Water Scarcity and International Agricultural Trade

Jing Liu*[1], Thomas W. Hertel[1], Farzad Taheripour[1], Tingju Zhu[2], and Claudia Ringler[2]

[1]Department of Agricultural Economics, Purdue University, IN, USA
[2]International Food Policy Research Institute, Washington, DC, USA

October, 2013

Abstract

There is increasing interest in the water-food nexus, and the potential implications of future water scarcity for food production. However, little is known about the macro-economic implications of future water scarcity, and the potential impacts on global trade and economic welfare. In this paper, we utilize a recently developed model, GTAP-BIO-W, in order to study the global economic effects of projected water scarcity for 126 river basins, globally in the year 2030. Projected irrigation shortfalls are obtained from the IMPACT-WATER model, and these are imposed upon the present day economy. We find that regional production impacts are quite heterogeneous, depending on the size of the shortfall, the irrigation intensity of crop production, as well as the global commodity price effects. Projected 2030 scarcity leads to significant output declines in China, South Asian, Middle East and North Africa, with increases in crop production sub-Sahara Africa. We find that projected irrigation shortfalls significantly alter the geography of international trade. The global welfare loss amounts to $3.7 billion (2001 prices) both due to the reduction in irrigation availability, as well as due to interactions with domestic support for agriculture.

Keywords: water scarcity; agriculture; international trade
JEL: C68, D58, Q01, Q17, Q25, Q56

1 Introduction

Agriculture is by far the largest user of the world's water resources, with 70 percent of global freshwater withdrawals being directed to irrigation (Molden, 2007). Agriculture's heavy reliance on water is largely driven by climate – in arid and semi-arid regions production would not be possible in the dry season without irrigation, by intensification needs on smaller land areas (irrigation often allows to

*Corresponding author at: 403 West State Street, West Lafayette, Indianan 47907, USA. Tel: +1 765 494 4321. Email: liu207@purdue.edu

grow a second crop) and by the type of crop grown (rice thrives under irrigated conditions). Indeed, 60 percent of cereal production in the developing world originates from irrigated lands (Bruinsma, 2009). However, when faced with water shortages, agriculture is also the most likely candidate for water rationing or the elimination of irrigated cropping (Colorado River Board of California, 2000). Irrigators typically pay a small fraction of the water price charged to residential, industrial and commercial uses (Cornish and Perry, 2003), suggesting a relatively low-value use, at the margin – another factor pointing to irrigation as the balancing variable when supply shortages arise. This raises an important question: As water scarcity intensifies in many parts of the world over the coming decades, what will be the impact on irrigated cropping, agricultural trade and food security?

The world appears to be facing a looming water challenge. It is projected that by 2030 global water requirements will be 40 percent greater than current sustainable supplies, and that one-third of the world's population, mostly in developing countries, will live in areas where this deficit is larger than 50 percent (Addams et al., 2009). Alexandratos and Bruinsma (2012) argue that global water resources will be sufficient to feed the world, but the "devil is in the details" with water shortages causing high stress in specific localities. Falkenmark et al. (2009) argue that water shortages in some countries could be offset by food imports from water rich countries. In this vein, there is an emerging body of literature documenting the role of "virtual water trade" as a vehicle for achieving global water savings in the face of local shortfalls (Konar et al., 2013; Lenzen et al., 2013).

Figure 1 offers a conceptual overview of the water-food nexus. Most of the existing literature in this area focuses on some subset of the linkages portrayed in this figure. One set of studies, denoted by the blue arrow, aims to assess green-blue water footprints[1] of agricultural production for domestic consumption and export at the global (Hoekstra and Mekonnen, 2012), national (Fader et al., 2011; Hoekstra and Chapagain, 2007) and city levels (Hoff et al., 2013). Because the assessment is based on the concept of a crop's virtual water content, this line of research often contains discussions about virtual water trade. The second key linkage in the water-food nexus focuses on water use for food production and factors that potentially exacerbate or mitigate the future water availability for food production (Gerten et al., 2011; Rosegrant and Cai, 2002). This is denoted by the green arrow in Figure 1. Among these factors, agriculture's overwhelming dependence on irrigation has been a long-standing concern, which is drawing greater attention as more water is being claimed for municipal, industrial and environmental uses, thereby posing serious threats to water for food (Strzepek and Boehlert, 2010). During the past decade, there has been a surge of interest in climate change and its impact on long-term and interannual variability of water demand and supply (Hejazi et al., 2013; Kummu et al., 2013). More recently, the Renewable Fuel Standard enacted in 2005 and 2007 added a bioenergy link to water consumption, and started research on

[1]Green water refers to the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. Blue water refers to fresh surface and groundwater, in other words, the water in freshwater lakes, rivers and aquifers. The water footprint is an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer (Hoekstra and Mekonnen, 2012).

the "blue impacts of green energy" (de Fraiture, 2007; Gerbens-Leenes et al., 2012, 2009; Rosegrant et al., 2013). Moreover, in water-stressed regions water resources are often already subject to degradation of water quality, thereby exacerbating shortages (Pereira et al., 2009). Investment in water infrastructure and on-farm technologies, crop breeding strategies, implementing innovative water conservation measures and changes in policies will increase water use efficiency in both the agricultural and non-agricultural sectors, which can make more water available for food (Rosegrant et al., 2013; De Fraiture and Wichelns, 2010).

Research related to the themes of water footprints and water availability and allocation aspects usually lean heavily on hydrological modeling (e.g. the LPJml, CLIRUN-II and WGHM) or water management models (e.g. GCWM and IWSM) to answer the questions of "will there be enough water for food" and "what to do to secure the future of water for food". In contrast, the objective of this study is to explore a third aspect of the water-food nexus denoted by the red arrow in Figure 1. Specifically, we seek to evaluate the impact of projected water scarcity on the overall economy and especially on international trade in food products as well as patterns of food production and consumption. Understanding these broader impacts of water scarcity is important since the large gaps between water demand and supply in key producing regions will have to be closed by trade, investment in and adoption of technologies, and these will all come at a cost. The consequences of water scarcity are likely to be felt at the macro-economic level and can best be described through an aggregate economic modeling framework.
Research related to the themes of water footprints and water availability and allocation aspects usually lean heavily on hydrological modeling (e.g. the LPJml, CLIRUN-II and WGHM) or water management models (e.g. GCWM and IWSM) to answer the questions of "will there be enough water for food" and "what to do to secure the future of water for food". In contrast, the objective of this study is to explore a third aspect of the water-food nexus denoted by the red arrow in Figure 1. Specifically, we seek to evaluate the impact of projected water scarcity on the overall economy and especially on international trade in food products as well as patterns of food production and consumption. Understanding these broader impacts of water scarcity is important since the large gaps between water demand and supply in key producing regions will have to be closed by trade, investment in and adoption of technologies, and these will all come at a cost. The consequences of water scarcity are likely to be felt at the macro-economic level and can best be described through an aggregate economic modeling framework.

We are aware of a few global-scale modeling studies that have attempted to understand the impacts of water scarcity through an integrated hydrologic-economic analysis approach, but most of them are partial equilibrium models which take macro-economic activity as given. These include: IMPACT (Rosegrant et al., 2008), GLOBIOM (Schneider et al., 2011; Havlík et al., 2013), MagPIE (Lotze-Campen et al., 2008) and WATERSIM (de Fraiture, 2007). Although a partial equilibrium model can provide excellent sectoral detail, it does not account for interactions across the economy through labor and capital markets or inter-industry linkages. These models also treat international trade in a very simple way and abstract altogether from international capital flows. In seeking to overcome these limitations, Calzadilla et al. (2010) disaggregate irrigation in the GTAP global general equilibrium model. However, this pioneering work had serious limitations. Firstly, rainfed and irrigated production were treated as part of the same aggregate, national production function. So it was not possible to shut down irrigation in one region in favor of rainfed agriculture, or expanding irrigation in another region. Secondly, the model ignores the competition for rainfed land between agriculture and forestry. Thirdly, by specifying aggregate production relationships at the national scale, the model is unable to deal with scenarios in which different river basins in one country/region are differentially affected. As we will see below, this is a very common situation.

In this study, we first identify localized irrigation water shortfalls using a sophisticated water balance model (the IMPACT Water Simulation Model (IWSM)), and then embed these estimates within an extended version of the GTAP model (GTAP-BIO-W) to explore how changes in future water availability for irrigation will affect regional economies. In particular, we explore pathways through which irrigation constraints may affect crop production, food prices and income, and the resultant effects of these changes on bilateral trade patterns. Compared with previous studies, our approach allows for new interactions across sectors, which includes inter-sectoral linkages through intermediate inputs and competition for land, water, labor, capital and energy. Moreover, the model we proposed has the special advantage of analyzing bilateral trade flows and providing macro-economic impacts of water scarcity.

2 Methods

2.1 Model

The standard GTAP model is a multi-region, multi-sector, computable general equilibrium model, with perfect competition and constant returns to scale(Hertel, 1999). To estimate the impacts of water scarcity on agricultural production and trade, we use a special version of this model which takes into account blue water as an explicit input into irrigated agriculture. This new model is dubbed GTAP-BIO-W and is documented in (Taheripour et al., 2013a) (hereafter THL). An important improvement THL made to the GTAP model is to distinguish irrigated and rainfed cropping such that water enters irrigated production as a complementary input of land (see Figure A1). Meanwhile, the land-water composite is substitutable for other value-added inputs (labor, capital and energy), allowing for a modest endogenous yield response to prices.

Another key modification in this model is the introduction of river basins. An earlier version of the model employed agro-ecological zones (AEZ) in recognition of the fact that significant climate and soil variations within economic regions require more refined spatial units for modeling. However, the presence of irrigation water, drawn from a given river basin, further complicates this picture.

