Water Scarcity and International Agricultural Trade

Jing Liu
Department of Agricultural Economics, Purdue University
liu207@purdue.edu

Thomas W. Hertel
Department of Agricultural Economics, Purdue University
hetel@purdue.edu

Farzad Taheripour
Department of Agricultural Economics, Purdue University
tfarzad@purdue.edu

Tingju Zhu
International Food Policy Research Institute
t.zhu@cgiar.org

Claudia Ringler
International Food Policy Research Institute
c.ringler@cgiar.org

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

Water Scarcity and International Agricultural Trade

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

[1]Purdue University
[2]International Food Policy Research Institute (IFPRI)

Abstract

Agriculture's reliance on irrigation and concerns over water scarcity raise the question of how global food output and trade could be affected if the issue of water shortfall needs to be resolved on the back of agriculture. To understand changes in food production and international agricultural trade as the responses to local water shortage, we construct a computable general equilibrium model in which irrigation water supply reliability is perturbed. The results suggest that regions under water stress cut back food production and turn into net food importers, although domestic water productivity improves. The regions' welfare falls, primarily due to less endowment available for agriculture and decline in the terms of trade.

Keywords: CGE modeling; water scarcity; irrigated and rainfed agriculture; food security; international agricultural trade
JEL Codes: Q25, Q17

Introduction

Water is an essential input for agricultural production. Irrigated agriculture accounts for about 70 percent of global freshwater withdrawals and is often seen as one of the main factors behind the increasing global scarcity of freshwater (Bruisma, 2009). Agricultural dependence on irrigation, however, varies quite considerably across geographical regions. In Sub-Saharan Africa, only 16 percent of crop output is from irrigated land, while this ratio in the Middle East and North Africa is 3 times higher.[1] Water stress, measured as consumptive water use in irrigation as a percentage of renewable water resources, is estimated to be 6 percent for the world in 2005/07. Similarly, there are wide variations between countries and regions, with the Near East/North Africa region using 58 percent of its water resources in irrigation while Latin America barely uses 1 percent of its resources (Bruisma, 2009).

The world faces a looming water challenge ahead. Current projections of population and economic growth imply that in 2030 global water requirements will be 40 percent greater than current sustainable supply, and that one-third of the world's population, mostly in developing countries, will live in basins where this deficit is larger than 50 percent (Addams et al., 2009). The effects of changes in population and economy on water shortage greatly outweigh the changes in water availability as a result of long-term climatic change (Kummu, 2010; Vörösmarty, 2000).

While the gap between supply and demand will inevitably be closed, the question is how, and with what impact on agricultural production and trade patterns. Since irrigation water is often a residual after domestic, industrial and commercial demands are satisfied, it's very likely that irrigation for agriculture will be constrained to release water for other uses in many regions. Reduction in irrigated area, especially in irrigation-dependent regions, could have a significant impact on the location and volume of production.

---

[1] Authors' own calculation based on MIRCA2000 dataset (Portmann et al, 2010), which represents global irrigated and rainfed crop production around the year 2000.

In this paper we seek to estimate the changes in production and trade induced by projected shortfalls in certain regions around the world.

Methods

1. Model

To estimate the impacts of water scarcity shocks on agricultural production and trade, we use the Global Trade Analysis Project (GTAP) general equilibrium GTAP-BIO (Taheripour et al., 2013a; hereinafter cited as THL) and its recently developed water module and accompanying database. The standard GTAP model is a multiregion, multisector, computable general equilibrium model, with perfect competition and constant returns to scale. Producers are assumed to maximize profits, while consumers maximize utility. Factor market clearing requires that supply equals demand for skilled and unskilled labor, capital, natural resources and agricultural land. Adjustments in each of these markets in response to the experiment shock determine the resulting resource reallocation, output, prices and bilateral trade flows.

GTAP-BIO used by THL extends the standard GTAP model by allowing a more disaggregated modeling of the production of crops and agricultural land market. One limitation of this model is that water is not considered as an independent input, but embedded in the irrigated land. The role of water is played through expanding or contracting irrigated land. The present study relies on a modified version of GTAP-BIO model developed by Taheripour et al., (2013b). The new model highlights the modification that water is explicitly added as an input endowment. In particular, the same crop can be produced by either irrigated or rainfed sectors, but only the latter use water. The two types of productions are linked to the same input-output structure for non-water inputs and both pay the same price for a given input. By implication, the cost shares are the same for each input except for water. Thus, the additional productivity associated with irrigated production is completely explained by the use of irrigation.

