Hydrol. Earth Syst. Sci. Discuss., 10, C482–C500, 2013
www.hydrol-earth-syst-sci-discuss.net/10/C482/2013/

Hydrology and Earth System Sciences Discussions

Interactive comment on "Virtual water trade flows and savings under climate change" *by* M. Konar et al.

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Received and published: 26 March 2013

March 26, 2013

Dear HESS Editorial Board and Reviewers,

The authors would like to thank you for your time spent in reviewing our manuscript "Virtual water trade flows and savings under climate change [HESS-2012-514]" submitted to Hydrology and Earth System Sciences. The Reviewers have raised a number of points that have enabled us to improve upon the original submission. In particular, this Revision has provided us with the opportunity to expand upon our methods section, incorporate a discussion section, add a figure, and refine certain conclusions.

We have addressed the comments of the Reviewers and incorporated revisions to

the manuscript where appropriate. Our responses to the specific Reviewer comments are provided below. We have included Reviewer comments in regular font and our replies in bold font, in order to ensure that the document is self-contained. With these Revisions, we believe that the manuscript will now be suitable for publication as part of the Hydrology and Earth System Sciences special issue "Predictions Under Change".

Sincerely,

Megan Konar (On behalf of all authors)

Reviewer #1

General comments:

This paper deals with a very important question: how climate change may affect virtual water trade. This topic, if well analyzed and interpreted, has the potential of taking virtual water research a step forward and giving interesting hints about adaptation options. While the topic of the manuscript fits well within the Journal's scope, the manuscript seems to have been written in a hurry: formulations have to be strongly improved, some parts are repeated over and over again, terminology is not consistent across the paper, there is no discussion provided, very important sections (such as shortcomings of the models used) are completely missing, methodology is poorly described and conclusions are oversimplified. Also, the second important crop by harvested area globally, maize, is not considered in this study and it is not even mentioned why.

We thank Reviewer #1 for his/her appreciation of our research question! You have made several helpful comments and suggestions that we have endeavored to incorporate into the paper. We hope that you will find the paper much improved as a result.

Specific comments:

Introduction

You may give some examples or quantities: which regions are becoming more/less suitable? How much water does international trade save?

Thank you for this suggestion. We have added in an example, where Japan is projected to increase rice yields by 2%, while Pakistan, currently a major rice exporter, will experience a 15% decline in rice yields, under a low-yield scenario. We have added in an estimate of how much water the international trade of staple crops saves in the year 2008: 238 km3 yr-1, equivalent to 9% of global agricultural water use.

You may want to shortly mention the crops considered and the models used.

Thank you. We have added this information to the introduction.

There is little connection between the paragraphs, this is why it is hard to see the common thread of this section. Consider improving this point while presenting the coming sections in an interesting, attractive way.

Thank you for this suggestion. We have re-written the introduction and hope that it now reads more coherently.

Methods

Why do you consider only three crops and even leave maize out of the analysis?

We consider all crops available for analysis in both the GTAP and H08 models. Unfortunately, maize is not available from GTAP. We now highlight this point in lines 127-130.

P71 L 24 and elsewhere: Why do you use the phrase “yield shocks” instead of yield changes? That would certainly represent better what you mean, since changes are positive and negative.

Thank you for allowing us to clarify this terminology. We use “yield shocks” since this is the standard terminology in the economics literature. “Yield shocks” is equivalent to “yield changes”, as it does allow for positive and negative adjustments to current yield values (refer to Table 3). However, “yield shocks” is additionally useful terminology,

since it is indicative of a comparative static modeling framework, as performed here. In other words, the GTAP model productivity parameters are “shocked” according to projections for 2030, maintaining all else equal to baseline values. The baseline and climate change model outcomes are then compared. We have added a statement regarding our choice of this term in lines 157-159.

P 72 L 13-19 This assumption would require that you consider adaptation costs (including those for technology development) in GTAP for the medium and high-yield scenarios.

Thank you for this comment. We do not directly consider adaptation costs in our analysis. We explore trade outcomes based solely on productivity shocks. However, our uniform implementation of productivity scenarios can be thought of as “adaptation scenarios”. This is because we implement low-, medium-, and high- productivity scenarios in each country for each model run, rather than the various (and many!) combinations of low- in X countries, medium- in Y countries, and high- in Z countries. We explain this in lines 160-171.

