Do virtual water transfers act as an adaptation mechanism to droughts? A global Analysis

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Abstract

The current article tries to understand whether virtual water flows respond to green water scarcity taking a global dataset of water embodied in grains trade during the period of 1982 to 2007. The current state of knowledge is that the virtual water flows are not following (blue) water scarcity but follows affluence. In order to statistically analyze the question, a panel data of global virtual water flows embodied in selected grain crops, standardized annual precipitation index, drought indicator, GDP levels and other relevant variables is compiled for 160 countries. Panel data regressions on the data provide interesting insights on virtual water as an adaptation mechanism and how to tap the possibility. Under mean level conditions, drought events increases net global virtual water flows by 5×10^9 m^3 yr−1 to 6.34 $\times 10^9$ m^3 yr−1. The net flows are sensitive to precipitation with a threshold SPI value of 0.92. The GDP levels monotonically increases virtual water net imports and each additional square kilometer of agricultural land area reduces the net virtual water import by 10620 to18419 m^3. The major message of the article is that there is a need of broadening the current focus on the transition to climate smart production systems to climate smart food supply systems, while avoiding over reliance on the virtual water flows.

Keywords: Virtual water, panel regressions, drought, green water, adaptation

Introduction

Food production in the world is dependent upon the blue (ground and surface water) and green (rainwater that is not run off) water resources (Falkenmark, 1997) and climatic change is affecting their availability over time and space (Rockström et al, 2009, Orlowsky et al., 2014). Changes in green water availability due to changes in rainfall quantity and distribution, especially due to drought events, can affect food security of countries if not compensated by utilizing blue water resources (Falkenmark, 1997, Siebert and Döll, 2010, Orlowsky et al., 2014) through irrigation or importing virtual water through food trade. Often excessive abstraction of ground and surface resources for irrigation (blue) to compensate green water deficit leads to degradation of the resources, which eventually causes reduction in resilience to rainfall anomalies in future (Hanjra and Qureshi, 2010). Though the possibility of using virtual water as an adaptation mechanism to drought looks appealing, there is only limited evidence that global virtual water flows respond to drought events (Novo et al., 2009). The existing studies (eg: Kumar and Singh, 2005; Horlemann and Neubert, 2007, Wang et al., 2016) mainly concentered on finding relationship between blue water scarcity and virtual water trade flows and were less successful in revealing any direct connection. Hence the available evidence shows that it follows purchasing power rather than water scarcity (Wang et al., 2016). Liu et al. (2009) showed that around 94% of the world crop-related virtual water trade is related to green water and hence it can be expected that the virtual water trade flows are sensitive to events of green water scarcity (rather than blue water scarcity) i.e. rainfall deficits or drought events. Our hypothesis is that there exist threshold levels of rainfall deviation that may trigger the import of virtual water or limit its' export.

Relevant Literature

When stressed of water, trade allows counties to access water virtually in terms of agricultural commodities, especially in terms of water intensive cereal crops and livestock products (D'Odorico et al., 2010). Nevertheless the role of virtual water in ameliorating water scarcity is a topic of divided opinions. Yang et al. (2003) found that there exists a threshold level of water scarcity above which the virtual water imports (cereals), increases exponentially. Counter intuitive evidence was put forward by Kumar and Singh (2005) where it was argued that there is no relation between virtual water flows and water scarcity. According to them the major determinant of virtual water flows is the amount of arable land available in a country. Seekell et al (2011) support this line of thought and argue that virtual water flows may not equalize the water use among countries. Recently Wang et al. (2016) proposed that affluence is the major determinant of virtual water flows and less affluent water scarce countries may not be able to use the virtual water mechanisms for ameliorating water scarcity. Horlemann and Neubert (2007) argue that labour availability is also an important factor in addition to capital in determining production and trade of virtual water embodied in agricultural products. The past literature mainly focused on quantifying virtual water flows between countries and regions and establishing possibilities of handling absolute water scarcity (blue) and uncovering the potential of water saving (Chapagain and Hoekstra, 2008, Konar et al., 2011). Konar et al. (2011) shows the diversity of trading partners' also enhances the virtual water trade, especially the import volumes. An Odorico et al. (2010) shows that virtual water flows can be an adaptation mechanism to droughts using a theoretical model but cautions that over dependence on virtual water flows could undermine long term social resilience to water scarcity. Given the insights on various levers affecting virtual water trade, we construct econometric models that can test our hypotheses that rain water deficit, especially moderate and severe drought events influence export, import and net import of virtual water and hence act as an adaptation mechanism.