The second major modification in Taheripour et al., (2013b) is the introduction of river basins. In GTAP-BIO, Agro-ecological zones (AEZs) are drawn, out of recognition of the fact that significant climate variations within regions make the use of large spatial units inappropriate for modeling. The presence of water further complicates this variation. As AEZ and water shed boundaries intersect with each other, production condition within the same AEZ is no longer uniform due to the variable water availability for irrigation in each basin. Competition for land and water takes place not at the AEZ but at the intersected AEZ-river basin level. In addition, unlike land market where cropland supply is endogenous, the supply of water is exogenous. Total water available for irrigation is fixed in each river basin, although depending on competitiveness water can be drawn by any AEZ that belong to the basin.

2. Data to develop land and water modules

In order to assess the effects of future water scarcity on agricultural production and trade, we draw on prior work by others. Monfreda et al. (2008) is the main source of geographic distribution of land cover, crop areas and yields used in this study. MIRCA2000 developed by Portmann et al. (2010) provides us with gridded data on global area equipped for irrigation, the irrigated/rainfed yield differential, and water used for irrigation by crops. The modified GTAP-BIO-AEZ model is featured by a finer disaggregation of region-AEZ-basin, which represents the spatial intersection of 19 GTAP regions, 18 AEZs and 126 river basins. GTAP v.6 database is split into irrigated and rainfed categories using the method applied in THL (2013a).

3. Water scarcity shock

While on an absolute basis irrigation accounts for about 70 percent of freshwater water withdrawals globally, water available for agriculture is often a residual after the non-agricultural water demands have been satisfied. Thus, the concept of irrigation supply goes beyond water circulation and includes a synthesis of factors that determines total water supply and the demand of water for non-agricultural uses. To let the water shock reflect these factors, we adopt Irrigation Water Supply Reliability (IWSR) index as the metric of irrigation availability. IWSR is defined as the ratio of irrigation water supply to demand, at an annual basis. One means all demand is met and there is no irrigation shortfall. In a global analysis undertaken at the “food-producing units” (FPU) level by Rosegrant et al. (2013), IWSR for 2000 and

2030 are constructed out of the IMPACT model which estimates water demand and supply for irrigation and other non-agricultural uses in 281 FPUs and simulates water transport in 126 hydrological basins. An optimization approach is employed to minimize total water shortage followed by inter-sectoral allocation according to prescribed priorities of water uses. Domestic water use has the highest priority followed by industrial and livestock water uses while the priority of irrigation is the lowest.

Basin level water supply is then shocked by the percent that IWSR index changes from 2000 to 2030.[2] The IWSR projection through 2030 used here is in the scenario of business as usual, which assumes a continuation of current trends in population and economic growth, water use efficiency in agricultural, industrial and domestic uses, and existing plans in water policies and agricultural investments. The evolving of IWSR depends on the interplay among several drivers. The supply side considers water supply infrastructure capacity (e.g. reservoir storage, surface water withdraw, groundwater withdraw), while the demand side considers water demand growth and water use efficiency changes, in particular basin irrigation efficiency changes.

Results and discussion

1. Impacts on food output

Although more secured irrigation supply raises total crop output with no exceptions, the consequences of less secured irrigation are not qualitatively the same across regions (Figure1). Crop output reduction occurs most dramatically in regions that anticipate largest degree of water scarcity or rely heavily on irrigation, or both. Significant drop of crop production in Middle East and North Africa, China, India, the rest of South Asia and Southeast Asia overweighs the output gain from American and European countries, leading to a global reduction in output for all crops. Livestock and processed food sectors, which use crops as primary inputs, are negatively affected, too. The only exception is the processed feed sector. Its

[2] Since FPU is defined as the intersection of economic region and water shed, one river basin may contain multiple FPUs. In that case, basin level shock is computed as the simple average of the shocks at the related FPUs.

growing output is attributed to strong demand from the expanded livestock productions in the USA, EU and China. Moreover, processed feed uses more biofuel byproducts than crops as primary inputs, making them appealing substitute for crop feed while crop prices are high. World food prices rise (Figure 2), but the change is more pronounced for crops (direct effect) than for the rest food items (indirect effect).