P 72 L 23 How realistic is the relative price change from GTAP taking into account that you keep population and income fixed?

In this paper we perform a comparative static analysis. In this framework, we compare “worlds” under current crop yields and projected crop yields, keeping all other variables fixed. There will be other changes in the future (i.e. population, policy, technology, etc), but we are just capturing bilateral trade projections based on yield impacts. In other words, we are not projecting the dynamic future world in 2030. The relative price change is realistic for the given productivity changes. Similarly, all results in this paper are based solely on the productivity changes. We have added lines 100-104 to emphasize this point.

Section 2.2. How does H08 deal with irrigation? You mention that you used Siebert 2005 for irrigation areas. Still, do you average irrigated and non-irrigated areas to

obtain national VWC? How? Do you have coexistence of both in a grid-cell? Which is the method used to calculate water irrigation requirements and evapotranspiration?

H08 subdivides a grid cell into four by land use: (1) two-crop irrigated cropland (only for low latitudes), (2) one-crop irrigated cropland, (3) one-crop rainfed cropland, and (4) non-agricultural land. The areal fraction of irrigated sub-cells was estimated using Siebert et al. 2005. For irrigated sub-cells, irrigation water is applied in order to keep the soil moisture at a certain level during the cropping periods. Therefore irrigation water requirement is calculated from the deficit of soil moisture. Hanasaki et al. (2008a) and Hanasaki et al. (2008b) explain the methodology in detail. Evaporation from cropland is estimated for each sub-cell at a daily interval. To estimate national VWC, we aggregated them taking into account the areal fraction of sub-cells and cropping durations. Water is always balanced in both the hydrological simulation and VWC calculation.

Hanasaki, N., S. Kanae, T. Oki, K. Masuda, N. Shirakawa, Y. Shen, and K. Tanaka (2008a), An integrated model for the assessment of global water resourcesâĂŤPart 1: Model description and input meteorological forcing, Hydrol. Earth Syst. Sci., 12, 1007–1025.

Hanasaki, N., S. Kanae, T. Oki, K. Masuda, K. Motoya, N. Shirakawa, Y. Shen, and K. Tanaka (2008b), An integrated model for the assessment of global water resourcesâĂŤPart 2: Applications and assessments, Hydrol. Earth Syst. Sci., 12, 1027–1037.

Section 2.2. At which spatial and temporal resolution does H08 work?

H08 operates globally on 0.5° x 0.5° spatial grids and runs on a daily time-step. We have added this information to line 186.

Section 2.2. How does H08 deal with CO2-fertilization?

H08 does not currently deal with CO2 fertilization.

Equation (1): I first thought you correct VWC calculated with H08 for the future with a

correction factor (1/(1+r)). But then I saw that the index of Y is “Baseline” instead of “GCM”. Please explain what this (ETGCM/YBaseline) represents. For me it does not make any sense to calculate VWC with current yields and evapotranspiration under climate change, since they are strongly coupled in a biophysical way.

Thank you for raising this important point. Ideally, a coupled trade and water-use model would exist for this analysis. However, given that a coupled model does not exist, we chose the next best option and utilize an independent economics model and an independent hydrology model to address our question. Crop yield is the variable that connects both models. For this reason, we decided to maintain identical yield values across models. There were two options to maintain yield values across models. We could either (1) utilize expert assessments of climate impacts on crop yield or (2) utilize yield output from the H08 model.

We chose option (1) for a few reasons. First of all, the impacts of climate change on crop trade and human welfare has been investigated using expert projections of yield (refer to Hertel et al. 2010). In this way, our results directly build upon the existing literature. Secondly, H08 does output yield, but work is still underway to improve these results. For this reason, H08 researchers currently use data from the Food and Agricultural Organization of the United Nations (FAO) on yield to obtain VWC rather than H08 model output (refer to Hanasaki et al 2010; Konar et al 2011; Dalin et al 2012; Konar et al 2012). For these reasons, we decided to harmonize output from the GTAP and H08 models according to Equation 1.

Hertel, T., Burke, M., and Lobell, D. (2010), The poverty implications of climate-induced crop yield changes by 2030, Global Environ. Chang., 20, 577–585. Equation (1): the correction factor 1/(1+r) follows an exponential function. Is it a fit from H08 results? Or did you adopt this function based on literature? Does it make sense, and if yes, why?