Dataset

In order to statistically analyze the relationship between drought events and the flows, a global data set of virtual water embodied in grain trade (in m^3) including soybean and major cereals (Maize, Wheat, Rice, Barley) is aggregated from the virtual water global dataset (1987-2008) used in Konar et al (2011) and Konar et al. (2012). The virtual water flows here are calculated by multiplying the international trade flow of unprocessed cereal crops by the associated virtual water content (total evapotranspiration during period of crop growth/yield) of the products in the country of export, which is calculated using H08 global hydrological model (Hanasaki et al., 2008a, 2008b). The details of the calculation are given in Konar et al (2011). The same dataset is used for calculating the virtual water trade diversity indices in the current study. Standardized precipitation index and drought indicators (https://crudata.uea.ac.uk/cru/data/hrg/) are created from CRU CY v. 3.24 dataset (Harris et al., 2014) for each country and year. Other explanatory variables of virtual water trade considered here are accessed from World Bank and FAO Databases. From these sources a dynamic panel data set is created taking 160 countries for the years 1987, 1992, 1997, 2002 and 2007. A summary of the virtual water flows in the considered years is given in Figure 1.

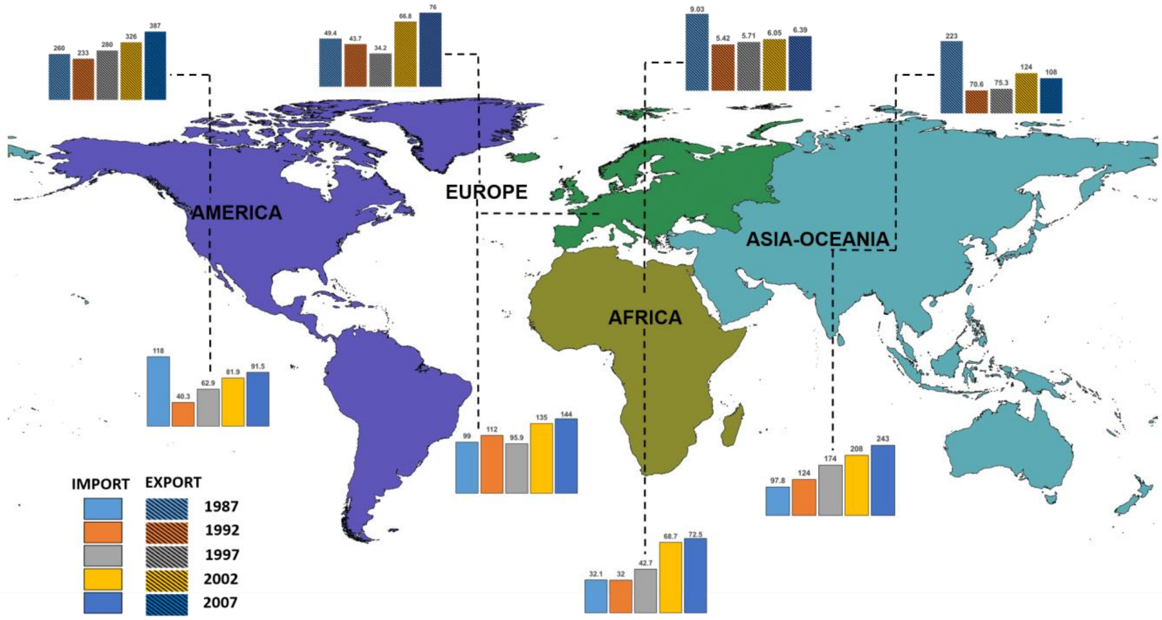

Figure 1: Virtual water flows (embodied in grains) at billion m^3 during 1987, 1992, 1997, 2002 and 2007 aggregated to continental scale.