We partition total impacts on each crop into contributions from two categories, irrigated and rainfed, as displayed in Figure 3. The former is determined by the percentage change of irrigated output and the proportion of output that is irrigated, while the latter is determined by the same elements but on rainfed crops. Water rich regions tend to produce more from irrigated land to substitute for the more expensive imported crops. As a contrast, regions confronted with water stress are more likely to cut back production of irrigated production and expand rainfed output. Given the fact that irrigation increases yields, production contraction is generally bigger than the expansion, leading to less aggregate output. When comparing different crops, the impacts on fruit and vegetables are relatively small, while the output of paddy rice is more deviated from the base data after the shock, because rice is water-intensive crop and its elasticity of substitution is relatively low in countries where rice is the major staple food.

2. Impacts on water reallocation and water productivity

In the case that water supply for irrigation shrinks, competition for irrigation among crops bids up water price. Since irrigated crop sectors that share a watershed face the same price of water, producers who use more water in production bears a larger burden than those who do not. Unless commodities can be sold at prices that are high enough to cover the water bill, water will shift away from water intensive crops to the other crops, or even worse, away from agricultural uses. The producers who remain in the sector must be able to use less water to produce one unit of output than those who have been crowded out. In other words, water content, measured by the amount of water used per unit of output, should be lower (indicating higher water productivity) in the water scarcity region after resource reallocation. Figure 4 compares pre and after water content by crop. The most marked drop occurs in China, India and rest of South Asia, where the change of irrigation supply is most pronounced.

3. Impacts on trade and food security

Endowment price increase caused by resource scarcity leads to higher commodity price. Price surge is more significant in the regions that experience the most severe water shortage for irrigation. These regions' domestic supply price increases much faster than that of their exporting competitors', making them lose the price advantage and export less than before. On the other hand, the rest of the world has the relative price advantage and tends to export more to these regions. It's worth noting that change of import and export volume results from the change of quantity as well as price. It's true that the negatively shocked regions can benefit from the higher exporting price. Nevertheless, the change of price cannot overweigh the change of quantity, because domestic product and foreign product are not perfect substitutes. Effect of rising price will be exaggerated with the presence of Armington preference, leading to an even larger impact on export quantity. Thus, the overall effect on these regions' export is negative. Import volume, however, will go up without uncertainty, since they import more at higher prices. More import and less export together explain the worsened agricultural trade balance in the water scarcity regions (Figure 5). We use Figure 6 to show how bilateral trade flow has changed compared to the baseline. It's clear that the most severely shocked regions become net food importers. Furthermore, food self-sufficiency rate, which is defined as the ratio of self-production to total food consumption, is lower for most food categories in the three hardest hit regions, namely South Asia, MENA and China.

4. Impacts on welfare change

The major source of welfare reduction in the water scarcity regions including China and South Asia is less endowment that can be used to produce food (Figure 7). The second main reason explaining welfare change is the terms of trade. Exporting agricultural products to world market at a higher price improves the terms of trade, Nonetheless, some countries like China exports non-agricultural products at a lower price in order to make even trade balance. The decline in the terms of trade for non-agricultural industries dominates because of its higher value, indicating that overall price of exports falls relative to imports. In most of the regions, allocation of resource becomes less efficient after the water shock, but for different reasons. In water rich regions like the US and EU, water is "overused" with the highly subsidized agriculture. While in regions lack of water, rainfed land is "overused" to compensate the lost production due to irrigation constraint.

Conclusion

Agriculture's dependence on irrigation and concerns over water scarcity raise the question of how global food output and trade could be affected if the issue of water shortfall needs to be resolved on the back of agriculture. To understand changes in food production and international agricultural trade as the responses to local water shortage, we construct a computable general equilibrium model in which supply of water for irrigation can be perturbed to see changes in global food supply and demand, agricultural resource reallocation, and pattern of international trade compared to the base data. The most sophisticated water balance model that considers interaction of water supply and demand is used to simulate the evolution of water availability for irrigation. The results suggest that regions under water stress cut back food production and turn into net food importers, although domestic water productivity improves. These regions' welfare falls, primarily due to less endowment available for agriculture and decline in the terms of trade.

