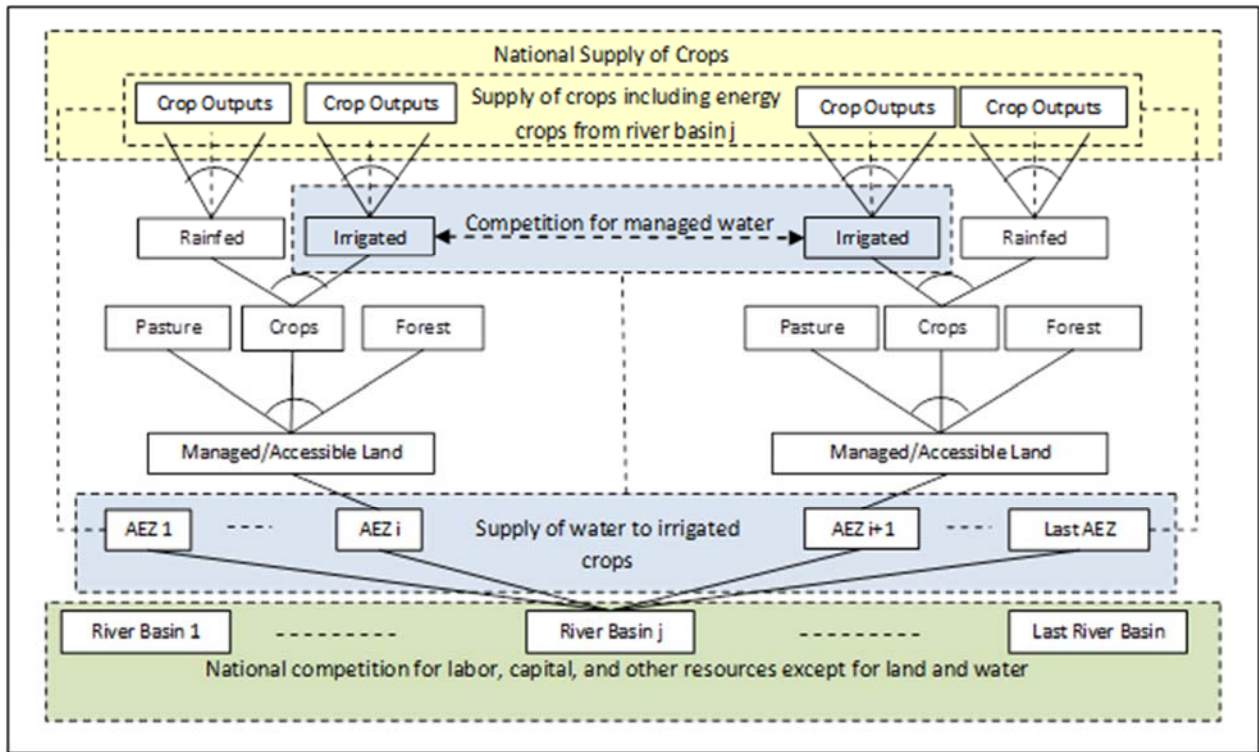


Figure 1. Structure of the GTAP-BIO-W model

To implement the new modeling structure, each country/region is divided into several RBs (currently constrained to be a maximum 20 RB's per region) and each RB serves several AEZs (maximum 18). Hence, the value added nests of the irrigated crop production functions are modified to trace demands for water and land at the RB-AEZ level, as shown in Figure 2. At the very bottom level of the value added nest, water and land are combined to create a composite input. For a given RB, the mix of this composite is aggregated across AEZs within the RB, and subsequently across RBs to determine the national demand for the mix of water and land in irrigated crop production. This set up also traces the demands for water and land at the RB and AEZ levels, respectively. In this model, the substitution rate between water and land inputs can vary across regions, industries, RBs, AEZs. Land can also move between irrigated and rainfed cropping according to the transformation elasticity as specified in the model.