When AEZs cut across river basins, production conditions may differ, even within the same AEZ. Therefore, the GTAP-BIO-W model allows crops to compete for land within the AEZ, in addition to a second layer of competition in which irrigated cropping activities compete for irrigation water within a river basin. The total water available for irrigation is exogenously specified in each river basin and will be varied in the context of our scarcity scenarios.

2.2 Data

The core data we are using is the GTAP v6 database, which represents the level of production, consumption and trade in 2001. The reason for adopting this older GTAP data set is that it is compatible with the land and water data currently available on a global basis (Portmann et al., 2010; Monfreda et al., 2008). Each crop sector is split into two distinct sectors–irrigated and rainfed, based on the share of irrigated versus rainfed output as reported in the MIRCA2000 data (Portmann et al., 2010). In addition, this source provides estimates of the irrigated/rainfed yield differential, as well as the water used for irrigation by crop type. We attribute the value of higher irrigated yields within a given AEZ to the presence of irrigation. Subtracting this imputed input value from the water-land composite yields the (residual) contribution of land. The third step is to distribute the land and water value-added to each river basin-AEZ. We assume that the spatial distribution of value-added follows that of output across basin-AEZs. Segmentation of each region into Basin-AEZs is achieved by overlaying the Global Agro-Ecological Zone map (Fischer et al., 2000) with the IWSM river basin map (Rosegrant et al., 2008). Because each segment is matched with grids using geographical coordinates, we are able to aggregate grid-cell level output provided by Monfreda et al. (2008) into values at basin-AEZs. The procedures about preparing the dataset follow Taheripour et al. (2013b). Our GTAP-BIO-W data base breaks out 19 GTAP regions. Each region contains up to 18 AEZs and 20 river basins. Globally, the water system is divided into 126 river basins (Table A1). See Table A2 for a breakdown of sectors that comprise each regional economy.

2.3 Experimental Design: Water scarcity shock

Not only is irrigated agriculture the most important source of demand for global freshwater withdrawals, it is also typically the residual claimant on water within a given river basin. Therefore, in order to deduce the supply of water for irrigation at any point in time, it is important to understand not only the hydrological flows, but also the residential, industrial and environmental demands for water. If the latter expand, and total water availability in the river basin is unchanged, then the effective supply of water for irrigation purposes is likely to be reduced. Conversely, if there are strong efficiency gains in industrial water use, for example, this might translate into increased water availability for irrigation, even though supply in the river basin is unchanged. To this one must add investments in dams and other infrastructure for capturing water. In short, estimating future water availability for irrigation is a significant challenge.

In this study, we adopt the Irrigation Water Supply Reliability (IWSR) index as the metric of irrigation water availability. IWSR is defined as the proportion of potential demand that is realized in actual consumption[2], on an annual basis. If this index equals one, then all demand is met and there is no irrigation shortfall. In a global analysis undertaken at the level of 126 hydrological basins and 281 "food-producing units" (FPUs), Rosegrant et al. (2013) estimate IWSR's for 2000 and 2030 using the IMPACT-WATER model (see Appendix B).

Of course the IWSR in 2030 depends on a great variety of forces. Therefore, Rosegrant et al. (2013) consider several different scenarios. Here, we draw on their "business as usual" scenario, which assumes a continuation of current trends in population and economic growth, water use efficiency in agricultural, industrial and domestic uses, and the implementation of existing plans for investments in water supply infrastructure capacity (e.g. reservoir storage, surface water withdrawals and groundwater withdrawals). The impact of climate change is not included in these projections due to the high degree of uncertainty in precipitation projections. Moreover, several studies have shown that the effects of changes in population on water shortages are much more important than changes in water availability as a result of climate change (Kummu et al., 2013; Vörösmarty et al., 2000).

It is important to note that our experimental design amounts to investigation of the impact of future water scarcity on the pattern of economic activity in the current economy. In this way, we avoid confounding the uncertainty associated with economic projections of the future, with the response of the economy to water scarcity. Therefore, we run a comparative static simulation in which only basin water supply is shocked to reflect water available for irrigation in 2030. This is analogous to the approach taken by Hertel et al. (2010) to the poverty impacts of climate change.

The results of the underlying water modeling based on Rosegrant et al. (2013) are summarized in Map 1 which reports IWSRs globally for these two base years. The difference between these two maps (see also Table B1) provides the basis for our experiment in which basin level water supply for irrigation is shocked by the percentage change in the IWSR index from 2000 to 2030. Contrasting 2030 with the IWSR for 2000, we see an increase of irrigation water scarcity in parts of Asia–particularly Pakistan (Indus basin, -43%), China (Haihe, -64%) and India (Luni basin, -61%), as well as in East Africa and parts of South America. These estimates suggest that, among the nineteen regions in our global economic model, IWSR index will fall in eleven regions by 2030, with the largest reductions occurring in the South Asia excluding India (-33%) and China (-22%) as scarcity outpaces significant investments. Irrigation water supply will remain largely unchanged in Canada and Japan, and will slightly increase in the US, EU, Central and Caribbean Americas and Oceania countries as a result of anticipated investment in irrigation infrastructure.

[2]Potential demand is the demand for irrigation water in the absence of any water supply constraints, whereas actual consumption of irrigation water is the realized water demand, given the limitation of water supply for irrigation.

3 Results and discussion

3.1 Impacts on agricultural output

A reduction in water available for irrigation might be expected to result in a reduction in irrigated output, but this is not necessarily the case. One of the key determinants is the location of the irrigated crop production. With current irrigated areas and crop composition unchanged, less irrigation may lower yields and output. However, if irrigated farming is allowed to migrate from arid AEZs to less arid AEZs[3] within the same river basin, it is not impossible that at least the same amount of crop can be produced from less water. Furthermore, even though irrigated production is negatively affected due to insufficient irrigation, total output may not fall by much if irrigated farming accounts for only a small portion of total crop production in that country, and if the supply of rainfed land is relatively price responsive.

Figure 2 plots the change in regional crop output in response to irrigation stress in 2030. While more secure irrigation raises total crop output in every case[4], less irrigation does not always mean lower regional output. The biggest output reductions occur in the rest of South Asia, the Middle East and North Africa (MENA), China and India. These regions face significant and growing water scarcity and also rely heavily on irrigation. Sub-Saharan Africa and Russia, on the other hand, are projected to increase agricultural output, despite having more unmet irrigation demand. The reason is that irrigated farming is modest in these regions, providing only 14.3 and 5.5 percent of total crop output value, respectively. In the face of higher crop prices, these regions expand rainfed production and therefore increase overall output.[5] Globally, the large output losses in Asian and MENA countries outweigh the gains elsewhere, leading to a reduction in world crop output (Figure C1). Livestock and processed food sectors, which use crops as primary inputs, are negatively affected as well. The only exception is the processed feed sector, the supply of which goes up marginally (0.29%), primarily driven by the strong demand for processed feed inputs from the USA, EU and China. Moreover, producing processed feed uses a substantial amount of oilseeds meal, a by-product of vegetable oil, making it an appealing substitute for higher priced crops.

3.2 Land use change

With sufficient inputs to allow production to take place at competitive prices, water rich regions tend to produce more from both irrigated and rainfed land, not only to substitute domestic goods

[3]Global AEZ in GTAP is defined as the combination of moisture regime and climate zone. Global climate is divided into three zones–tropical, temperate and boreal. Each climate zone has the possibility of covering up to six types of moisture regimes ranging from arid to year-round growing season humid.

[4]The endowment market clearing condition assures that any augmentation of irrigation water supply at a certain basin will be fully absorbed by crop production through either expanding irrigated areas or adjusting the output composition of irrigated crops (representing different irrigation intensity). Hence, the situation of excessive irrigation water supply and flooding is ruled out.

[5]Also note that in our model, consumers adjust consumption to price change. If otherwise we assume consumers maintain their food consumption regardless of price, the expansion of rainfed output is expected to be even larger.

for imports, but also to expand their exports. By contrast, regions confronted with water stress are more likely to cut back irrigated acreage and switch production to rainfed areas if and when precipitation is sufficient for crops to grow. Given the fact that irrigated land is generally more productive, farmers using less irrigation will need more land to produce the same amount of output. If the yield differential is large enough, even producing less would need more hectares. Within our framework, this additional rainfed crop area must be converted from either forest or pasture land. Less pasture land leads to higher grazing costs. This imposes pressure on livestock supply, which–when combined with climbing demand for meat–could further drive up prices of livestock products. In addition, forests and grazing land are generally more carbon-rich than cropland (Plevin et al., 2011). That means land use change is likely to create more carbon emissions in the water scarce regions (Taheripour et al., 2013b).

To examine the land use effects of projected changes in irrigation water availability, we partition the total output change into contributions from two categories, irrigated and rainfed (Figure 3). Not surprisingly, irrigation stress leads to reduced irrigated output and expanded rainfed output in those regions experiencing increased scarcity but with sufficient precipitation levels to allow for a rainfed crop. Map 2 displays the change of irrigated and rainfed harvested areas and land conversion between cropland and other land cover types, compared to the pre-experiment situation. We find that land use conversion toward agriculture is highest in sub-Sahara Africa, followed by India and MENA, with area increases of 1.61, 1.20 and 0.89 million hectares, respectively. Globally, 7.61 million hectares of land needs to be converted from forest and range for cropping. This amount is equivalent to 0.5% of the world's total cropland resource, and is roughly equal to the area Panama.

3.3 Impacts on bilateral international trade

Future water scarcity can change the global patterns of trade in farm and processed food products as it raises the cost of crop production and, as a result, domestic commodity prices. Indeed, in this scenario, prices rise almost everywhere, but much more in the water scarce regions, making it more appealing for water-short countries to buy from the international market. For the same reason, water scarce regions reduce price advantages in overseas markets and export less than before. We use Figure 4 to show changes in bilateral net flows of food between regions, compared to the pre-experiment status. After the shock, South Asia, China, and the MENA countries' status as net food importers are strengthened. They import primarily from North and South America, Europe and Southeast Asia. South Asia, excluding India, is the only region fails to increase net exports to any other regions. Even China increases net exports to one region – namely Rest of South Asia. This result is consistent with the fact that Rest of South Asia experiences the largest reduction in IWSR.