Thank you for this question. The intention of the fraction 1/(1+r) is to modify the denominator (e.g. baseline crop yield) by the projected change in crop yield [%] indexed

by country, crop, and scenario. In other words, this fraction simply adjusts the yield according to expert projections as provided in Table 3.

What is the difference between CT and T? And why is CT indexed by scenario and T is not? Compare equation (2) and (3) and clarify.

Thank you for pointing out this inconsistency. We have corrected the equations. Both now have CT indexed by country of export, country of import, crop commodity, and scenario.

Results

Consider explaining or discussing the variations in results coming from different GCMs. Also comparing to variations coming from different productivity scenarios.

The uncertainty due to the selection of GCMs is substantially smaller than the selection of yield scenarios (refer to Figures 2 and 3). For this reason we focus on our selection of yield scenarios in the paper.

P77 L1-5 Why?

Thank you for this question. We have re-written the section describing our results on virtual water content projections to better explain this.

P77 L 22 I do not see that what you explained let you conclude that changes disproportionately impact their export prospects. Please clarify.

We have removed “disproportionately”.

Conclusions

Page 82 “It would be advantageous to reduce: : :” Why? Do we really need high water efficiency in water-rich regions? Or in regions where opportunity costs are low? Is there a relation between water-efficiency and sustainability of the production?

Thank you for this raising this point. We have re-written the conclusions section ac-

cordingly.

Page 82. Your implications concerning trade liberalization and cut of subsidies are very simplistic and I would even say unfounded. Please consider adding arguments, citations and looking at that from a broader perspective, referring also to, for example, consequences for sustainability, deforestation and poverty.

Thank you for this raising this point. We have re-written the conclusions section accordingly and added some discussion to section 4.2.

Missing: I strongly recommend adding following sections: a) Discussion (shortcomings of the models used, influence of assumptions, etc.), b) Evaluation/validation of yields and VWC under climate change with estimates from other authors.

Thank you for this helpful suggestion. We have added a discussion section as you suggest, with specific sub-sections on model assumptions/limitations and the implications of our results.

The crop yield projections that we use follow directly from the literature. Specifically, Hertel et al. (2010) compile expert estimates from the literature of how the yield of rice, soy, and wheat would change in the year 2030 in each country under a changing climate. They then use these yield shocks to determine how projected changes in bilateral crop trade will impact poverty using the GTAP model. We follow this approach and use identical yield shocks. We then transform these crop flows into virtual water flows. This enables us to quantify the impact of climate change on virtual water flows and associated water savings. We have added this information to lines 450-465.

Technical comments:

Abstract

Crops considered should be mentioned.

We have added this information.

L 8 and elsewhere: Be consistent with the terminology relating water productivity (virtual water content, water-use efficiency or crop water use).

Thank you for pointing this out. We now consistently use virtual water content.

L11: If I understood right you do not use the H08 model to "transform crop flows into virtual water flows", but you calculate this in post-processing by multiplying VWC by trade volumes. If I am right, please correct this sentence.

Thank you. We have done so.

L 12: Why does total volume of virtual water trade goes down? Please clarify.

Thank you. We have explained this in further detail in section 3.3. Please refer to lines 318-321.

L14: It is unclear what are you referring to with "climate impact scenarios". Please clarify or use another formulation.

Thank you. We have done so.

L15: it may be a good idea to shortly clarify what you mean by "more water-efficient structure".

Thank you. We have done so.

Introduction

P68 L 20 cacophony through "changing climate" 2 times

We have re-written the introduction section as suggested.

P69 L5: consider adding a short clarification on how international trade may exacerbate the negative consequences of climate change.

Thank you for this suggestion. We have added clarification and an example to lines 52-60.

P69 L14: reference missing (to my knowledge linking virtual water trade to food and water security is a difficult task and has not been made yet. Assuming for example that imports improve food security would be too simple)

We have removed this statement accordingly.

Methods

P70 L21 "of each national economy". Is it so? Or do you refer to the regions described in Table 1? In that case "some national economies" or something similar would be a better formulation.

It is true that some of the 92 GTAP political units are regions rather than countries. However, we refer to these political units as countries throughout the paper for simplicity, except for the instances where we specifically refer to regions. We have included lines 123-125 to clarify this point.

P70 L23 consider clarifying what "factor market clearing prices" are, since only economists are familiar with this terminology.