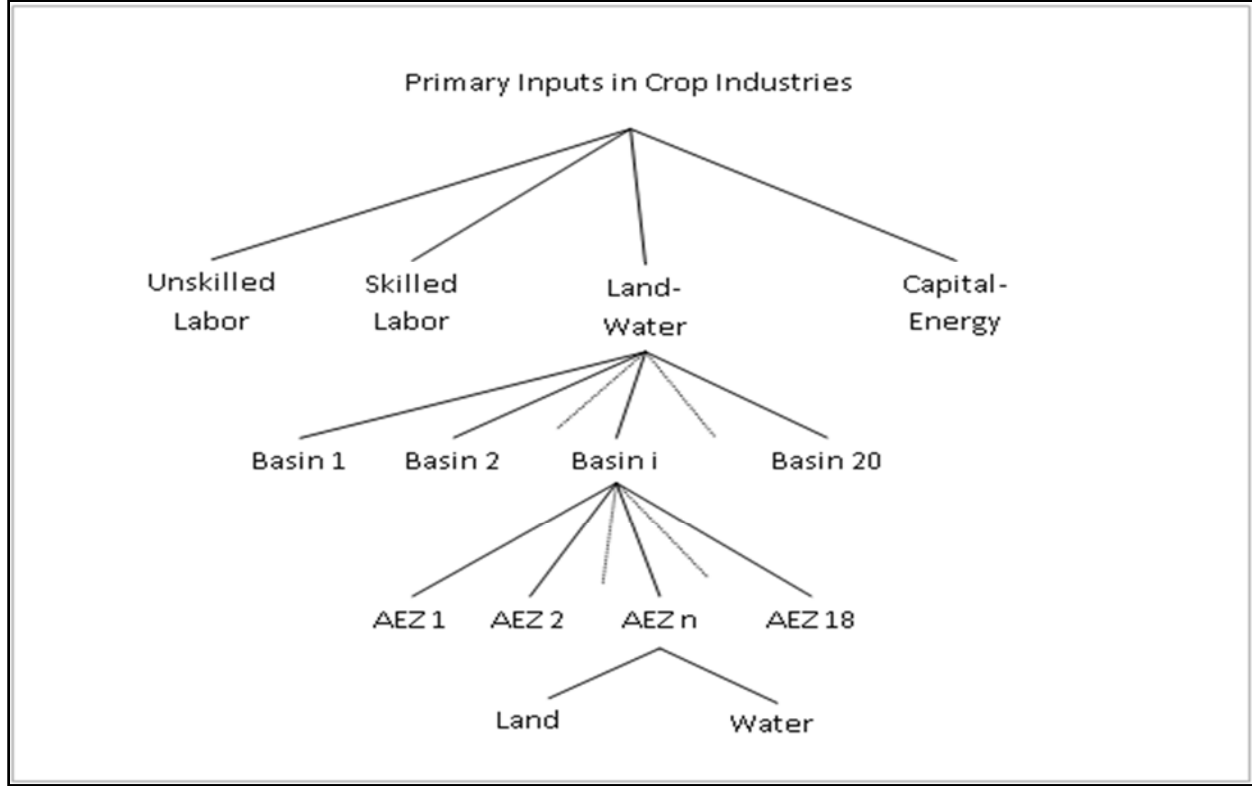


Figure 2. Demand structure for primary inputs

To implement this modeling structure we made major modifications in the GTAP TABLO code. In addition to extensive changes in the demand and supply functions and market clearing conditions, we included the following market clearing condition for water to determine the shadow price of water at the river basin level:

$$qobasin(i, r) * \sum_{z=1}^{z=18} VOM(i, z, r) = \sum_{z=1}^{z=18} \sum_j VFM(i, z, j, r) * qfe(i, z, j, r) \quad (1)$$

In this equation indices of i, z, j, r stand for RB, AEZ, industry, and region, respectively. The variables $qobasin$ and qfe show percentage changes in the supply of, and demand for, water. Finally, VOM and VFM represent the implied values of water and water used by industries. In this equation: $\sum_{z=1}^{z=18} VOM(i, z, r) = \sum_{z=1}^{z=18} \sum_j VFM(i, z, j, r)$. The left hand side of this relationship represents implied value of water at the river basin level and the right hand side represents sum of values of water used by industries again at the river basin level. The river basin market clearing conditions for water determine the shadow price of water at the river basin level.