Next, we consider the trade balance. As discussed above, water scarce regions tend to export less and import higher volumes, but at higher prices. The aggregate effect on exports is usually dominated by changes in export quantities. Thus, the export value falls in regions that are losing water for irrigation. The import value rises due to both larger quantities and higher prices. Higher import and lower export values together explain the worsened agricultural trade balance in the water scarce regions. Model projections suggest the largest agricultural and food trade deficit owing to irrigation stress for the rest of South Asia ($US -1.35 billion), with a relatively large gap also for China ($US -1.08 billion), India ($US -0.44 billion) and the MENA region ($US -0.6 billion).

The 2030 irrigation shocks strengthen regional heterogeneity in terms of resource endowment, thereby encouraging international trade. Future water scarcity results in increased global trade volumes for most farm and food commodities. Exceptions include raw sugar crops and dairy cattle (both very lightly traded internationally), processed ruminant meats, processed rice and processed food. One reason for the reduced trading in these commodities is that water scarce regions are the major suppliers in the global market. For example, Asian and MENA countries currently supply more than 60% of global processed rice exports. In addition, the US and EU, the world's largest processed ruminant and processed food suppliers, produce less as inputs are diverted to crop sectors. Besides, a significant portion of the exports of these products are traded with Japan, North American and EU countries[6], where demand for imports has not been increased as much as in Asian developing countries.

Apart from its macroeconomic implications, international trade in food products is closely intertwined with food security and the debate on food self-sufficiency versus specialization in agriculture. The degree of self-sufficiency is normally measured by a food self-sufficiency ratio or the share of domestic production in total domestic use. Our results show that this ratio falls slightly for most of the Asian countries, indicating their increasing dependence on international food markets. This signals a likely rise in virtual water trade, as has been projected in several studies (Rosegrant et al., 2010; Dalin et al., 2012) since exporting a hectare of less water-intensive crop allows for the import of a greater amount of more water-intensive food than what would be produced if the hectare were devoted to high water-consuming crops.

3.4 Water productivity and water content over land

When water becomes expensive, it is expected that crop production will become more water-saving. This can happen in two different ways. First of all, the distribution of crop production can change, so that it is produced in AEZs where less irrigation water is required. The significance of this composition effect can be observed by comparing pre- and post-experiment regional water content over land[7]. If this content at the region is lower after the simulation, irrigated production is shifted

[6]In particular, as represented by GTAP V6 data, the US and EU produce 60% of world's processed ruminant (PR) products and 51% of processed food (PF). 58% of US's PR export and 53% of US's PF export go to the EU, Canada and Japan. 87% of EU's PR export and 80% of EU's PF export go to the EU, US, Canada and Japan.

[7]Water and land in the GTAP-BIO-W model are complementary inputs for crop production. That means water content over land remains unchanged at basin-AEZ level after the simulation, but the regional water content could

away from the parcel that needs a large amount of irrigation. We find that water content per hectare of land harvested drops the most in water scarcity regions (Figure C2).The second mechanism for sparing irrigation water is to substitute water with other value-added inputs, which could involve increased capital or labor costs. Comparing the rate of irrigated output change relative to the rate of input change, we find that, in most cases, the "crop per drop" of irrigation water increases, indicating that water productivity rises (Figure 5). This enhancement is particularly prominent in China, and South and Southeast Asia.

3.5 Macro-economic effects of water scarcity

Globally, welfare (a money metric equivalent of aggregate household utility) declines by $US3.7 billion (2001 prices) as a result of the changes in water scarcity between 2000 and 2030. About one-third of the welfare loss is attributed to less efficient resource allocation (both for water and non-water resources), while the rest is attributed to the reduced water availability for irrigation. The latter is quite understandable given the increased irrigation water shortages in many regions. The former, however, is a little more complicated because inefficiency occurs both in regions with and without irrigation reduction, but for different reasons. The intuition behind welfare change associated with resource allocation is that, increasing (decreasing) the level of a subsidized (taxed) activity will tend to harm the economy, since it further encourages the inefficient resource usage that already exists under the protection of subsidy. Our base data reflects the fact that agriculture in the US and EU tends to be heavily subsidized, but was taxed in China at the time this data base was constructed[8]. Thus, future water scarcity shifts agricultural production towards relative high cost regions where farming is heavily subsidized, thereby reducing global welfare.

While the terms of trade do not affect global welfare, they are the second largest contributor to regional welfare changes following the effects of endowment loss. Because of the higher commodity prices in the global market, net exporters (e.g. American and Oceanian countries) benefit while net importers (e.g. EU, East Asian and MENA countries) experience a welfare loss from international price changes.

Since our analytical framework does not model water usage by municipal and industrial sectors or aquatic ecosystems, the corresponding welfare changes are not included in the assessment. Hence, the welfare loss estimation provided here serves only as a lower bound of the actual welfare loss that could be caused by future water scarcity.

be different depending on the weighting of each water-land composite. The water content over land in this paper is computed as the share of water in total value of water-land composite.

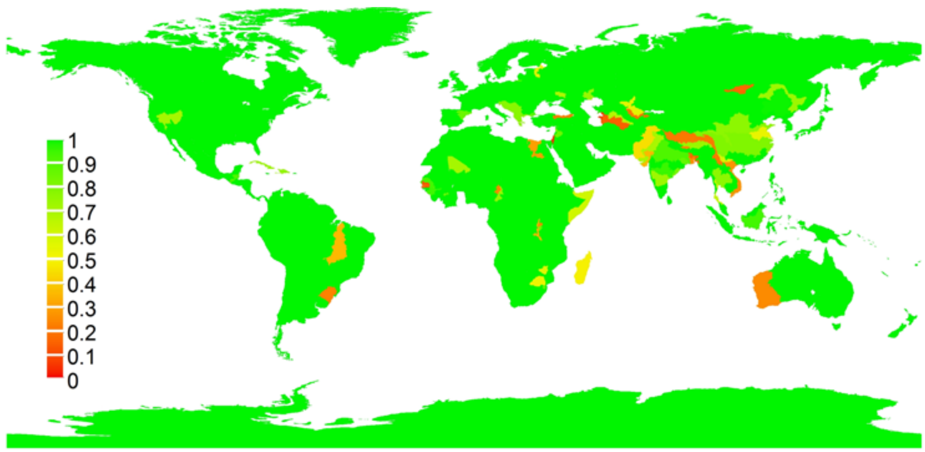
[8]As Anderson and Martin (2009) note, the nominal rate of assistance to agriculture in China has been evolving from taxation to subsidization. If we reran this analysis with more current data (no yet available), we would expect this aspect of the efficiency impacts to diminish and potentially to reverse sign

4 Conclusion

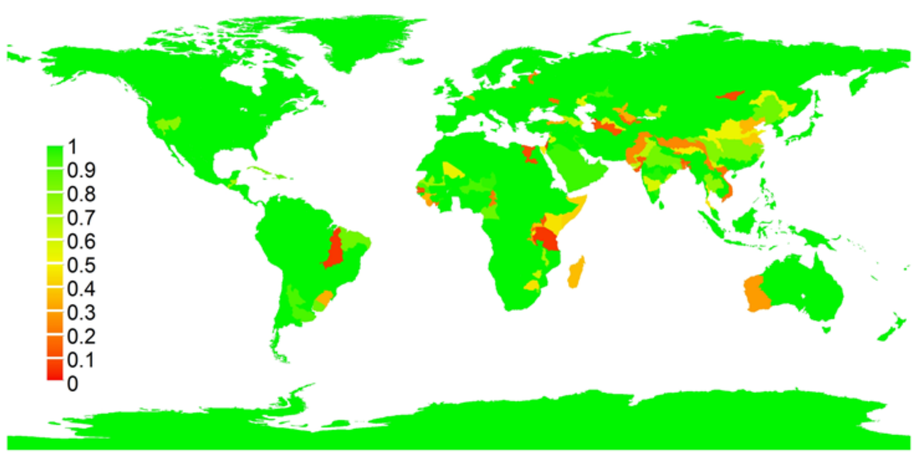
This study contributes useful insights into research concerned with water availability and how it affects agriculture and international trade. First, water scarcity does not always translate into less total regional crop output. The outcome depends on price effects and regional supply response. In affected regions where irrigation is less dominant (e.g. Sub-Sahara Africa) crop output may rise under water scarcity due to higher world prices. Thus, analyses of the water-food nexus that overlook supply responses to price will likely overstate the negative effect of water scarcity on regional and global food supplies.

Second, water scarcity tends to boost international agricultural trade as well as altering its geography. Although the overall increase in world food exports is only modest, some types of inter-regional food trade are strengthened as America and Europe export more to Asia. Some Asian countries that used to rely on imports from China and India are expected to trade more heavily with non-Asian partners as their neighbors export less agricultural and food commodities due to water scarcity. This change may also have implications for trade policies and incentives to engage in regional trade agreements.

Third, many water scarcity studies focus on crop production impacts, but this tells only part of the story. Apart from the direct effect of water shortages on yields and crop areas, macro-economic outcomes are also affected by prices and international trade. Despite experiencing negative output shocks due to water scarcity, some countries may gain from higher commodity prices. Regions can also take advantage of trade to adjust the composition of agricultural income and specialize in more beneficial commodities. Our approach has the advantage of capturing these economic adaptations and spillover effects, as well as providing a money metric measure of what future water scarcity for agricultural irrigation will cost the world–which we estimate to be $US3.7 billion at 2001 prices.