Thank you. We have added lines 417-420 accordingly.

P71 typo "constant"

Thank you. This has been fixed.

P 72 L3-4: you already explained this in P 71 L 8-9.

Thank you. We have removed this sentence as suggested.

P 72 L 28. This has to be a weighted average, but by what? area, production?

We perform an un-weighted average. We have added re-written this sentence to indicate this.

Results

When you refer to Fig.x,a-c, you use lowercase in the text, but in the figures you use uppercase. Be consistent.

Thank you. We have changed all lowercase occurrences to uppercase.

You do not need to define abbreviations that you already defined in the methods.

We have removed these occurrences.

P76 L 10. Formulation may be confusing, since “climate scenario” may be understood as the outputs of the GCMs. But you do use 14 GCMs, not only one. Please clarify, maybe replacing “climate scenario” by “emission scenario”.

Thank you. We have replaced with “emission scenario”, as suggested.

P 77 L6-7 “decreased planting times”? You mean earlier sowing date or shorter growing periods?

We have changed the text to indicate “shorter growing periods”.

Section 3.4. “Large values of VWC indicate. . ..” You already explained that a few times.

Thank you for pointing this out. We have removed multiple occurrences of this.

P80 last paragraph and Page 81 first paragraph. This is discussion, not really material for the result section.

We have moved these paragraphs to the discussion section as suggested.

Tables and figures

Tables 1, 2 and 4 may be moved to the appendix (they are not needed to understand the results).

Thank you for this suggestion. We have moved Tables 1, 2, 3, 4, 8, and 9 to the appendix as suggested.

Table 1: typo in number 92.

This has been fixed.

Table 2: consider alphabetical order.

Thank you for this suggestion. We have alphabetized the country names within each region. The order of the regions follows the GTAP coding system provided in Table 1.

Table 3 may be moved to the appendix since most of the information there is depicted in Fig. 1. Typo in last line.

Thank you for this suggestion. We have moved Tables 1, 2, 3, 4, 8, and 9 to the appendix as suggested. The typo has been fixed.

It would be a very good idea to convert some tables (at least Table 7) in maps with arrows like the ones in Fig. 5.

Thank you for this helpful suggestion. We have converted Table 7 to a map figure as suggested. We now have two geographical figures. Our new Fig 3 presents maps of VWC and maps of the largest links by scenario. Our new Fig 6 presents maps of the links that save and lose the most water by scenario.

Table 8 and 9 may be moved to the appendix since Fig. 5 contains most of the information.

Thank you for this suggestion. We have moved Tables 1, 2, 3, 4, 8, and 9 to the appendix as suggested.

Fig. 1 What do grey colors mean? Consider changing colors (for example giving values around cero some “low-profile”-color). Caption: “shows” instead of “show” (5 times). Add units to the legend (%).

Grey indicates countries without data. We have added this information to the caption. We have corrected typos and added units to the legend as well. Additionally, we have changed map colors to emphasize deviations from zero as suggested. For the low yield scenario, colors now range from red (largest losses; -20% minimum) to blue (some

gains; 5% maximum). For the high yield scenario, colors now range from dark blue (smallest gains; 4% minimum) to light blue (most gains; 24% maximum). Indeed, the maps presented in this figure are now easier to interpret. We thank you for these suggestions.

Fig. 2 VWC dimensionless? Please explain. And which red stars? I can't see them (in other graphics I do see them). Consider harmonizing y-axes (if possible) to simplify comparison.

Recall that VWC = ET [kg m-2] / Y [kg m-2]. Note that the units of ET and Y are the same. Since the units of the numerator and the denominator are the same, VWC is dimensionless. We have added this point to the text in lines 199-200. There are no data outliers in Fig 2, so we have removed the description of red stars from the caption.

Fig. 5 Consider harmonizing the legend if the range of values allows for it. Please add units to the legend. What do the grey colors in the first column mean? You actually do not need black and red arrows since you have different columns for losses and savings.

Thank you for these suggestions. Unfortunately, the visual interpretation is lost if the axes are harmonized, so we have chosen not to adjust the map color scheme. Although black and red arrows are not necessary, we have chosen to keep the colors for visual interest and ease of interpretation. VWC is dimensionless and grey indicates countries for which we do not have data. We have added this information to the caption.