3. Data base

While the modeling framework developed in the previous section is very general and with minor modifications can handle competition for water among all water-using industries, in this section we assume that only irrigated crop industries compete for managed water. To build the new data base we begin with the data base developed by THL. This data base is a modified version of the

standard GTAP data base version 6 which represents production, consumption, and trade of a wide range of good and services, including biofuels and their by-products, at the global scale in 2001. This data base divided the world economy into 19 region, 37 industries, and 33 commodities as listed in Appendix A. We made several major modifications in this data base as explained in the following sections.

3.1. Modification in bio-physical data

THL developed a data base which traces land cover, irrigated and rainfed harvested areas, and production of irrigated and rainfed crops for 2001 at the 5x5 degree spatial resolution at the global scale and then aggregated that into AEZ level by country. We added a map of RBs² (obtained from Impact Water Simulation Model (Rosegrant et al., 2012)) to the gridded data base developed by THL and then re-aggregated their data base at the RB-AEZ level by country³. In addition, the data base developed by Siebert and Döll (2010) which represents water used for irrigation by crop for 2001 at the 5x5 arc minutes spatial resolution is utilized to introduce water used for irrigation by region and crop at the RB-AEZ level into our biophysical data base. According to this data base, at the global scale about 1,200 km³ water were used for irrigation in 2001. Figure 3 shows water used for irrigation in large river basins across the world. This figure shows that the Indus and Ganges are the world most prolific river basins when it comes to irrigated crop production. These two river basins provide about 23.6% of water used for irrigated cropping worldwide. River basins presented in this figure provided about 62% of water used for irrigation globally.

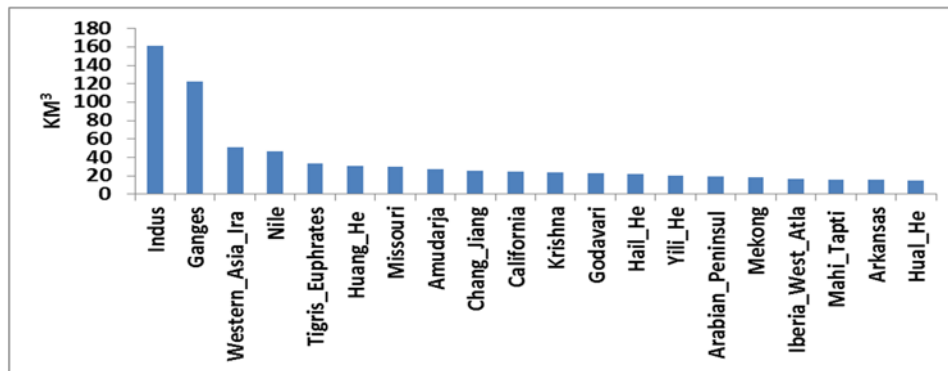


Figure 3. Water used for irrigation in twenty largest river basins worldwide

At the global scale India, Middle and North Africa, Rest of South East Asia, China and USA are the largest users of water for irrigation as shown in Figure 4. These regions jointly consumed 76% of the irrigated water worldwide in 2001.

² Appendix B represents the list of river basins by region.

³ As an example the US land cover data by river RB-AEZ are presented in Appendix C.

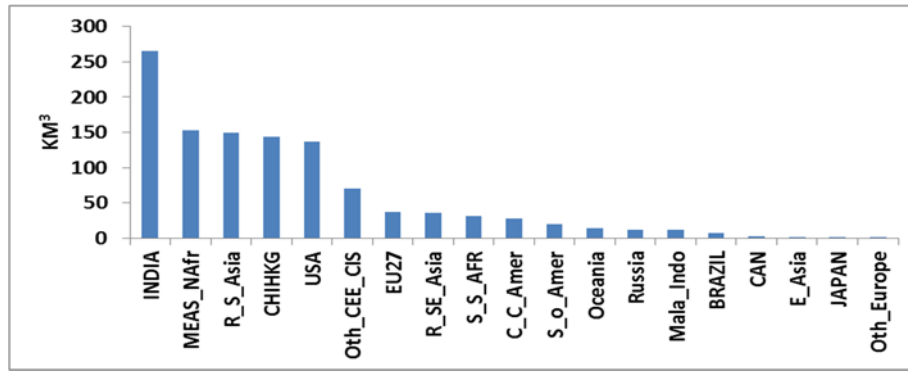


Figure 4. Water used for irrigation by region

Distribution of water used for irrigation among crops varies greatly by region. As shown in Figure 5 managed water is mainly used in global production of other crops (including vegetable and fruits), rice, and wheat. In China and India water is mainly used to produce rice and wheat, while in USA it is mainly used in production of other crops (including vegetable and fruits) and coarse grains (maize).