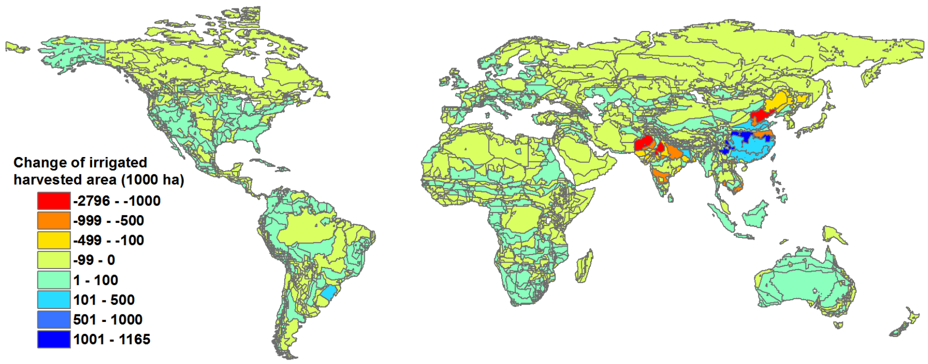


(a) IWSR in 2000

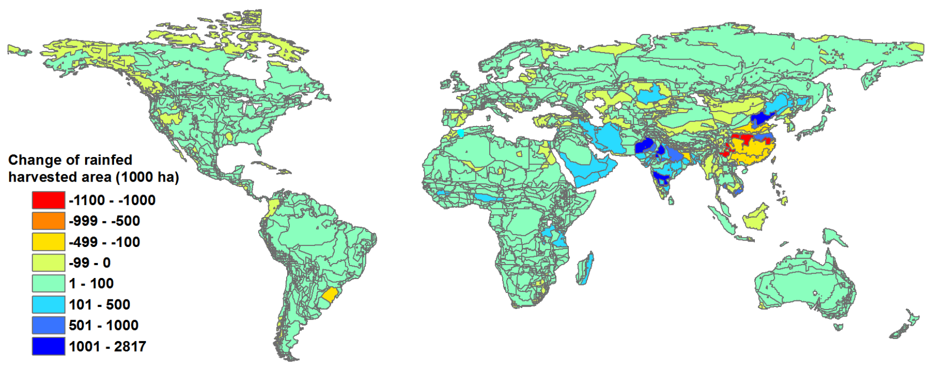


(b) IWSR in 2030

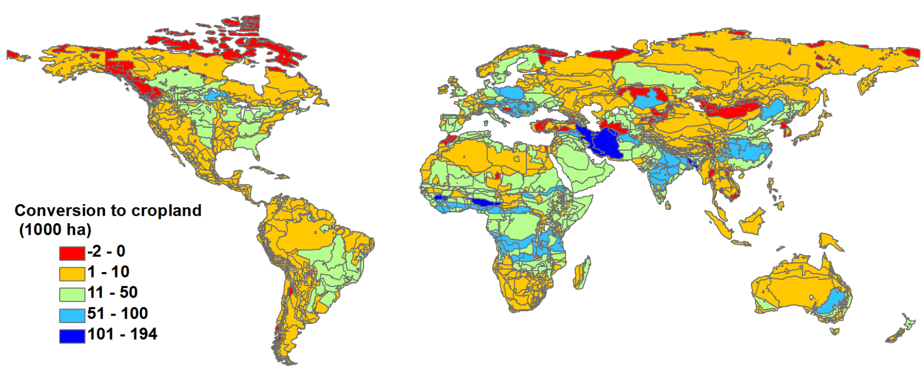
Map 1. Evolving irrigation water supply reliability (IWSR) index at river basin level Rosegrant et al. (2013).



(a) Change of irrigated harvested area (Global total reduction: 11.45 million hectares).



(b) Change of rainfed harvested area (Global total increase: 19.06 million hectares).



(c) Total land conversion to cropland (Global total conversion: 7.61 million hectares).

Map 2. Global harvested area change and land conversion, shown at river basin-AEZ level. In (a) and (b), positive numbers indicate area expansion compared to the pre-experiment situation. Conversion in (c) is calculated as the sum of (a) and (b), in which positive numbers indicate that forest and pasture are converted to cropland.

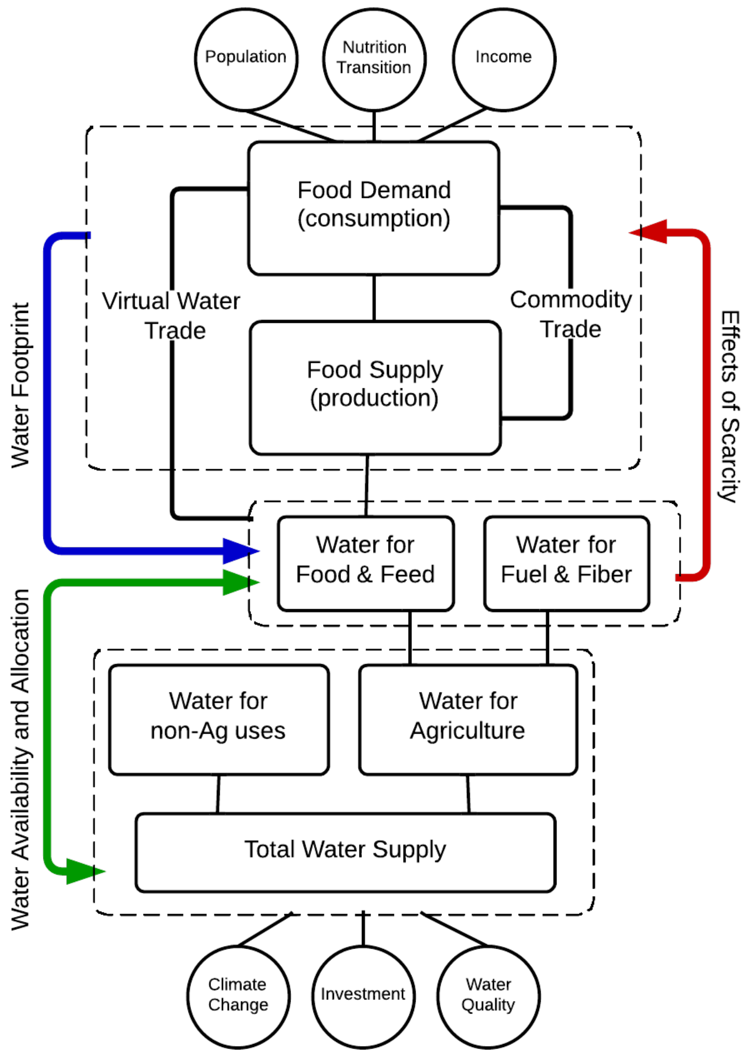


Figure 1. Conceptualizing the water-food nexus

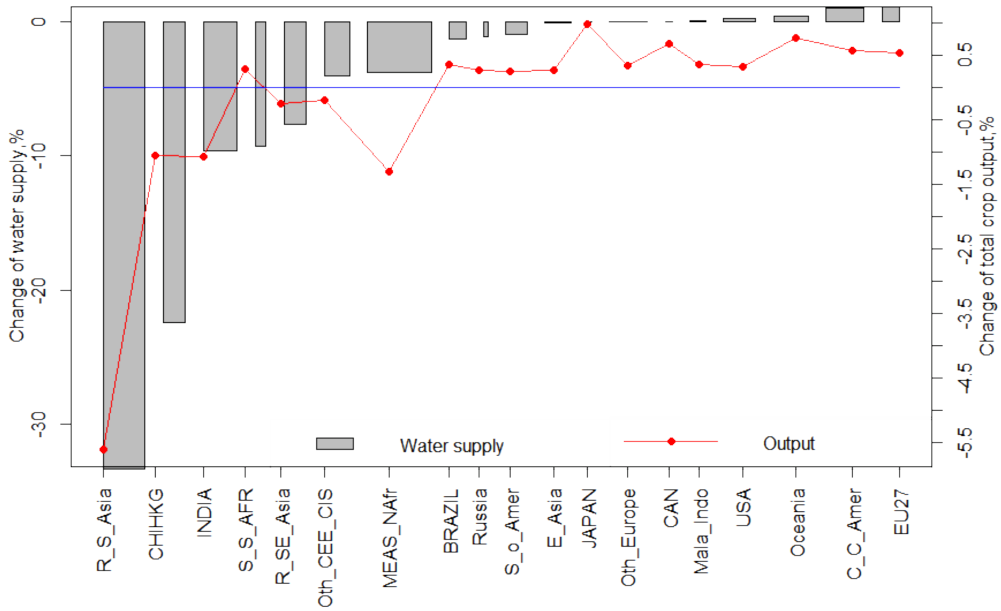


Figure 2. Crop output (left axis) response to regional water scarcity (right axis). Output change is computed as the weighted-average of each individual crop's output change. The weight is determined by the crop's contribution to total output value. Regional water scarcity is computed as the weighted-average of basin-level changes. The share is determined by each basin's contribution to the region's output value added by water. Bar width is proportional to the share of output value that is from irrigated crops in the region.