Method

In order to examine whether virtual water trade is responsive to changes in rainfall availability and drought events, a set of fixed and random effect panel regressions is used with all relevant variables as discussed in previous section.

$$V_{i,t}^{exp} = \beta_0 + \beta_3 LAB_{i,t} + \beta_4 AGAREA_{i,t} + \beta_5 GDP_{i,t} + \beta_6 GDP_{i,t}^2 + \beta_7 SPI_{i,t} + \beta_8 SPI_{i,t}^2 + \beta_9 HIDE_{i,t} + \beta_{10} TO_{i,t} + \beta_{11} TO_{i,t}^2 + \beta_{12} DR_{i,t} + \varepsilon_i + \vartheta_{i,t} \quad (1)$$

$$V_{i,t}^{imp} = \beta_0 + \beta_3 LAB_{i,t} + \beta_4 AGAREA_{i,t} + \beta_5 GDP_{i,t} + \beta_6 GDP_{i,t}^2 + \beta_7 SPI_{i,t} + \beta_8 SPI_{i,t}^2 + \beta_9 HIDI_{i,t} + \beta_{10} TO_{i,t} + \beta_{11} TO_{i,t}^2 + \beta_{12} DR_{i,t} + \varepsilon_i + \vartheta_{i,t} \quad (2)$$

$$V_{i,t}^{nimp} = \beta_0 + \beta_3 LAB_{i,t} + \beta_4 AGAREA_{i,t} + \beta_5 GDP_{i,t} + \beta_6 GDP_{i,t}^2 + \beta_7 SPI_{i,t} + \beta_8 SPI_{i,t}^2 + \beta_9 HIDE_{i,t} + \beta_{10} HIDI_{i,t} + \beta_{11} TO_{i,t} + \beta_{12} TO_{i,t}^2 + \beta_{13} DR_{i,t} + \varepsilon_i + \vartheta_{i,t} \quad (3)$$

Where $V_{i,t}^{exp}, V_{i,t}^{imp}, V_{i,t}^{nimp}$ are aggregate virtual water export, import and net import of country "i" for the time period "t". Other variables included are share of workforce in agriculture (LAB), area under agriculture (AGAREA) , gross domestic product (GDP) and its squared term (GDP^2), standardized precipitation index (SPI) and its squared term (SPI^2) , Herfindahl index for virtual water export diversity (HIDE), Herfindahl index for virtual water import diversity (HIDI), trade openness (TO) indicator and its squared term (TO^2) and a dummy variable to indicate drought (DR) for i^{th} country on t^{th} year . ε_i is the unobserved country-specific effect and $\vartheta_{i,t}$ is the residual term. Hefindahl index for import diversity (HIDI) and Hefindahl index for export diversity (HIDE) indices are calculated as

$HIDI_{i,t} = 1 - \sum_k SI_{i,k,t}^2$ and $HIDE_{i,t} = 1 - \sum_k SE_{i,k,t}^2$

where $SI_{i,k,t}$ and $SE_{i,k,t}$ are share of import and export (virtual water) of i^{th} country originating from k^{th} country (See a similar index in Amjath-babu and Kaechele, 2015).

Drought index is given a value of 1 when the SPI of t^{th} year falls below -1 (which indicates moderate to extremely dry) [WMO, 2012] while trade openness indicator represents share of value of trade with GDP of i^{th} country on t^{th} year. The regression equation is also intended for finding threshold levels of GDP, trade openness and SPI values at which the direction of their influence on virtual water flows changes. The first derivatives of the equation are utilized for finding the thresholds of respective variables. The considered panal data regression models are fitted to the dataset using xtreg command of Stata 13 software.

Results and Discussion

Correlation of virtual water net imports (import-export) to standardized precipitation index presented in Figure 2 shows the varied responses of the flows to relative water scarcity. Correlations observed range from 0.75 (Colombia) to -0.55 (Afghanistan). In case of countries with a negative correlation, they are able to compensate the deficit by import of virtual water. The major reason for positive correlation can be the dependence on export oriented cash crops production like Coffee and tea in Colombia or rubber in Indonesia or countries with high dependence on subsistence agriculture where reduced (or increased) rainfall conditions can lead to reduction (or increase) in net virtual water import. It can be possible that high negative correlation of SPI with virtual water can also due to food aid flows. Correlations near zero can be possible with adequate blue water resources to compensate any deficit in rainfall. It is to be noted that green water covers more than $2/3^{rd}$ of consumptive us of water in case of most of the cereal crops and soybean (Liu et al.,2009) and hence the reason for the observed strong correlation. The lower share of blue water in consumptive use can be a reason for the failure of previous studies that attempted to find a relationship between water scarcity and virtual water trade (Horlemann and Neubert , 2007, Kumar and Singh,2005). flows. Even the recent studies such as Wang et al. (2016) did not include the rainfall deviations as an explanatory variable of virtual water flows.