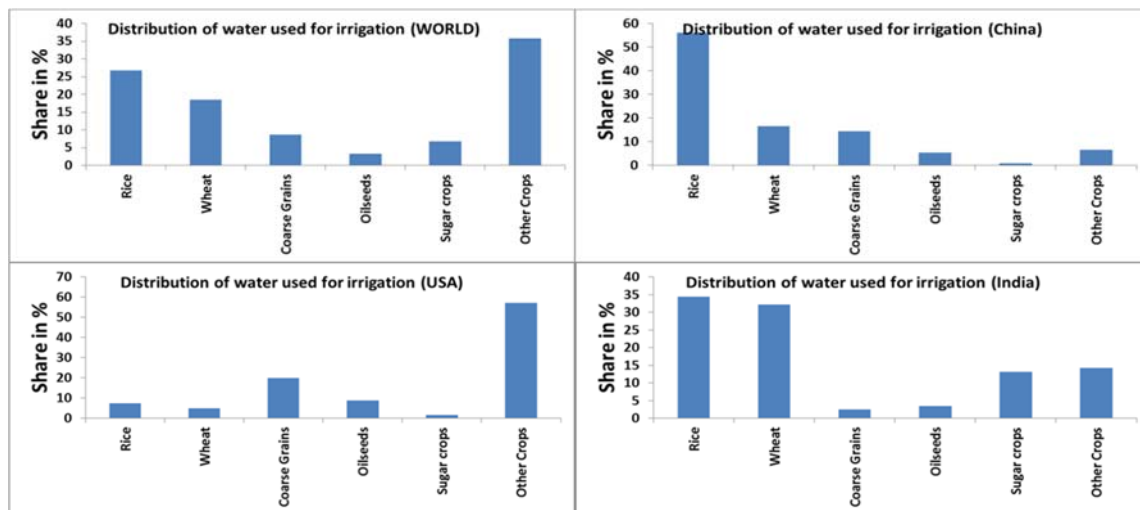


Figure 4. Water used for irrigation by crop at the global scale and for three selected regions

3.2. Allocation of valued added of land among river basins

The data base developed by THL represents the land value added headers by country, industry, and AEZ. We added a new dimension (RB) into these headers and used the following rules to split the value added headers among RBs:

- 1) In each region, for each crop, it is assumed that the spatial distribution of value added of land follows that of output across RB/AEZs.

- 2) In each region for the forestry sector it is assumed that the spatial distribution of value added of land follows that of forest land across RB/AEZs.
- 3) In each region for each livestock industry is assumed that the spatial distribution of value added of land follows that of pasture land across RB/AEZs.
- 4) It is assumed that the rate of taxation (subsidy) on the land input does not vary across RB/AEZs.

3.3. Splitting value added of irrigated land between water and land

The value added of irrigated cropland presented in the data base developed by THL measures the value added of the mix of land-water. We denote this mix, valued at agent's prices, by $EVFA_LW(i,z,j,r)$. To split this mix between land ($EVFA_L(i,z,j,r)$) and water ($EVFA_W(i,z,j,r)$) the following formulas and steps are used:

- 1) Rents per hectare of land are calculated:

$$RENT(i, z, j, r) = \frac{EVFA_LW(i,z,j,r)}{AREA(i,z,j,r)}, \text{ for all RBs, AEZs, crop industries, and regions} \quad (2)$$

Here EVFA and AREA represent land value added (in million dollar) and harvested area (in hectare). Of course for rainfed crops $EVFA_LW(i,z,j,r)=EVFA_L(i,z,j,r)$, because they do not use managed water for irrigation.