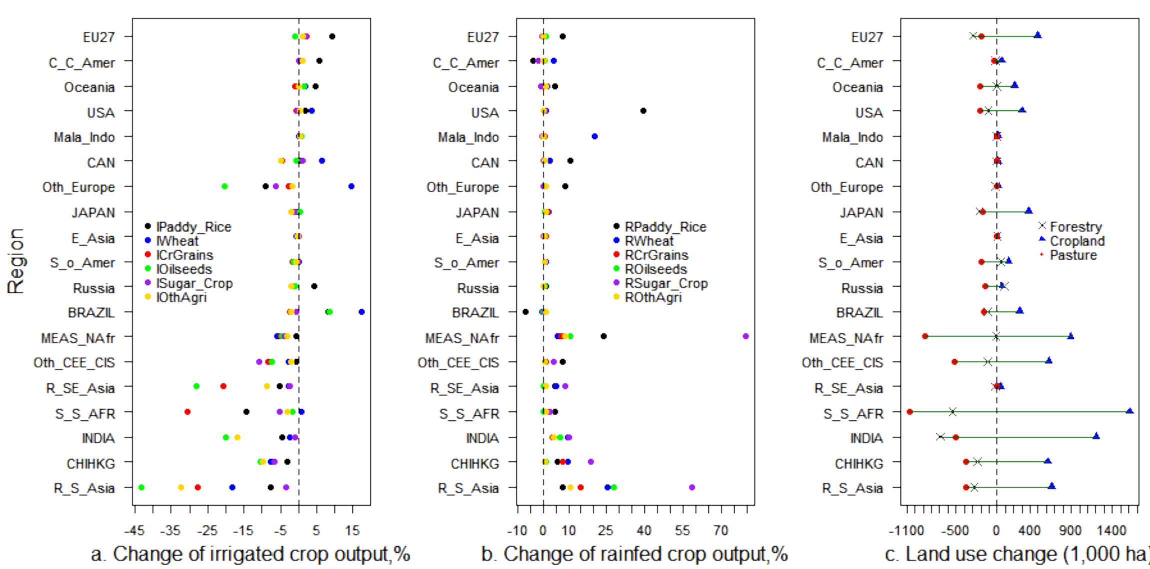


Figure 3. Change of irrigated (a) and rainfed (b) crop output and subsequent land use change (c).

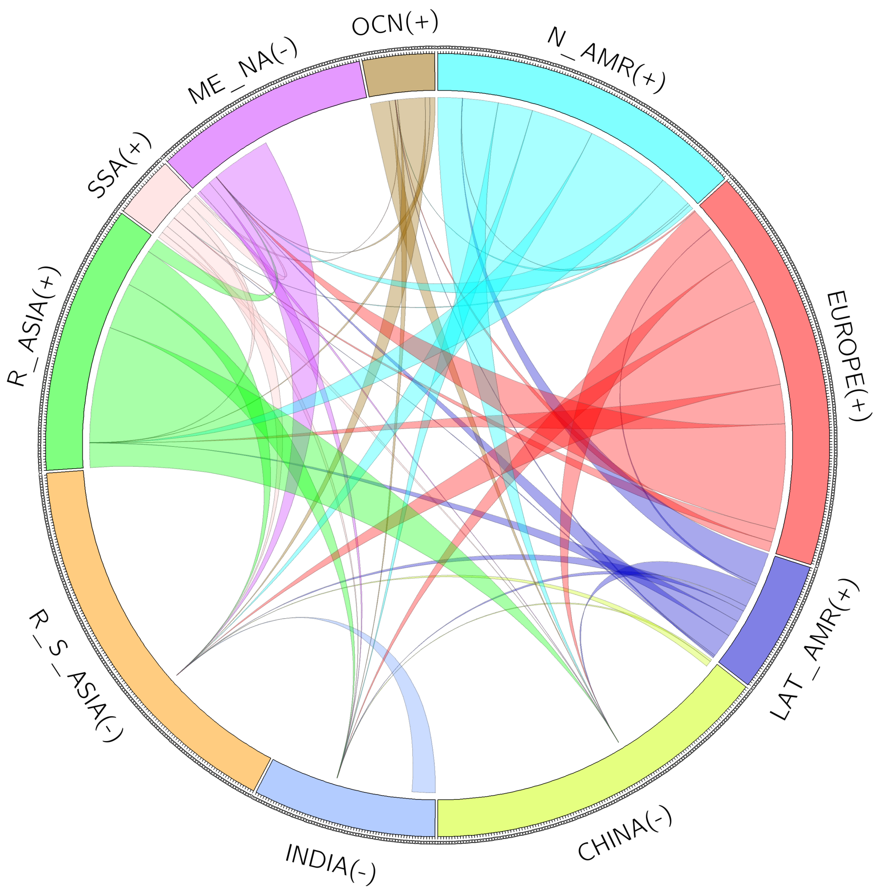


Figure 4. Change in net bilateral trade flow of food and agricultural products. Here food and agricultural products include crops, livestock and processed livestock products and processed food products (see Table A2 for detailed information). The Arc length is proportional to the magnitude of the flow. Wide end is the sending region; pointed end is the receiving region. + means increase in net exporting; - means increase in net importing. Trading within the region is excluded.

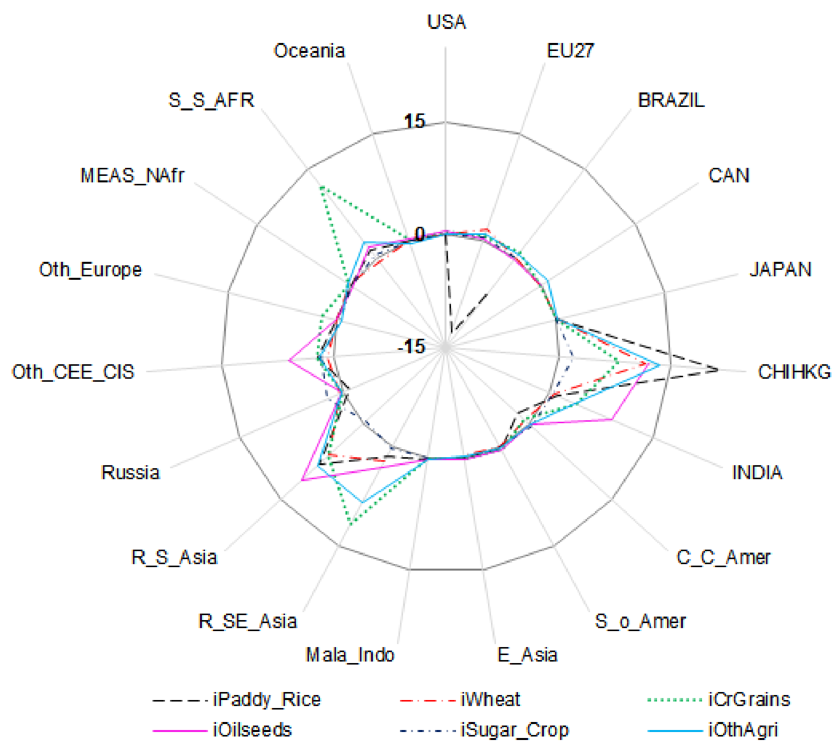


Figure 5. Change in aggregate water efficiency. What is plot is the percentage change of irrigated output minus the percentage change of irrigation water input. Positive number means that the rate of output increase is faster than input increase, or conversely the rate of output reduction is slower than input reduction. In other words, there is an irrigation efficiency gain after the water shock.

References

Addams, L., G. Boccaletti, M. Kerlin, and M. Stuchtey (2009). Charting our water future: economic frameworks to inform decision-making. *McKinsey & Company, New York, USA. OpenURL*.

Alexandratos, N. and J. Bruinsma (2012). World agriculture towards 2030/2050: the 2012 revision. Technical report, ESA Working paper Rome, FAO.

Anderson, K. and W. Martin (2009). Chapter 9: China and southeast asia. in distortions to agricultural incentives: A global perspective, 1955-2007.

Bruinsma, J. (2009). The resource outlook to 2050. In *expert meeting on How to Feed the World in 2050*.

Calzadilla, A., K. Rehdanz, and R. S. Tol (2010). The economic impact of more sustainable water use in agriculture: A computable general equilibrium analysis. *Journal of Hydrology 384*(3), 292–305.

Colorado River Board of California (2000). *California's Colorado River Water Use Plan*.

Cornish, G. and C. Perry (2003). Water charging in irrigated agriculture. lessons from the field. *Report OD 150*.

Dalin, C., M. Konar, N. Hanasaki, A. Rinaldo, and I. Rodriguez-Iturbe (2012). Evolution of the global virtual water trade network. *Proceedings of the National Academy of Sciences 109*(16), 5989–5994.

de Fraiture, C. (2007). Integrated water and food analysis at the global and basin level. an application of watersim. *Water Resources Management 21*(1), 185–198.

De Fraiture, C. and D. Wichelns (2010). Satisfying future water demands for agriculture. *Agricultural Water Management 97*(4), 502–511.

Fader, M., D. Gerten, M. Thammer, J. Heinke, H. Lotze-Campen, W. Lucht, and W. Cramer (2011). Internal and external green-blue agricultural water footprints of nations, and related water and land savings through trade. *Hydrology and Earth System Sciences Discussions 8*(1), 483–527.

Falkenmark, M., J. Rockström, and L. Karlberg (2009). Present and future water requirements for feeding humanity. *Food security 1*(1), 59–69.

Fischer, G., H. Van Velthuizen, F. Nachtergaele, and S. Medow (2000). Global agro-ecological zones (global-aez). *FAO/IIASA*.

Gerbens-Leenes, P., A. v. Lienden, A. Hoekstra, and T. H. van der Meer (2012). Biofuel scenarios in a water perspective: The global blue and green water footprint of road transport in 2030. *Global Environmental Change 22*(3), 764–775.

Gerbens-Leenes, W., A. Y. Hoekstra, and T. H. van der Meer (2009). The water footprint of bioenergy. *Proceedings of the National Academy of Sciences 106*(25), 10219–10223.

Gerten, D., J. Heinke, H. Hoff, H. Biemans, M. Fader, and K. Waha (2011). Global water availability and requirements for future food production. *Journal of Hydrometeorology 12*(5), 885–899.

Havlík, P., H. Valin, A. Mosnier, M. Obersteiner, J. S. Baker, M. Herrero, M. C. Rufino, and E. Schmid (2013). Crop productivity and the global livestock sector: implications for land use change and greenhouse gas emissions. *American Journal of Agricultural Economics 95*(2), 442–448.

Hejazi, M., J. Edmonds, L. Clarke, P. Kyle, E. Davies, V. Chaturvedi, J. Eom, M. Wise, P. Patel, and K. Calvin (2013). Integrated assessment of global water scarcity over the 21st century-part 2: Climate change mitigation policies. *Hydrology and Earth System Sciences Discussions 10*, 3383–3425.