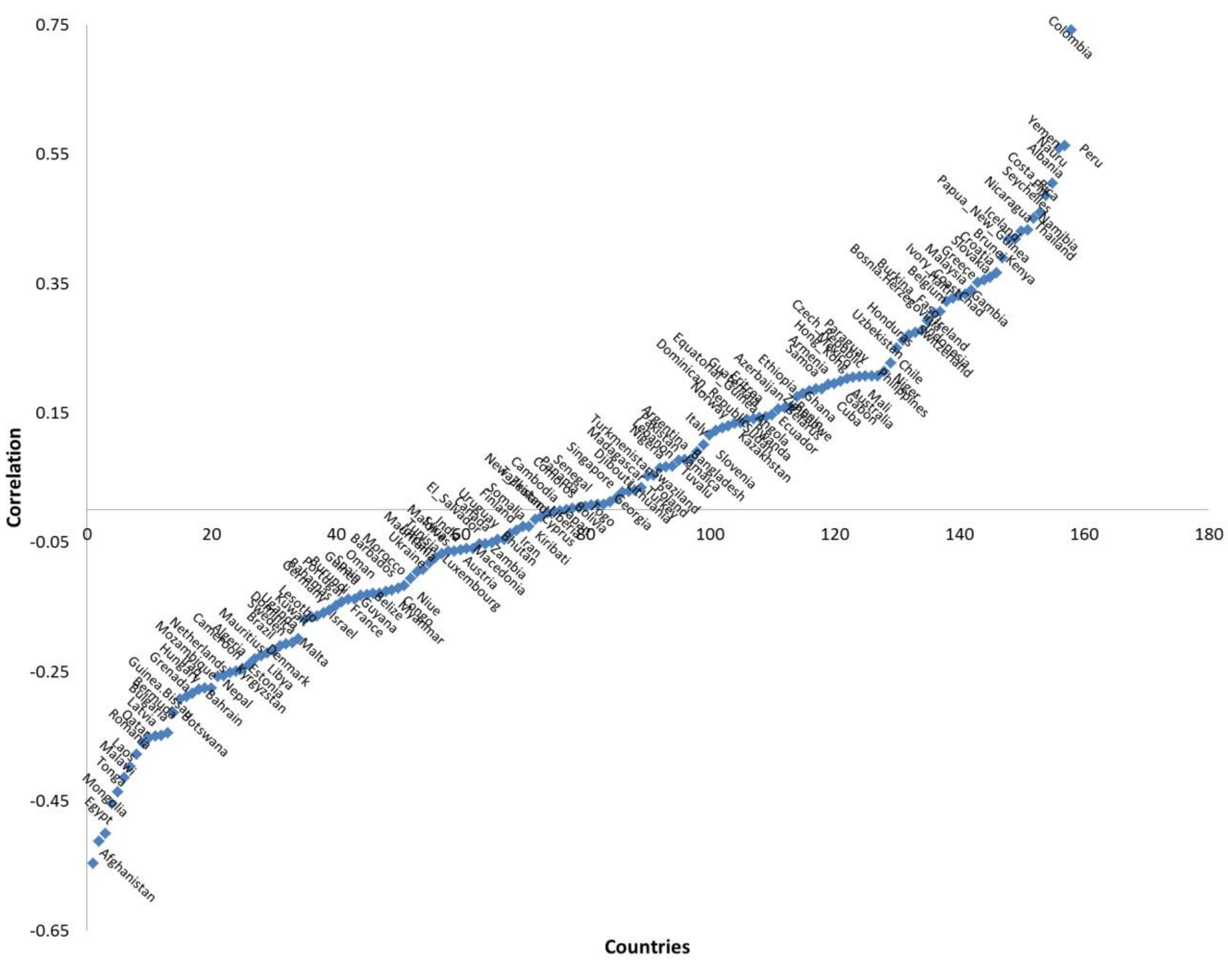

Figure 2. Correlation of rainfall with virtual water net-imports (grains) during 1982-2007

(See the data in supplementary file)

In addition to other variables, we assume that the diversity of the trade links can also influence the virtual water trade and the figure 3 shows how the diversity of virtual water imports (Herfindahl index) changed from 1992 to 2007. The diversity of virtual water flow increased significantly within the period in addition to aggregate traded volume of virtual water. For the considered countries, the virtual water import increased from 347 billion in 1982 to 551 billion in 2007 (1.6 times). Konar et al (2011) also suggest that an increase in trading partners increases the virtual water trade. We intend to check the relationship further by including the diversity indices in the panel regressions and the results are presented in the relevant section.