References

Bruinsma, J. (2009). The resource outlook to 2050: By how much do land, water and crop yields need to increase by 2050?. In *How to feed the World in 2050. Proceedings of a technical meeting of experts, Rome, Italy, 24-26 June 2009.* (pp. 1-33). Food and Agriculture Organization of the United Nations (FAO).

Addams, L., Boccaletti, G., Kerlin, M., & Stuchtey, M. (2009). Charting Our Water Future: Economic Frameworks to Inform Decision-making. *New York, McKinsey & Company*.

Kummu, M., Ward, P. J., de Moel, H., & Varis, O. (2010). Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. *Environmental Research Letters*, *5*(3), 034006.

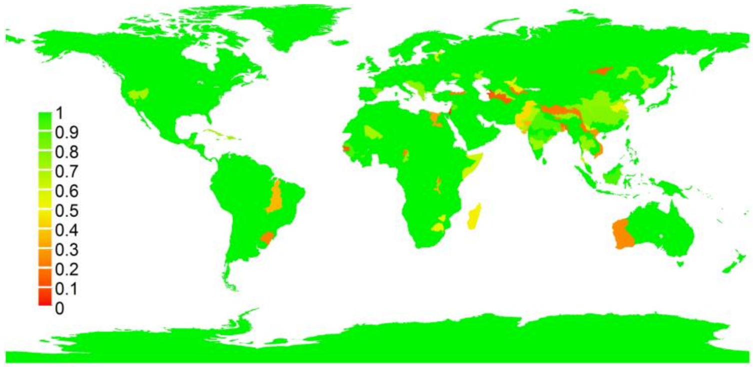
Vörösmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global water resources: vulnerability from climate change and population growth. *Science*, *289*(5477), 284.
Taheripour, F., Hertel, T. W., & Liu, J. (2013a). The role of irrigation in determining the global land use impacts of biofuels. *Energy, Sustainability and Society*, *3*(1), 4.

Taheripour, F., Hertel, T. W., & Liu, J. (2013b). Water reliability, irrigation adoption, and land use changes in the presence of biofuel production. Working paper.

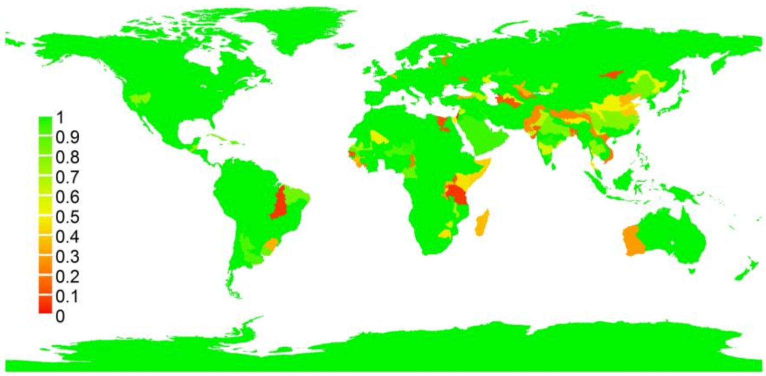
Monfreda, C., Ramankutty, N., & Foley, J. A. (2008). Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles*, *22*(1).

Portmann, F. T., Siebert, S., & Döll, P. (2010). MIRCA2000—Global 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., Ringler, C., Zhu, T., Tokgoz, S., & Bhandary, P. (2012, August). Water And Food In The Bioeconomy—Challenges And Opportunities For Development. In *Plenary Paper, International Association of Agricultural Economists Triennial Conference, Foz do Iguacu, Brazil* (pp. 18-24).



(a). IWSR in 2000



(b). IWSR in 2030

Map 1. Evolving irrigation water supply rellability (IWSR) index at river basin level.
(a) IWSR in 2000; (b) IWSR in 2030.