Hertel, T. W. (1999). *Global trade analysis: modeling and applications.* Cambridge university press.

Hertel, T. W., M. B. Burke, and D. B. Lobell (2010). The poverty implications of climate-induced crop yield changes by 2030. *Global Environmental Change 20*(4), 577–585.

Hoekstra, A. Y. and A. K. Chapagain (2007). Water footprints of nations: water use by people as a function of their consumption pattern. *Water resources management 21*(1), 35–48.

Hoekstra, A. Y. and M. M. Mekonnen (2012). The water footprint of humanity. *Proceedings of the National Academy of Sciences 109*(9), 3232–3237.

Hoff, H., P. Döll, M. Fader, D. Gerten, S. Hauser, and S. Siebert (2013). Water footprints of cities–indicators for sustainable consumption and production. *Hydrology and Earth System Sciences Discussions 10*(2), 2601–2639.

Konar, M., Z. Hussein, N. Hanasaki, D. Mauzerall, and I. Rodriguez-Iturbe (2013). Virtual water trade flows and savings under climate change. *Hydrology and Earth System Sciences Discussions 10*(1), 67–101.

Kummu, M., D. Gerten, J. Heinke, M. Konzmann, and O. Varis (2013). Climate-driven interannual variability of water scarcity in food production: a global analysis. *Hydrology and Earth System Sciences Discussions 10*(6), 6931–6962.

Lenzen, M., D. Moran, A. Bhaduri, K. Kanemoto, M. Bekchanov, A. Geschke, and B. Foran (2013). International trade of scarce water. *Ecological Economics 94*, 78–85.

Lotze-Campen, H., C. Müller, A. Bondeau, S. Rost, A. Popp, and W. Lucht (2008). Global food demand, productivity growth, and the scarcity of land and water resources: a spatially explicit mathematical programming approach. *Agricultural Economics 39*(3), 325–338.

Molden, D. (2007). Water for food, water for life: a comprehensive assessment of water management in agriculture: summary.

Monfreda, C., N. Ramankutty, and J. A. Foley (2008). Farming the planet: 2. geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles 22*(1).

Pereira, L. S., I. Cordery, and I. Iacovides (2009). *Coping with water scarcity: Addressing the challenges.* Springer.

Plevin, R., H. Gibbs, J. Duffy, S. Yui, and S. Yeh (2011). Agro-ecological zone emission factor model. *USA: California Air Resource Board. OpenURL.*

Portmann, F. T., S. Siebert, and P. Döll (2010). Mirca2000global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modeling. *Global Biogeochemical Cycles 24*(1).

Rosegrant, M. W. and X. Cai (2002). Global water demand and supply projections: part 2. results and prospects to 2025. *Water International 27*(2), 170–182.

Rosegrant, M. W., S. A. Cline, and R. A. Valmonte-Santos (2010). *Global Water and Food Security: Megatrends and Emerging Issues.* Springer.

Rosegrant, M. W., S. Meijer, and S. A. Cline (2008). *International model for policy analysis of agricultural commodities and trade (IMPACT): Model description.* International Food Policy Research Institute Washington, DC, USA.

Rosegrant, M. W., C. Ringler, T. Zhu, S. Tokgoz, and P. Bhandary (2013). Water and food in the bioeconomy: Challenges and opportunities for development. *Agricultural Economics*.

Schneider, U. A., P. Havlík, E. Schmid, H. Valin, A. Mosnier, M. Obersteiner, H. Böttcher, R. Skalskỳ, J. Balkovič, T. Sauer, et al. (2011). Impacts of population growth, economic development, and technical change on global food production and consumption. *Agricultural Systems 104*(2), 204–215.

Strzepek, K. and B. Boehlert (2010). Competition for water for the food system. *Philosophical Transactions of the Royal Society B: Biological Sciences 365*(1554), 2927–2940.

Taheripour, F., T. W. Hertel, and J. Liu (2013a). Introducing water by river basin into gtap model. *GTAP working paper 77, Center for Global Trade Analysis, Purdue University, West Lafayette, IN, USA*.

Taheripour, F., T. W. Hertel, and J. Liu (2013b). The role of irrigation in determining the global land use impacts of biofuels. *Energy, Sustainability and Society 3*(1), 1–18.

Vörösmarty, C. J., P. Green, J. Salisbury, and R. B. Lammers (2000). Global water resources: vulnerability from climate change and population growth. *science 289*(5477), 284.

Zhu, T., C. Ringler, M. M. Iqbal, T. B. Sulser, and M. A. Goheer (2013). Climate change impacts and adaptation options for water and food in pakistan: scenario analysis using an integrated global water and food projections model. *Water International 38*(5), 651–669.

Appendix A: Structure of the GTAP-BIO-W model

A brief description of the standard GTAP model can be found in Hertel et al. (2010). Details about the GTAP-BIO-W model can be found in Taheripour et al. (2013a). This section describes some salient features of the model.

Each crop production is split into two sectors – irrigated and rainfed. They produce the same commodity and share the same cost structure for non-water inputs. Thus, any additional productivity associated with irrigated crop is completely explained by the use of irrigation. The revenue difference generated by water is equivalent to the shadow value of water.

Total water endowment is fixed at the river basin level, but water can be drawn by different AEZs. To represent this fluid water movement, we give a relatively large elasticity of substitution parameter (Ω=20) to land parcels that share the same river basin. Irrigated farming in different AEZs competes for water (blue boxes). Livestock, rainfed crops and forestry compete for land (yellow boxes). The model also allows for land conversion by assigning a relatively large elasticity of substitution parameter (Ω=10) to the nesting of managed land. See Taheripour et al. (2013b) for region and crop aggregation. See Table A1 and A2 for river basins and sectors included in the model.

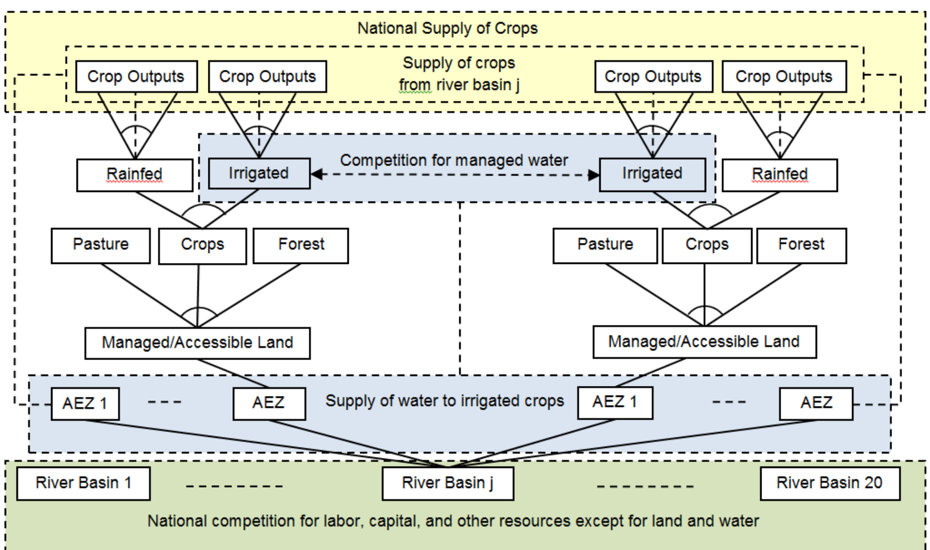


Figure A. Schematic of crop production in the GTAP-BIO-W model

Table A1: Basin codebook

Basin No.	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG
B1	Arkansas	Baltic	Amazon	Canada Arctic Atlantic	Japan	Amur
B2	California	Britain	North South Amri. Coast	Central Canada Slave Basin	Others	Brahmaputra
B3	Canada Arctic Atlantic	Danube	Northeast Brazil	Columbia	NA	Chang Jiang
B4	Colorado	Dnieper	Orinoco	Great Lakes	NA	Ganges
B5	Columbia	Elbe	Parana	Red Winnipeg	NA	Hail He
B6	Great Basin	Iberia East Med	San Francisco	US Northeast	NA	Hual He
B7	Great Lakes	Iberia West Atlantic	Toc	MacKenzie	NA	Huang He
B8	Mississippi	Ireland	Uruguay	Pacific Namer North	NA	Indus
B9	Missouri	Italy	Others	Others	NA	Langcang Jiang
B10	Ohio	Loire Bordeaux	NA	NA	NA	Lower Mongolia
B11	Red Winnipeg	North Euro Russia	NA	NA	NA	North Korea Peninsula
B12	Rio Grande	Oder	NA	NA	NA	Ob
B13	Southeast US	Rhine	NA	NA	NA	SE Asia Coast
B14	US Northeast	Rhone	NA	NA	NA	Songhua
B15	Upper Mexico	Scandinavia	NA	NA	NA	Yili He
B16	Western Gulf Mex	Seine	NA	NA	NA	Zhu Jiang
B17	Pacific Namer North	Others	NA	NA	NA	Mekong
B18	Others	NA	NA	NA	NA	Others
B19	NA	NA	NA	NA	NA	NA
B20	NA	NA	NA	NA	NA	NA