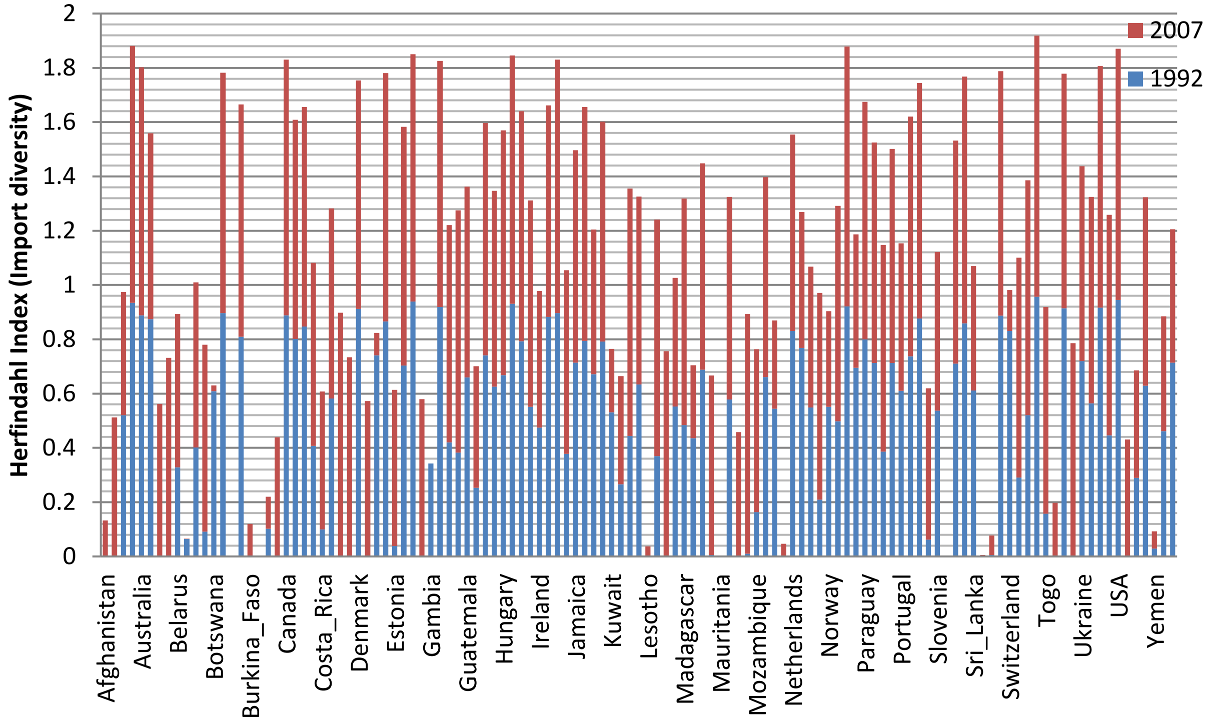

Figure 3: Change in diversity of virtual water import links from 1992 to 2007

The major questions that we ask here are whether the virtual water trade is sensitive to green water scarcity? and is it possible to use virtual water flows to mitigate droughts? The results show (table 1) that in times of green water scarcity, especially in events of droughts, virtual water mechanism works in ameliorating the scarcity. Under mean level conditions, drought events increases global virtual water flows by $5 \times 10^{9}\,m^{3}$ yr−1. The dummy variable representing the SPI value of -1 or below is highly significant in the regressions. It is negative for exports and positive for imports which show that droughts triggers enhanced virtual water import and curtail virtual water export. It may not be the absolute scarcity that matters in virtual water network rather than the relative water scarcity, given the deviation from normal rainfall. Nevertheless it does not mean that such adjustments may not exacerbate blue-water scarcity in exporting countries as money can override the scarcity signals. The calculated threshold levels of SPI for export (1.2), import (0.48) and net import (0.92) show that deviation from normal rainfall indeed affects the virtual water flows and it is emerging as a mechanism to alleviate impact of drought at least for the grain crops in countries with adequate purchasing power. Given the higher threshold level of exports, it can be stated that an increase in imports are triggered at a lower SPI threshold levels than the decline in exports. The increasing diversity of trade links also tends to increase net imports. A point gain in diversity of trade links can attract increased flows to the tune of $9.7 \times 10^{8}\,m^{3}$. Nevertheless the capability to use virtual water flows depends highly on GDP of a given country which is highly significant in the estimated regression equations. In a nutshell, the results show that virtual water act can as an adaptation mechanism which is triggered when rainfall availability reaches critical thresholds, but significant GDP levels with high diversity of trade linkages are required for utilizing this mechanism.