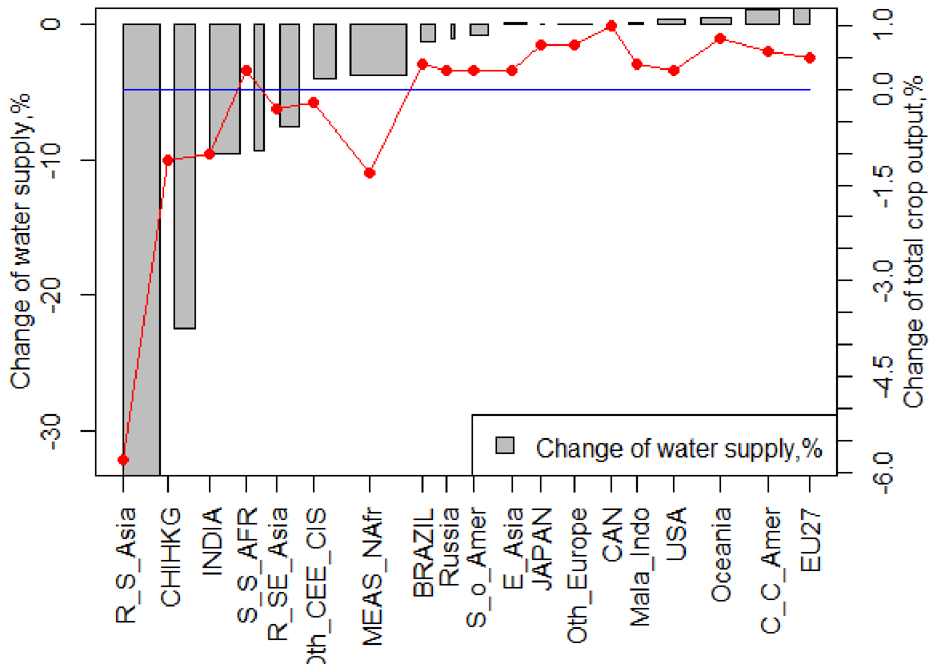


Figure 1. Change of total crop output by region. Bar width in the plot is proportional to the aggregated share of crop output that is irrigated in the region.