- 2) The difference between the irrigated and rainfed rents is calculated for each crop:

$$DIFF(i, z, j, r) = RENT(i, z, irrigated j, r) - RENT(i, z, rainfed j, r). \quad (3)$$

- 3) It is assumed that the coefficient $DIFF$ represents the implicit value of water per hectare of irrigated land. Hence the value added of water is calculated for each irrigated crop using the following formula:

$$EVFA_W(i, z, irrigated j, r) = DIFF(i, z, j, r) * AREA(i, z, irrigated j, r). \quad (4)$$

- 4) Finally the value added of land is calculated for each irrigated crop using the following formula:

$$EVFA_L(i, z, irrigated j, r) = EVFA_LW(i, z, irrigated j, r) - EVFA_W(i, z, irrigated j, r) \quad (5)$$

- 5) The same process is followed to split the value added at market price as well.

3.4. Arrangement of value added headers in the final data base

The GTAP standard data base represents five primary inputs including: skilled labor, unskilled labor, capital, land, and resources and handles value added headers using the $ENDW_COMM$ set with a vector with 5 rows. The GTAP-BIO model follows the same tradition but divides the land input into 18 AEZs. Hence in the GTAP-BIO model the $ENDW_COMM$ set has 22 rows (including 4 non-land inputs and 18 AEZs). In the new model the endowment set has 724 rows. The first 18 rows represent land in RB1-AEZ1 to RB1-AEZ18; the second 18 rows represent land in RB2-AEZ1 to RB2-AEZ18; and so on. Hence, the rows 343 to 360 represent land in RB20-AEZ1 to RB20-AEZ18. The next 360 rows (i.e. rows 361 to 720) represent water following the same order used for land. Finally, the last four rows (i.e. rows 721 to 724) represent skilled labor, unskilled labor, capital, and resources.

4. Applications

The modeling framework developed in this paper provides a flexible tool that can be used to examine a wide variety of water related topics and issues. Two primary applications of this model are discussed in Liu et al. (2013) and Taheripour et al. (2013). The first application examines the consequences of water scarcity for the food security and trade of food and the second application studies consequences of water scarcity and climate change in the presence of biofuel production for rainfed and irrigated agriculture. More applications will be developed in future.

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Appendix A: Regional, industry, and commodity aggregation schedules

Table A1. Regional aggregation and members of each region

Region	Description	Corresponding Countries in GTAP
USA	United States	Usa
EU27	European Union 27	aut, bel, bgr, cyp, cze, deu, dnk, esp, est, fin, fra, gbr, gre, hun, irl, ita, ltu, lux, lva, mlt, nld, pol, prt, rom, svk, svn, swe
Brazil	Brazil	Bra
Canada	Canada	Can
Japan	Japan	Jpn
China	China and Hong Kong	chn, hkg
India	India	Ind
C-America	Central and Caribbean Americas	mex, xna, xca, xfa, xcb
S-America	South and Other Americas	col, per, ven, xap, arg, chl, ury, xsm
E-Asia	East Asia	kor, twm, xea
Mala-Indo	Malaysia and Indonesia	ind, mys
R-SE-Asia	Rest of South East Asia	phl, sgp, tha, vnm, xse
R-S-Asia	Rest of South Asia	bgd, lka, xsa
Russia	Russia	Rus
E-Europe-RFSU	Other East Europe and Rest of Former Soviet Union	xer, alb, hrv, xsu, tur
Other Europe	Rest of European Countries	che, xef
M-East-N-Africa	Middle Eastern and North Africa	xme,mar, tun, xnf
Sub Saharan Africa	Sub Saharan Africa	bwa, zaf, xsc, mwi, moz, tza, zmb, zwe, xsd, mdg, uga, xss
Oceania	Oceania countries	aus, nzl, xoc