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Reviewer #2

The topic of the paper is interesting and important but there are a number of issues that make the analysis vulnerable to criticism. In general, it is not clear what the paper adds to the existing literature.

We thank Reviewer #2 for his/her appreciation of our work. We apologize if the paper contribution was unclear in the first draft. The major contribution of our paper is quan-

tifying the impact of climate change on virtual water trade flows and savings. To do this, we use both an economics and a hydrology model. Of particular importance, we project bilateral (i.e. link-level flows rather than net flows) crop and virtual water flows, which allows us to calculate trade-based water savings. To our knowledge this has not been done at the global scale before. We have re-written the introduction to make our contribution more clear.

1) The authors provide no references to the previous literature. This is somewhat surprising since first papers were published several years ago. A number of those studies are based on a CGE modelling framework (for a review see Dudu and Chumi, 2008) others use optimization models (e.g. Fader et al., 2011) or input-output methodologies (e.g. Antonelli et al., 2012). Some of those have looked at the impact of climate change (Calzadilla et al., 2011).

Thank you for pointing out these papers. We now appropriately cite these papers.

2) The concept of virtual water used in the analysis considers only direct (final) water usage, ignoring many indirect (intermediate) uses as input to production. Also, recent studies have shown that it is important to distinguish between different types of water (green or blue water).

Thank you for raising this important point. The main concern with considering only direct trade flows when calculating virtual water flows is in assigning the appropriate virtual water content when transforming the crop flow into water flow. In our paper, we consider the trade of only staple crops, which are unlikely to be re-traded without being processed. However, there are likely a few exceptions, as in the case of major trade hubs, such the Netherlands or the United Arab Emirates. Thus, the virtual water content data that we use is likely correctly matched up with the country of production. Additionally, most calculations of virtual water trade flows in the literature are based upon this approach, which we desire to compare our projections with.

As you correctly point out, there are important differences between green and blue

water use and trade. In fact, we have explored this very concept in previous work (see e.g. Konar et al, 2012). However, the main purpose of the current paper is to determine the impact of climate change on total virtual water trade flows and savings. Distinguishing virtual water trade flows and savings by the source of water is beyond the scope of the current paper.

Konar, M., C. Dalin, N. Hanasaki, A. Rinaldo, and I. Rodriguez-Iturbe (2012), Temporal dynamics of blue and green virtual water trade networks, Water Resources Research, 48, W07509, doi:10.1029/2012WR011959.

3) The GTAP model is used but water is not included as a factor of production.

Thank you for this comment. As you correctly state, our paper uses the standard GTAP model. This version of the model has five factors of production: skilled labor, unskilled labor, capital, land, and natural resources. Unfortunately, water is not considered as a factor production and introducing it is beyond the scope of our current study. There is an ongoing project working to add water as a factor of production in the GTAP model (i.e. the GTAP-W model, refer above to Calzadilla et al, 2011).

We choose to use the standard GTAP model for two main reasons: (1) GTAP-W is not publicly available and (2) The standard GTAP model is publicly available, clearly documented, and widely used. By using the standard GTAP model, our results contribute to the broad GTAP literature and are directly comparable with previous GTAP results. In particular, our approach and results directly build upon the work of Hertel et al (2010), which quantifies how climate change impacts poverty, using the same comparative static modeling approach in the standard GTAP model. We discuss these issues in the new discussion section.

Ideally, a coupled economic-hydrology model would exist that is suitable for our purposes. However, since such a model does not exist, we choose the next best solution, which is to use a separate hydrology and a separate economic trade model that have the capabilities that we require and harmonize crop yield across models.

Hertel, T., Burke, M., and Lobell, D. (2010), The poverty implications of climate-induced crop yield changes by 2030, Global Environ. Chang., 20, 577–585.

4) The authors consider only three agricultural sectors but the GTAP database would allow for a much more disaggregated analysis.

The GTAP database has 57 sectors, of which 8 are within agricultural activities. However, we analyze changes associated only with three major crop commodities (i.e. rice, soy, and wheat), as these are the commodities for which we also have hydrological projections through the H08 model. We have added lines 85-87 to address this point.

5) It is not clear why the authors base their analysis on a CGE model. The projections for 2030 consider changes in the productivity in the three agricultural sectors but ignore changes in all other sectors of the economy. A partial equilibrium model, like the IFPRI model, would have been sufficient for such an analysis.