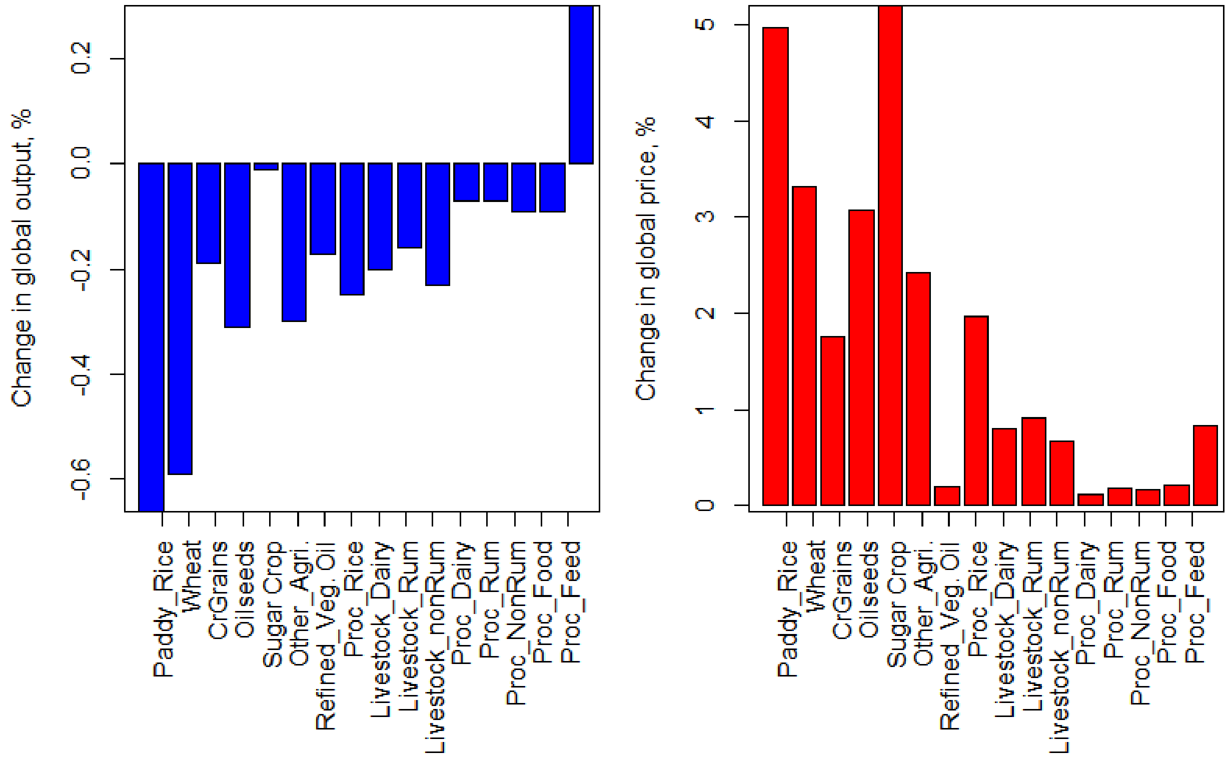


Figure 2. Change of global crop production and price.

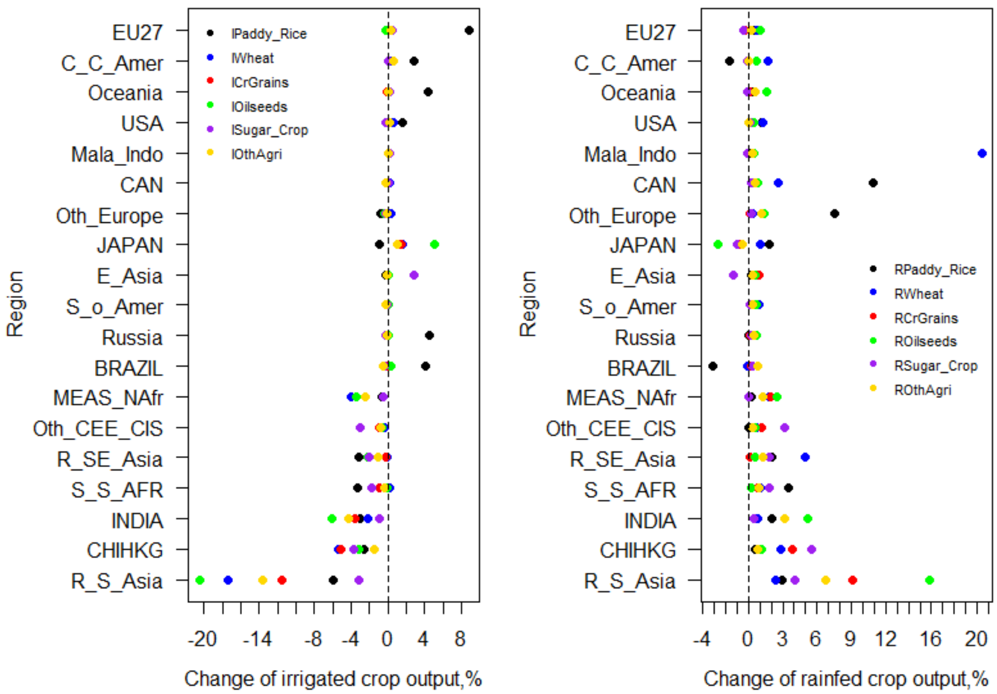


Figure 3. Contribution of irrigated and rainfed crop output, by crop and by region. The contribution of irrigated (rainfed) output is calculated as the weighted change in irrigated output. The weight is the share of total output that is irrigated.