Table A2. Industries and commodities

Industries	Commodities	Categories	
Irrigated paddy rice	Paddy rice	Crop	
Rainfed paddy rice			
Irrigated wheat	Wheat		
Rainfed wheat			
Irrigated coarse grain	Coarse grains		
Rainfed coarse grain			
Irrigated oilseeds	Oilseeds		
Rainfed oilseeds			
Irrigated sugar crops	Sugar crops		
Rainfed sugar crops			
Irrigated other crops	Other crops		
Rainfed other crops			
Forestry	Forestry	Forestry	
Dairy farms	Dairy farms	Livestock	
Ruminant	Ruminant		
Non-Ruminant	Non-Ruminant		
Processed dairy	Processed dairy		
Processed ruminant	Processed ruminant		
Processed non-ruminant	Processed non-ruminant		
Crude vegetable oil	Vegetable oils and fats		Processed food and feed
	Oilseeds meals		
Refined vegetable oil	Refined vegetable oil		
Beverage and sugar	Beverage and sugar		
Processed rice	Processed rice		
Processed food	Processed food		
Processed feed	Processed feed		
Grain ethanol	Ethanol1	Biofuel	
	DDGS		
Sugarcane ethanol	Ethanol2		
Biodiesel	Biodiesel	Traditional Energy	
Coal	Coal		
Oil	Oil		
Gas	Gas		
Oil products	Oil products		
Electricity	Electricity		
Primary sectors	Primary products		Industry
Energy intensive industries	Energy intensive products		
Other industrial sectors	Other industrial products		
Non-tradable services	Non-tradable services	Service	

Appendix B: List of river basins by region

Table B1. Regions and their river basins

	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	Central America	South America
RB1	Arkansas	Baltic	Amazon	Canada Arctic Atlantic	Japan	Amur	Brahmaputra	Carribbean	Amazon
RB2	California	Britain	North South Amri. Coast	Central Canada Slave Basin	Others	Brahmaputra	Brahmari	Central Amri.	Chile Coast
RB3	Canada Arctic Atlantic	Danube	Northeast Brazil	Columbia	NA	Chang Jiang	Cauvery	Cuba	Northeast South Amri.
RB4	Colorado	Dnieper	Orinoco	Great Lakes	NA	Ganges	Chotanagpui	Middle Mexico	Northwest South Amri.
RB5	Columbia	Elbe	Parana	Red Winnipeg	NA	Hai He	Easten Ghats	Northwest South Amri.	Orinoco
RB6	Great Basin	Iberia East Med	San Francisco	US Northeast	NA	Huai He	Ganges	Rio Grande	Parana
RB7	Great Lakes	Iberia West Atlantic	Toc	MacKenzie	NA	Huang He	Godavari	Upper Mexico	Peru coastal
RB8	Mississippi	Ireland	Uruguay	Pacific Namer North	NA	Indus	India East Coast	Yucatan	Rio colorado
RB9	Missouri	Italy	Others	Others	NA	Langcang Jiang	Indus	Others	Salada Tierra
RB10	Ohio	Loire Bordeaux	NA	NA	NA	Lower Mongolia	Krishna	NA	Tierra
RB11	Red Winnipeg	North Euro Russia	NA	NA	NA	North Korea Peninsula	Langcang Jiang	NA	Uruguay
RB12	Rio Grande	Oder	NA	NA	NA	Ob	Luni	NA	Others
RB13	Southeast US	Rhine	NA	NA	NA	SE Asia Coast	Mahi Tapti	NA	NA
RB14	US Northeast	Rhone	NA	NA	NA	Songhua	Sahyada	NA	NA
RB15	Upper Mexico	Scandinavia	NA	NA	NA	Yili He	Thai Myan Malay	NA	NA
RB16	Western Gulf Mex	Seine	NA	NA	NA	Zhu Jiang	Others	NA	NA
RB17	Pacific Namer North	Others	NA	NA	NA	Mekong	NA	NA	NA
RB18	Others	NA	NA	NA	NA	Others	NA	NA	NA
RB19	NA	NA	NA	NA	NA	NA	NA	NA	NA
RB20	NA	NA	NA	NA	NA	NA	NA	NA	NA