Table 1: Random effect[*] Panel data models for global virtual water flows from 1982- 2007

	Export of virtual water		Import of virtual water		Net import of virtual water	
	Random	Fixed	Random	Random	Random	Fixed
Share of labour working in agriculture	-4.19e+07	6.81e+07	2.37e+07	2.37e+07	2.37e+07	-1.09e+08
Agricultural area (Sqkm)	12149.86***	21506.02***	-10620.88***	-10620.88***	-10620.88***	-18419.45****
GDP (in PPP terms)	0.0007347	0.0028507	0.0067124***	0.0067124***	0.0067124***	0.0050545***
Square of GDP (in PPP terms)	-4.43e-17	-1.40e-16	-3.05e-16***	-3.05e-16***	-3.05e-16***	-2.00e-16
Standardized Precipitation index	-1.41e+09***	-1.77e+09***	1.90e+09***	1.90e+09***	1.90e+09***	2.26e+09***
Square of Standardized Precipitation index	5.85e+08	7.20 e+08***	-1.03e+09***	-1.03e+09***	-1.03e+09***	-1.13e+09***
Herfindahl index (diversity of trading countries in export)	-9.31e+09***	-9.45e+09***	9.73e+09***	9.73e+09***	9.73e+09***	9.21e+09***
Herfindahl index (diversity of trading countries in import)			-9.09e+08	-9.09e+08	-9.09e+08	4.33e+08
Trade openness indicator	5.28e+07*	9.16 e+07***	-3.33e+07	-3.33e+07	-3.33e+07	-8.46e+07
Square of trade openness	-120102.9	--181911.2***	67376	67376	67376	141996
Drought (dummy)	-3.55e+09***	-4.62e+09***	5.34e+09***	5.34e+09***	5.34e+09***	6.34e+09***
Constant	3.23e+09	-5.21 e+09	-2.76e+09	-2.76e+09	-2.76e+09	5.62e+09

Results reveal that drought events increases 1.7- 1.9 billion m3 of virtual (grain) water import globally while curtailing virtual (grain) water export by 3.6 to 4.5 billion m^3. The relationship with GDP (table 1) shows that The GDP levels monotonically increases virtual water net imports until GDP reaches a threshold value of $10 trillion. Very high threshold of GDP indicates that the virtual water flows will monotonically increase with GDP. Though the "Kuznets curve" is observed (Wang et al., 2016), the point where the virtual water trade (especially import) decouples with GDP level, is very high that is not meaningful. The results also reveal that virtual water trade is to be viewed along with virtual land. The importing countries facing land constraints depends on virtual water imports (given the strong negative relation with net imports) but its linkage with the share of population working in agricultural sectors is indeed weak. Each additional square kilometer of agricultural land reduces the net virtual water import by 10620 to 18419 m^3. Large areas of arable lands can offer comparative advantage to countries even if there is water scarcity and may cause a water scarce country actually increase the export of virtual water (Seekell et al., 2011). In our research, it is clear from the positive and significant agricultural land area in the panel regression on virtual water export.

Though virtual water may not be an answer to persistent water scarcity, the results show that it can ameliorate relative water scarcity i.e. drought events. The major condition that may prevent countries from utilizing the mechanism is the inadequate level of GDP and lower diversity of trade relations. Given the results it can be argued that virtual water has a potential to be utilized for managing drought events and it can be possible to change the tariffs and other conditions to tap that opportunity under such circumstances (Reimer, 2013). The degree of trade openness and diversity of trade also represents the presence of favourable tariffs, logistic facilities and governance mechanisms related to international food trade in addition to the availability of foreign exchange reserves.