Thank you for raising this point. Partial equilibrium analyses focus only on the sector affected by some change. These models assume that the rest of the economy is not affected. General equilibrium models, on the other hand, consider all sectors in the economy to determine the economy-wide effect. Partial equilibrium models generally do have more detail for the sector considered. However, we chose to use a general equilibrium model for this study, because agriculture is a sector with implications for the entire economy. A partial equilibrium model will capture the first order effects and miss out on the potential feedback effects, representing an incomplete picture of the potential impacts of climate change.

The GTAP CGE model completely tracks bilateral trade flows between all countries in the world and explicitly models the consumption and production of all commodities of each national economy. Factor markets work to ensure that the demand and supply for the five factors of production (two types of labor, land, capital, and natural resources) are equalized across sectors in the wake of climate change shocks. The yield productivity changes will have implications for trade, production, consumption, and factor

employment in the rest of the economy for all countries considered in our paper. The model allows us to fully capture both the first order effects of the yield shocks and the associated and non-trivial feedback effects on all other sectors. The price and quantity changes that result from the climate change shock, therefore, represent the sum of both direct and feedback effects.

We have added lines 116-119 and 172-177 to address this important point.

Antonelli et al. (2012) Systemic Input-Output Computation of Green and Blue Virtual Water 'Flows' with an Illustration for the Mediterranean Region, Water Resource Management 26: 4133-4146

Calzadilla, A., K. Rehdanz and R.S.J. Tol (2011) Trade Liberalisation and Climate Change: A CGE Analysis of the Impacts on Global Agriculture, Water 3: 526-550.

Dudu, H. and S. Chumi (2008) Economics of Irrigation Water Management: A Literature Survey with Focus on Partial and General Equilibrium Models, Policy research working paper 4556, World Bank: Washington, DC.

Fader, M., Gerten, D., Thammer, M., Heinke, J., Lotze-Campen, H., Lucht, W. and W. Cramer (2011) Internal and external green-blue agricultural water footprints of nations, and related water and land savings through trade, Hydrol. Earth Syst. Sci. 15: 1641-1660.

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Interactive comment by J. Sušnik

While I value your contribution, I also agree with many of the comments from Reviewer 1. I also have an additional comment with regard to Figure 2. You state that that variability of wheat is greater than for soy or rice. Of course it is: you compare a scale of 10ËĘ8 against scales of 10ËĘ7 and 10ËĘ6. More useful would be not to state the absolute change/variability, but rather the relative change (as %). This would allow for a more fair comparison of the predicted change.

We thank Dr. Sušnik for his helpful suggestion and interest in our work! We include a figure below with crop trade under each scenario presented as a percentage change from the baseline value, as suggested. Wheat does display the most variability when displayed in this format as well. Indeed, it is helpful to observe the results in this format. However, we maintain absolute values in the figures in the paper, since we translate crop volumes into virtual water volumes.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/10/C482/2013/hessd-10-C482-2013-supplement.pdf

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 67, 2013.

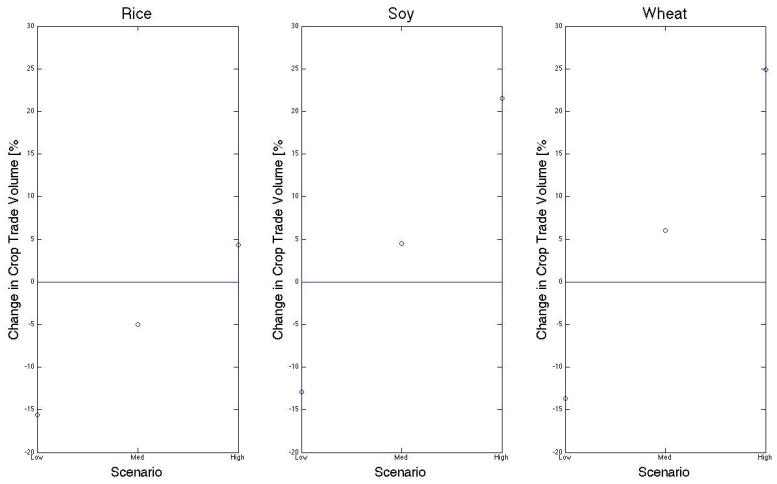
Rice
Soy
Wheat
Change in Crop Trade Volume [%
Scenario
Low
Med
High

Fig. 1.