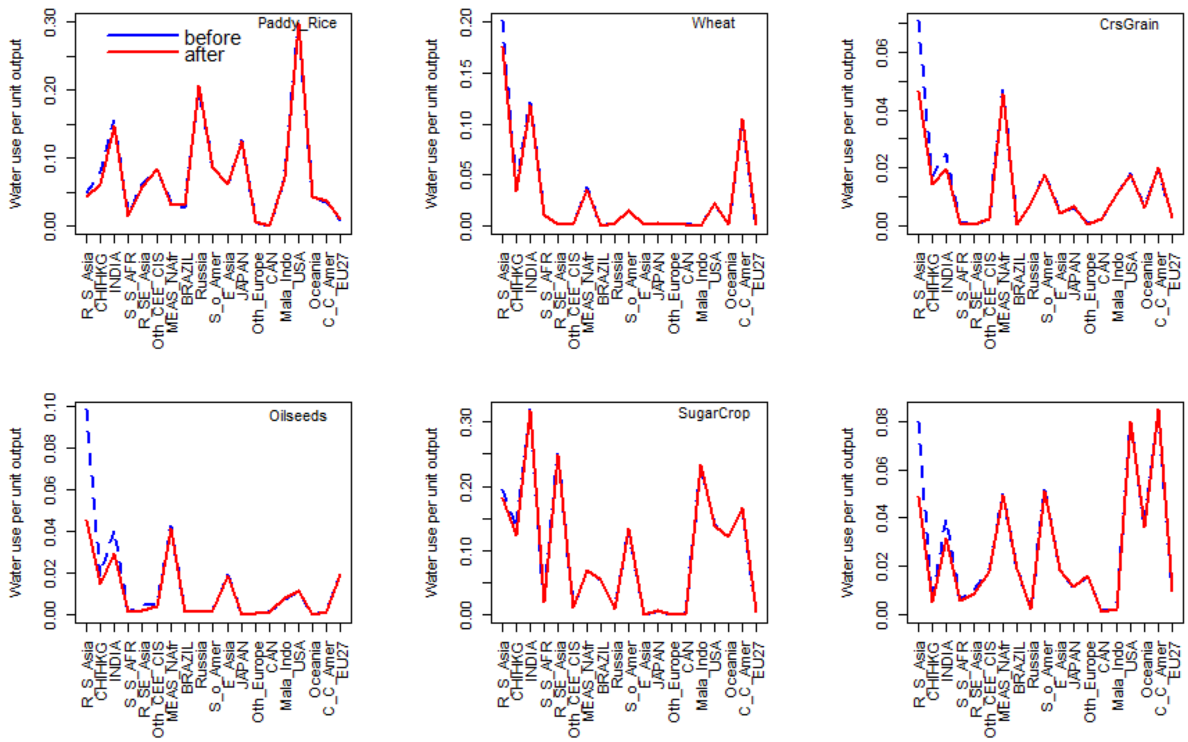


Figure 4. Comparison of water content before and after water shock. Water content is calculated as payment to water per unit of output (both in value terms).

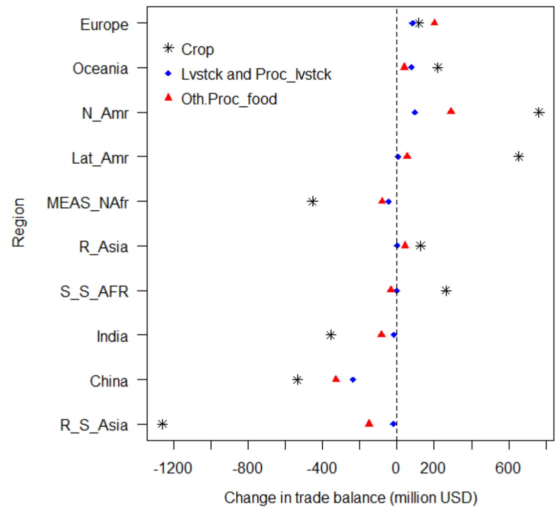


Figure 5. Trade balance in agricultural sectors.