	East Asia	MYS & IDN	R. Southeast Asia	R. South Asia	Russia	E-Europe-RFSU	R. Europe	M-East-N-Afri,	SSA	Oceania
RB1	Amur	Borneo	Borneo	Amudarja	Amur	Amudarja	Rhine	Arabian Peninsula	Central Afri. West Coast	Central Australia
RB2	North Korea Peninsula	Indonesia East	Langcang Jiang	Brahmaputra	Baltic	Amur	Rhone	Black Sea	Congo	Eastern Australia Tasmania
RB3	South Korea Peninsula	Indonesia West	Mekong	Ganges	Black Sea	Baltic	Scandinavia	Eastern Med	East Afri. Coast	Murray Australia
RB4	Lower Mongolia	Papau Oceania	Philippines	Indus	Dnieper	Black Sea	Others	Nile	Horn of Afri,	New Zealand
RB5	Upper Mongolia	Thai Myan Malay	SE Asia Coast	Sri Lanka	Lower Mongolia	Danube	NA	North Afri. Coast	Kalahari	Papau Oceania
RB6	Others	Others	Thai Myan Malay	Thai Myan Malay	North Euro Russia	Dnieper	NA	Northwest Afri. Coastal	Lake Chad Basin	Sahara
RB7	NA	NA	Others	Western Asia Iran	Ob	Eastern Med	NA	Sahara	Limpopo	Western Australia
RB8	NA	NA	NA	Others	Scandinavia	Iberia East Med	NA	Tigris Euphrates	Madagascar	Others
RB9	NA	NA	NA	NA	Upper Mongolia	Lake Balkhash	NA	Western Asia Iran	Niger	NA
RB10	NA	NA	NA	NA	Ural	Lower Mongolia	NA	Others	Nile	NA
RB11	NA	NA	NA	NA	Volga	Ob	NA	NA	Northwest Afri,	NA
RB12	NA	NA	NA	NA	Western Asia Iran	Syrdarja	NA	NA	Orange	NA
RB13	NA	NA	NA	NA	Yenisey	Tigris Euphrates	NA	NA	Sahara	NA
RB14	NA	NA	NA	NA	Siberia Other	Upper Mongolia	NA	NA	Senegal	NA
RB15	NA	NA	NA	NA	Others	Ural	NA	NA	South Afri. Coast	NA
RB16	NA	NA	NA	NA	NA	Volga	NA	NA	Southeast Afri. Coast	NA
RB17	NA	NA	NA	NA	NA	Western Asia Iran	NA	NA	Volta	NA
RB18	NA	NA	NA	NA	NA	Yenisey	NA	NA	West Afri. Coastal	NA
RB19	NA	NA	NA	NA	NA	Yili He	NA	NA	Zambezi	NA
RB20	NA	NA	NA	NA	NA	Others	NA	NA	Others	NA

Appendix C: US land cover data

Table C1. US forest areas by river basin and agro ecological zone

River basin	AEZ1 to AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	AEZ17 to AEZ18	Total
RB1	0	400657	47134	0	0	2463264	5563639	160965	0	0	0	0	8635658
RB2	0	247898	1806524	479852	2199463	233095	0	451180	576909	182313	0	0	6177233
RB3	0	0	0	100701	338498	0	0	0	0	0	0	0	439199
RB4	0	1321804	55603	0	0	0	0	767009	0	84605	0	0	2229020
RB5	0	422539	4515076	1556875	1813243	0	0	1184219	2666144	575250	0	0	12733344
RB6	0	225259	396153	0	0	0	0	531107	101769	0	0	0	1254289
RB7	0	0	0	501322	14099464	0	0	0	0	0	0	0	14600786
RB8	0	0	0	0	9238629	5635581	4541459	0	0	0	0	0	19415668
RB9	0	713240	748687	0	1325267	283627	0	732781	1662227	0	0	0	5465829
RB10	0	0	0	0	2172338	18534668	1129644	0	0	0	0	0	21836650
RB11	0	0	0	7058	1497385	0	0	0	0	0	0	0	1504443
RB12	0	525038	0	0	0	0	0	155876	76490	0	0	0	757404
RB13	0	0	0	0	284780	3548687	35286256	0	0	0	0	0	39119723
RB14	0	0	0	2128247	14235183	7865553	704638	0	0	101284	0	0	25034905
RB15	0	0	0	0	0	0	0	0	0	0	0	0	0
RB16	0	0	0	0	0	617933	2614813	0	0	0	0	0	3232746
RB17	0	0	0	0	4421145	2550371	3233790	3715383	22712772	24003524	2332634	0	62969619
RB18	0	0	0	0	0	0	0	0	0	0	0	0	0
RB19	0	0	0	0	0	0	0	0	0	0	0	0	0
RB20	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	3856434	7569177	4774056	51625394	41732776	53074238	7698519	27796311	24946975	2332634	0	225406515