Basin No.	INDIA	Central America	South America	East Asia	MYS & IDN	R. Southeast Asia
B1	Brahmaputra	Carribean	Amazon	Amur	Borneo	Borneo
B2	Brahmari	Central Amri.	Chile Coast	North Korea Peninsula	Indonesia East	Langcang Jiang
B3	Cauvery	Cuba	Northeast South Amri.	South Korea Peninsula	Indonesia West	Mekong
B4	Chotanagpui	Middle Mexico	Northwest South Amri.	Lower Mongolia	Papau Oceania	Philippines
B5	Easten Ghats	Northwest South Amri.	Orinoco	Upper Mongolia	Thai Myan Malay	SE Asia Coast
B6	Ganges	Rio Grande	Parana	Others	Others	Thai Myan Malay
B7	Godavari	Upper Mexico	Peru coastal	NA	NA	Others
B8	India East Coast	Yucatan	Rio colorado	NA	NA	NA
B9	Indus	Others	Salada Tierra	NA	NA	NA
B10	Krishna	NA	Tierra	NA	NA	NA
B11	Langcang Jiang	NA	Uruguay	NA	NA	NA
B12	Luni	NA	Others	NA	NA	NA
B13	Mahi Tapti	NA	NA	NA	NA	NA
B14	Sahyada	NA	NA	NA	NA	NA
B15	Thai Myan Malay	NA	NA	NA	NA	NA
B16	Others	NA	NA	NA	NA	NA
B17	NA	NA	NA	NA	NA	NA
B18	NA	NA	NA	NA	NA	NA
B19	NA	NA	NA	NA	NA	NA
B20	NA	NA	NA	NA	NA	NA

Table A1 (cont.): Basin codebook

Basin No.	R. South Asia	Russia	E-Europe-RFSU	R. Europe	M-East-N-Afri,	SSA	Oceania
B1	Amudarja	Amur	Amudarja	Rhine	Arabian Peninsula	Central Afri. West Coast	Central Australia
B2	Brahmaputra	Baltic	Amur	Rhone	Black Sea	Congo	Eastern Australia Tasmania
B3	Ganges	Black Sea	Baltic	Scandinavia	Eastern Med	East Afri. Coast	Murray Australia
B4	Indus	Dnieper	Black Sea	Others	Nile	Horn of Afri,	New Zealand
B5	Sri Lanka	Lower Mongolia	Danube	NA	North Afri. Coast	Kalahari	Papau Oceania
B6	Thai Myan Malay	North Euro Russia	Dnieper	NA	Northwest Afri. Coastal	Lake Chad Basin	Sahara
B7	Western Asia Iran	Ob	Eastern Med	NA	Sahara	Limpopo	Western Australia
B8	Others	Scandinavia	Iberia East Med	NA	Tigris Euphrates	Madagascar	Others
B9	NA	Upper Mongolia	Lake Balkhash	NA	Western Asia Iran	Niger	NA
B10	NA	Ural	Lower Mongolia	NA	Others	Nile	NA
B11	NA	Volga	Ob	NA	NA	Northwest Afri,	NA
B12	NA	Western Asia Iran	Syrdarja	NA	NA	Orange	NA
B13	NA	Yenisey	Tigris Euphrates	NA	NA	Sahara	NA
B14	NA	Siberia Other	Upper Mongolia	NA	NA	Senegal	NA
B15	NA	Others	Ural	NA	NA	South Afri. Coast	NA
B16	NA	NA	Volga	NA	NA	Southeast Afri. Coast	NA
B17	NA	NA	Western Asia Iran	NA	NA	Volta	NA
B18	NA	NA	Yenisey	NA	NA	West Afri. Coastal	NA
B19	NA	NA	Yili He	NA	NA	Zambezi	NA
B20	NA	NA	Others	NA	NA	Others	NA

Table A2. All sectors covered by the GTAP-BIO-W model

Sector No.	Sector Name	Sector Category
1	Irrigated paddy rice	
2	Rainfed paddy rice	
3	Irrigated wheat	
4	Rainfed wheat	
5	Irrigated coarse grain	
6	Rainfed coarse grain	Crops
7	Irrigated oilseeds	
8	Rainfed oilseeds	
9	Irrigated sugar crop	
10	Rainfed sugarcrop	
11	Irrigated other crops	
12	Rainfed other crops	
13	Forestry	Forestry
14	Dairy farms	
15	Ruminant	
16	Non-Ruminant	Livestock and
17	Processed dairy	processed livestock products
18	Processed ruminant	
19	Processed non-ruminant	
20	Crude vegetable oil (crude veg. oil & oilsds meals)	
21	Refined vegetable oil	
22	Beverage and sugar	Processed food
23	Processed rice	products
24	Other processed food	
25	Processed feed	
26	Other primary sectors	
27	Ethanol1 (producing ethanol and DDGS)	
28	Ethanol2	Bio-energy
29	Biodiesel	industries
30	Vegetable oil by-product	
31	Coal	
32	Oil	
33	Gas	Other energy
34	Oil Products	industries
35	Electricity	
36	Energy intensive industries	
37	Other industrial sectors	Rest of industries
38	Non-tradable service	

Appendix B: Structure of the IMPACT-Water Model

In the IMPACT modeling suite, natural water availability and supply for irrigation are determined with the Global Hydrologic Model (IGHM) and the Water Simulation Model (IWSM), respectively, as illustrated in Figure B. The IGHM is a semi-distributed hydrological model that simulates evapotranspiration, surface runoff and base flow on 0.5° latitude× 0.5° longitude grid cells over global land surfaces, except for Antarctica. It uses a temperature-index method adapted from NOAA's SNOW-17 model to simulate snowpack accumulation and ablation. Gridded hydrological output is spatially aggregated to the FPUs, weighted by grid cell areas, for use by the IWSM model.

The IWSM uses monthly runoff and potential evapotranspiration from the IGHM to simulate water management and allocation processes for river basins, using FPUs as the fundamental unit of water balance. It simulates reservoir regulation of natural flow and abstraction of surface and groundwater based on projected total water demand for domestic, industrial, livestock and irrigation sectors. Irrigation water demand is estimated using effective rainfall and potential evapotranspiration generated by the IGHM, plus irrigated areas, cropping patterns, crop characteristics, and basin irrigation efficiency. With projected sectoral water demand, the IWSM optimizes water supply according to demand, subject to water availability and capacity constraints of water infrastructure. Sequentially, the model first calculates total monthly water supply; second, it allocates the total supply to water-use sectors on a priority-based manner, assuming domestic water demand is the first priority, industrial and livestock demand is the second priority, and the remaining water is available for irrigation. Total irrigation water supply is further allocated to crops according to crop water requirements. As a water scarcity indicator, irrigation water supply reliability is determined as the ratio of total irrigation water supply to demand, on an annual basis.

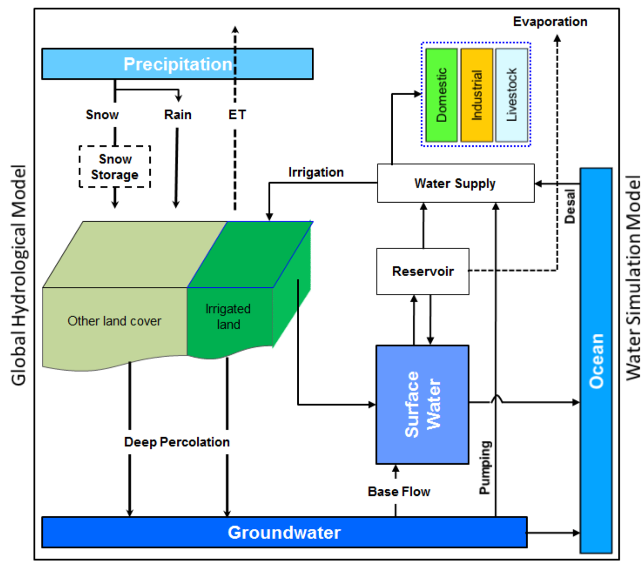


Figure B. Structure of the global hydrological model IGHM and water simulation model IWSM (Adapted from (Zhu et al., 2013)).

Table B1. Water scarcity shock (%).

Region	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20
USA	0	0	0	0	0	10.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EU27	0	0	0.7	0	0	18.1	0	0	0	0	0	-2	-11.4	0	0	0	0	0	0	0
BRAZIL	0	0	-16.1	0	0	0	-50	45.4	0	0	0	0	0	0	0	0	0	0	0	0
CAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JAPAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHIHKG	-23	-13.1	-1	-2	-64.3	-24	-32	0	13.1	0	0	0	-0.6	-15.5	-0.1	0	0	0	0	0
INDIA	-0.1	0	0	-10.6	-22	-9.2	2.9	-2.6	-7.9	-20	0	-61.3	0	0	0	0	0	0	0	0
Central America	19.1	0	11.8	0	0	0	0	-2.3	0	0	0	0	0	0	0	0	0	0	0	0
South America	0	0	0	0	0	0	0	0	-7.9	0	-15	0	0	0	0	0	0	0	0	0
East Asia	-10.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYS & IDN	5.1	0	0	0	-0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R. Southeast Asia	0	13.5	-0.1	0	-26.7	-2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R. South Asia	-0.6	-2	-1	-43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Russia	0	-58.4	0	0	0	0	0	0	-14.2	-8	-0.1	-16.2	0	0	0	0	0	0	0	0
E-Europe-RFSU	-0.6	0	-29.7	12.3	0	-0.2	18.1	0	0	-11.7	0	-0.3	-13.8	-8.3	-30.3	0	0	0	0	0
R. Europe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M-East-N-Africa	-4.8	-34.6	-30.1	0	-4.3	0	0	-0.4	0	0	0	0	0	0	0	0	0	0	0	0
SSA	-1.2	0	-84.5	-20.5	0	-1.1	-2.4	-26.6	-3	0	0	0	-0.7	-21	-0.2	9.8	0	-27.6	-1.2	0
Oceania	0	0	0	0	0	-24.4	15	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: Values are percentage change of IWSR from 2000 to 2030. Negative numbers indicate potential water demand will be less satisfied by actual water consumption in 2030 than in 2000.