In case of developing countries with less financial resources, tapping virtual water networks in events of drought is possible but there are impediments. The results mean that these countries need to increase diversity of trade relations by lowering barriers to import, especially in years of moderate to severe drought. It is already proven that reducing tariffs can increase the virtual water flows to a greater extent (Reimer, 2013). Reducing costs of logistics can also increase the trade relations, which may mean greater coordination between land limited and water scarce countries facing drought conditions with countries that can be net sellers of virtual water. The results also show that it may be difficult for low income counties to tap the virtual water mechanisms to ameliorate impacts of drought events. Hence there is a need for international mechanisms that can facilitate virtual water flows to ameliorate drought impacts in such countries. Given the need of purchasing power to utilize the virtual water as an adaptation mechanism to drought events, reducing the cost of its access is required for making it available to low income countries. In the current state of affairs, there is limited reciprocity for virtual water imports i.e. those developing countries, which export additional virtual water to third countries that faces water scarcity, may not receive virtual water when the country itself faces water scarcity, unless they have enough purchasing power.

D'Odorico et al (2010) cautions that perpetual dependence on virtual water mechanisms may undermine the social resilience to drought events and theoretically prove that a *water solidarity* scenario where the virtual water supplies are used as a temporary mechanism to ameliorate extensive drought events can offer large benefits. It also means that virtual water needs to be understood from a green water scarcity point of view and need not be a mechanism for alleviating blue-water scarcity in various regions. In or order to practice such a proposition, there is a need for changing tariffs and trade rules in times of drought. In normal years, higher tariffs are needed to assure that food consumption levels are more aligned to eco-hydrological carrying capacity of the regions. Such higher tariffs may also enhance more localized patterns of food consumption and may promote increased efficiency of locally available water resources. Using lower tariffs and trade impediments during drought events can make sure that the virtual water supplies are used sustainably to ameliorate extreme drought events. The current proposition needs additional verification for its validity, which we appeal to future studies. In addition, mechanisms like a global food gains bank (eg: http://foodgrainsbank.ca/) that can pool and stock grains in times of lower price levels (or excess production) may be able to supply food grains at favorable rates to developing countries affected with drought.

Conclusions

Most of the previous studies concentrated on blue water scarcity and virtual water flows. We rather focus on how drought events or rainfall (green water) deficit influences the virtual water trade along with other major determinants proposed in earlier research works. The panel data analysis results indicate that drought significantly affects the virtual water export and import. The thresholds of SPI and GDP on virtual water trade are also revealed. The research work confirms some of the previously known patterns, especially the effect of affluence on virtual water trade. In addition, the results show that virtual water flows indeed act as an adaptation mechanism to drought and sensitive to rainfall deviations. Finding ways to strengthen the linkage of virtual water import to green water availability can be useful in reducing climate change impacts globally. Especially manipulating trade barriers and developing trade links are required to utilize such an option by developing countries, especially as a drought mitigating mechanism. The results also suggest that the current model of virtual water trade may not ameliorate drought events in low income developing countries and hence mechanism such as global grain banks that stores grains in years of excess production or low prices and provides grains at favourable rates in to the countries affected with extreme drought conditions is required as an alternative option.

The findings also reveal that the possibility of a Kuznets curve i.e. decoupling of GDP growth from virtual water import is not meaningful though it exists. As previous studies (Konar, 2011 and Konar 2012) suggested, diversity of trade links is an important determinant of virtual water trade and our study results support the finding. The availability of larger land (arable) area can offset the impact of drought events and hence virtual land and is also a crucial aspect controlling virtual water flows. It can also be argued that countries that face increased number of drought events due to climatic change need to develop trade pacts and reduce trade barriers with countries that can supply virtual water. Investing in logistics and governance mechanisms can also enhance the utility of virtual water as a drought adaptation mechanism for developing countries. In a real world with unequal income levels, virtual water trade may not always help in increasing water use efficiencies, but it can certainly act as a remedial measure to occasional moderate to severe drought events and hence be an adaptation mechanism. In addition, using trade tariffs for water intensive commodities, countries can also reduce the virtual water flow out of countries when faced with drought conditions.

Given the fact that climatic changes may alter comparative advantages in production, strengthening the possibility of using virtual water use as an adaptation mechanism needs to be promoted. As the results shows that global virtual flows responds to relative green water scarcity, there is a need to go beyond efforts to ensure food security through increasing climatic resilience to food production at country level. It is to be noted that concept of “climate smartness” of food production needs to be expanded to climate smartness of food supply, expanding it to regional and global scales instead of individual agro-ecosystem or nation level. Developing climate smart food supply can also assist in overcoming limits of adaptation to occasional water scarcity at country level if exists.

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