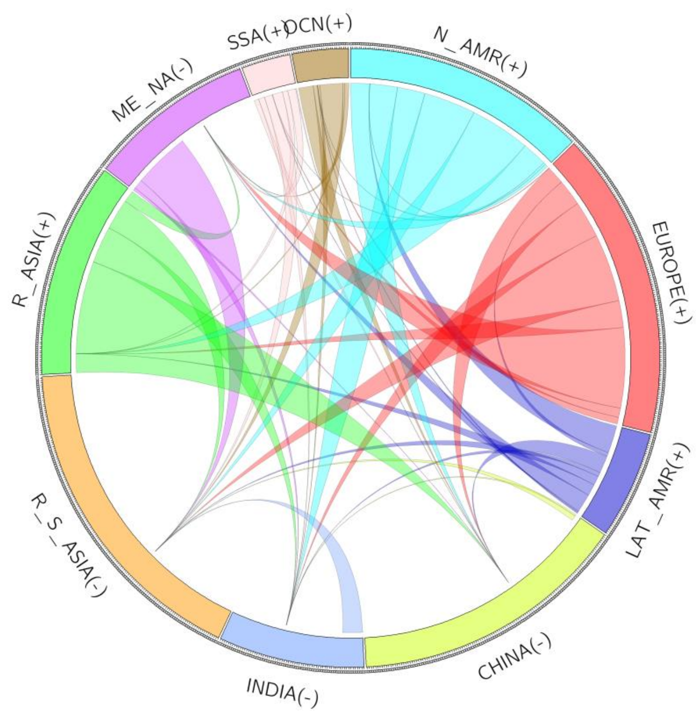


Figure 6. Net bilateral trade flow in food and agricultural products. Arc length is proportional to the magnitude of net trade flow. Wide end is the sending region; pointed end is the receiving region. + means net exporting; – means net importing. Internal trading is excluded.

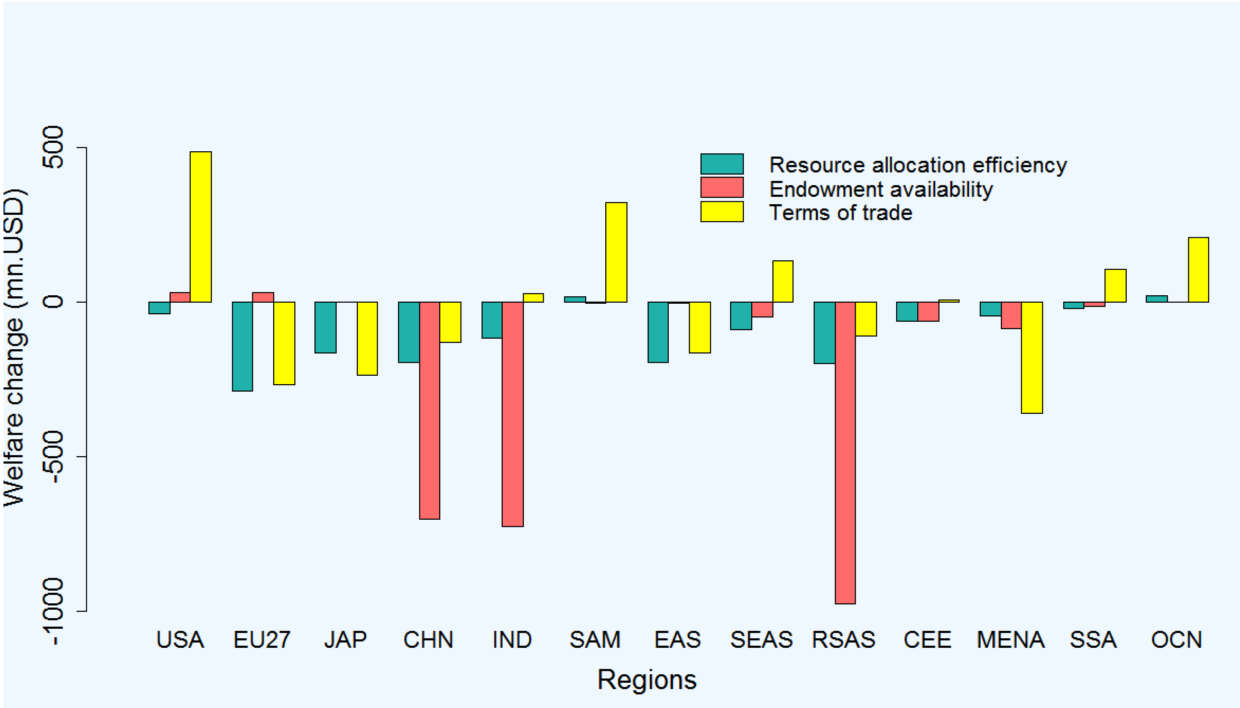


Figure 7. Welfare decomposition