Supplemental figures and tables

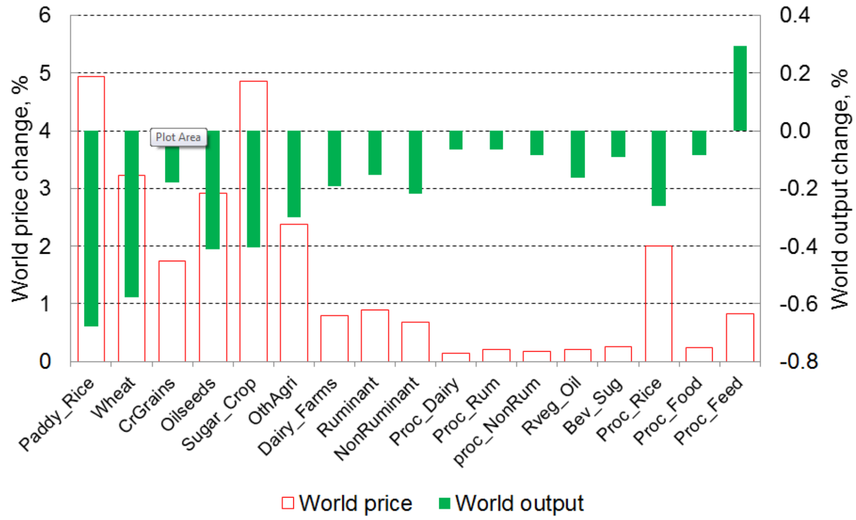


Figure C1. Percentage change of global price and output compared to the base data, by crop.

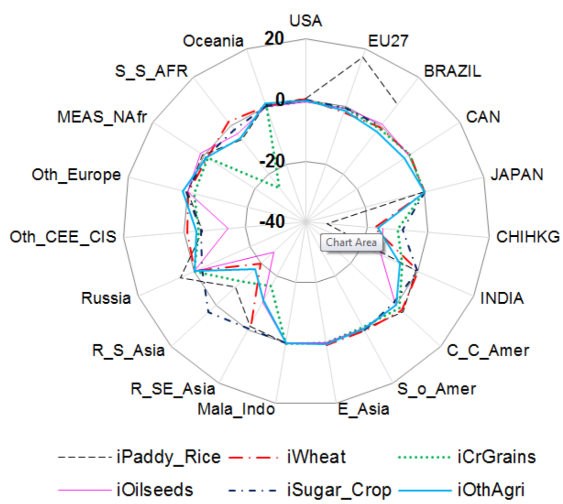


Figure C2. Change in aggregate irrigation water content over land. What is plot is the percentage change of regional irrigation water input minus the percentage change of regional land input. Negative number means that at regional level less irrigation water is attached to per unit of land, compared to pre-experiment situation.

Table C1. Change in Irrigated and Rainfed Crop Output (%)

Region	IRice	RRice	IWheat	RWheat	ICrGrains	RCrGrains	IOilseeds	ROilseeds	ISgr-Crp	RSgr-Crp	IOthAgri	ROthAgri
USA	1.67	39.30	3.42	1.41	-0.54	0.20	0.16	0.51	-0.25	0.67	0.31	0.08
EU27	9.04	7.66	1.03	0.71	2.24	-0.35	-0.84	1.35	1.81	-0.48	1.06	0.33
BRAZIL	8.24	-6.92	17.29	-0.18	-2.51	0.23	8.50	0.46	-0.70	0.93	-1.92	1.05
CAN	-0.09	10.57	6.44	2.61	-4.35	0.32	-0.55	0.75	1.17	0.25	-4.89	0.58
JAPAN	0.53	0.48	-0.25	2.24	-0.91	1.77	0.34	0.54	-1.25	1.43	-2.13	1.14
CHIHKG	-2.96	5.97	-7.64	9.53	-10.03	7.72	-10.53	1.14	-6.61	18.53	-9.67	0.94
INDIA	-4.40	6.58	-2.38	9.90	-16.75	3.78	-19.81	6.93	-1.09	10.06	-16.97	4.03
Central America	5.63	-3.56	0.49	4.18	0.19	0.01	0.19	0.61	-0.02	-1.74	1.21	0.00
South America	-0.24	0.83	0.23	1.04	-1.85	0.52	-1.34	0.68	-0.11	0.84	-0.72	0.53
East Asia	-0.14	0.71	-0.80	0.61	-0.41	1.09	-0.16	0.83	0.04	0.04	-0.45	0.47
MYS & IDN	0.11	0.20	0.01	20.42	0.46	0.50	0.82	0.44	0.30	-0.16	0.55	0.41
R. Southeast Asia	-5.25	4.63	-2.71	5.03	-20.68	0.16	-28.22	0.23	-2.54	8.55	-8.70	1.33
R. South Asia	-7.75	7.61	-18.20	25.36	-27.77	14.85	-43.28	27.99	-3.42	58.57	-32.38	10.91
Russia	4.46	1.41	-1.68	0.37	-1.90	0.11	-0.92	0.61	-2.05	0.25	-2.20	0.45
E-Europe-RFSU	-0.52	7.79	-2.72	0.87	-8.21	1.30	-7.17	0.52	-10.97	4.43	-1.99	0.69
R. Europe	-8.96	8.50	14.63	0.43	-2.75	0.19	-20.44	1.33	-6.39	0.25	-1.62	1.28
M-East-N-Africa	-0.76	23.78	-5.98	5.78	-4.82	7.10	-4.55	10.72	-3.82	79.40	-3.01	8.82
SSA	-14.26	4.59	0.69	1.35	-30.43	0.79	-1.71	0.17	-5.29	2.85	-3.19	1.07
Oceania	4.48	4.80	1.90	1.55	-0.91	0.20	1.43	1.44	0.22	-0.82	0.05	1.34

Table C2. Change in Bilateral Trade Flow (million USD)

Region	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C. Amr	S. Amr	E. Asia	MYS & IDN	R. SE.Asia	R. S. Asia	Russia	E-Erp-RFSU	R. Erp	MENA	SSA	Oceania
USA	0.00	9.63	0.46	31.78	83.07	108.44	28.59	-6.64	4.60	81.04	30.25	44.15	155.08	4.31	15.76	0.52	83.34	9.29	6.58
EU27	31.50	504.86	2.95	5.02	28.71	55.19	12.80	6.99	8.48	16.56	9.32	19.60	58.33	28.61	48.85	18.32	187.44	34.60	7.71
BRAZIL	2.12	4.62	0.00	0.01	4.58	24.35	4.66	0.31	4.33	10.67	1.44	2.61	10.56	-1.81	2.25	-0.26	21.91	0.06	0.85
CAN	-5.64	-6.37	-0.05	0.00	11.84	45.03	11.62	-8.54	-2.93	3.08	5.80	8.46	56.18	0.05	0.28	-0.58	27.54	0.31	0.55
JAPAN	2.13	0.97	0.14	0.26	0.00	19.40	0.46	0.09	0.09	75.38	0.77	5.10	1.74	0.11	0.07	0.04	1.17	1.84	0.94
CHIHKG	-76.94	-143.56	-2.25	-13.51	-267.93	-31.49	-2.92	-16.14	-5.19	-122.55	-43.19	-41.48	10.20	-15.48	-7.05	-6.52	-14.77	-11.11	-9.01
INDIA	-93.48	-143.10	-1.02	-6.08	-36.85	-10.83	0.00	-7.50	-1.50	-25.01	-35.30	-40.32	46.05	-19.64	-6.90	-3.51	-50.27	-7.89	-4.79
C. Amr	102.74	32.57	0.17	4.75	11.36	5.40	0.74	6.79	2.42	2.44	0.81	1.70	3.63	0.82	1.16	2.97	14.46	1.40	0.61
S. Amr	6.92	-19.95	-8.47	0.68	3.14	35.11	6.52	-3.38	5.49	5.59	8.10	4.31	8.46	3.51	2.52	-1.10	53.74	3.69	0.64
E. Asia	-5.24	-2.36	-0.05	-0.45	1.33	11.25	0.84	-0.61	-0.08	0.74	0.59	-0.11	3.54	-0.75	0.57	-0.17	0.73	1.38	-0.55
MYS & IDN	-3.92	-11.36	0.15	-0.34	3.34	23.03	24.52	-0.02	0.31	3.94	4.29	16.65	35.63	0.43	0.39	-0.22	15.74	1.45	0.87
R. SE.Asia	-57.27	-50.72	-0.54	-8.05	-34.04	41.48	25.00	-7.46	-1.57	-4.85	-9.86	-8.83	37.47	-2.89	-0.32	-2.29	20.29	-21.93	-5.23
R. S. Asia	-39.54	-160.88	-2.69	-5.64	-27.07	-13.95	-48.05	-12.85	-10.59	-12.19	-19.85	-17.36	-37.04	-35.13	-41.08	-3.56	-243.89	-26.50	-9.91
Russia	0.26	3.00	0.03	-0.03	6.70	9.37	0.31	0.00	0.03	2.98	0.04	0.36	18.44	0.00	8.62	-0.09	5.91	0.09	0.04
E-Erp-RFSU	-9.20	-67.66	-0.62	-1.02	-1.58	1.73	2.70	-0.66	-0.40	-0.46	-0.14	0.03	23.03	-7.05	0.63	-3.52	35.63	-0.54	-0.19
R. Erp	1.94	17.06	0.71	0.40	5.69	4.71	0.40	0.39	0.32	1.43	0.83	1.34	7.96	1.30	4.14	0.59	8.70	0.99	0.35
MENA	-20.93	-166.49	-1.86	-4.12	-10.35	-1.90	0.44	-3.21	-2.62	-3.34	-3.17	-3.75	33.39	-6.57	-10.22	-5.17	-19.38	-4.38	-1.44
SSA	-0.89	-25.87	0.05	0.00	1.67	14.39	23.36	-0.33	0.24	1.04	3.65	7.30	65.44	2.45	5.27	-1.26	36.36	7.98	0.83
Oceania	-9.90	-30.47	-0.07	-1.29	-7.61	66.71	28.20	-4.02	-0.60	5.01	8.97	8.85	101.20	-0.26	0.56	-0.78	19.88	-4.54	4.62

Note: The following sectors are included: Crops, Livestock and Processed livestock product (dairy, ruminant and non-ruminant), Refined vegetable oil, Beverage and sugar, Processed rice, Processed food and Processed feed.