Table C2. US cropland areas by river basin and agro ecological zone

River basin	AEZ1 to AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	AEZ17 to AEZ18	Total
RB1	0	9209110	1617910	965108	4334037	2398909	890013	61568	0	0	0	0	19476655
RB2	0	304851	1367746	1631023	1736998	138592	0	58379	5736	277	0	0	5243602
RB3	0	0	0	2500	5366	0	0	0	0	0	0	0	7866
RB4	0	1788608	99467	0	0	0	0	202852	0	734	0	0	2091660
RB5	0	2905038	3709671	228964	384462	324107	0	66167	197072	299	0	0	7815780
RB6	0	778192	594265	0	0	0	0	30707	393	0	0	0	1403556
RB7	0	0	0	2996	9115811	0	0	0	0	0	0	0	9118807
RB8	0	0	0	149104	18644750	9731053	3631229	0	0	0	0	0	32156135
RB9	0	13514360	15024782	4673001	6567659	3571135	0	1435643	61291	0	0	0	44847870
RB10	0	0	0	0	1751410	14495128	573762	0	0	0	0	0	16820300
RB11	0	488060	4170219	5953299	3513493	0	0	0	0	0	0	0	14125070
RB12	0	1675695	296005	0	22111	0	0	5645	864	0	0	0	2000320
RB13	0	0	0	0	247781	839118	8753053	0	0	0	0	0	9839953
RB14	0	0	0	114222	1781314	2602500	277675	0	0	153	0	0	4775864
RB15	0	754	0	0	0	0	0	0	0	0	0	0	754
RB16	0	4678822	566922	231691	1569602	2837617	1209308	0	0	0	0	0	11093962
RB17	0	0	30379	313992	470017	1110283	923084	0	61962	22998	1695	0	2934408
RB18	0	0	0	0	0	0	0	0	0	0	0	0	0
RB19	0	0	0	0	0	0	0	0	0	0	0	0	0
RB20	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	35343488	27477366	14265899	50144812	38048441	16258123	1860960	327318	24462	1695	0	183752564

Table C2. US pasture land areas by river basin and agro ecological zone

River basin	AEZ1 to AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	AEZ17 to AEZ18	Total
RB1	0	14235110	1627445	485854	3503025	2191211	570850	185788	0	0	0	0	22799282
RB2	0	1574045	1861351	1827435	1916824	233090	0	194248	79071	12444	0	0	7698508
RB3	0	0	0	249	44	0	0	0	0	0	0	0	294
RB4	0	37439636	780959	0	0	0	0	1433070	0	7325	0	0	39660990
RB5	0	12605094	5251285	391818	270815	292751	0	581440	986098	1557	0	0	20380857
RB6	0	16656493	1730267	0	0	0	0	191260	9988	0	0	0	18588008
RB7	0	0	0	1521	1699791	0	0	0	0	0	0	0	1701311
RB8	0	0	0	14076	1860586	1488379	669359	0	0	0	0	0	4032400
RB9	0	27067574	22246322	1044436	1988840	920882	0	4783342	856704	0	0	0	58908100
RB10	0	0	0	0	138010	2031681	169266	0	0	0	0	0	2338957
RB11	0	121441	833199	471794	164637	0	0	0	0	0	0	0	1591072
RB12	0	24963962	1410869	0	157903	0	0	118801	68866	0	0	0	26720401
RB13	0	0	0	0	288180	411847	3478423	0	0	0	0	0	4178449
RB14	0	0	0	28245	505058	563065	10007	0	0	276	0	0	1106651
RB15	0	225409	0	0	0	0	0	0	0	0	0	0	225409
RB16	0	9251397	1025090	1053059	3793512	3005176	1287336	0	0	0	0	0	19415569
RB17	0	0	164754	169686	400938	536006	870255	0	108754	119474	2292	0	2372158
RB18	0	0	0	0	0	0	0	0	0	0	0	0	0
RB19	0	0	0	0	0	0	0	0	0	0	0	0	0
RB20	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	144140160	36931541	5488174	16688162	11674088	7055496	7487948	2109481	141075	2292	0	231718417