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Understanding agricultural virtual water flows in the world from an economic perspective: A long term study

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ABSTRACT

The globalization process of the last half century entailed a growing trade in agricultural and food products. As a result, water has been transferred among countries, embodied in these goods. This paper studies the evolution of virtual water flows over the long term, analyzing the main driving factors through Decomposition Analysis. It contributes to the existing literature by offering a dynamic and economic interpretation of the historical changes in virtual water trade flows. In particular, this study points to a gradual increase in virtual water exchange, related to the upsurge of agricultural and food products trade in the world from 1965 to 2010. Although the origins and destinations of virtual water have changed, North America stands out as the primary net exporter of virtual water. Europe and Asia, on the other hand, with a high dependency on foreign water resources, appear as net importers of virtual water. Despite improvements in agricultural yields and the reallocation of production, the virtual water trade continues to increase globally via these significant commercial exchanges.

1. Introduction

Food production has experienced a marked increase during the last fifty years (Federico, 2005; Rask and Rask, 2011). Alongside this expansion, commercial exchanges of agricultural and food products have experienced significant growth in the past half century (Serrano and Pinilla, 2010, 2011a). This globalizing process has involved not only an important trade in commodities, but also very large exchanges of the natural resources embodied in these goods (Schmitz et al., 2012).

This is certainly the case for embodied water, which has been growing strongly in the products of international trade. A large number of studies have been carried out over the last decade (Clark et al., 2015; Duarte et al., 2014b; Hoekstra and Hung, 2005; Tamea et al., 2014) to examine the displacement of water resources resulting from the growing integration of global economies. In this framework, virtual water, first defined by Allan (1997), is the volume of water necessary for the production of a commodity. The water footprint is an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer (Hoekstra et al., 2011). The studies of virtual water and the water footprint distinguish between green and blue water; according to Hoekstra and Chapagain (2008), green water is the rainwater evaporated as a result of the production of a commodity, and blue water is surface or groundwater evaporated during a production process. Both are interrelated in the hydrological system, but blue water has higher opportunity costs, as it can be reallocated among the different users (Yang et al., 2007). Virtual water has been methodologically studied from the top-down and bottom-up approaches. The former adopts environmental input–output analysis to obtain virtual water and water footprints by accounting for regional, national and/or global supply chains (Cazcarro et al., 2013; Deng et al., 2015; Duarte et al., 2015b; Feng et al., 2012; Steen-Olsen et al., 2012; Yu et al., 2010). The latter obtains footprints on the basis of the virtual water content of internationally traded goods and services determined from detailed process data (Duarte et al., 2014a,c, 2015a; Hoekstra and Hung, 2005; Hoekstra and Mekonnen, 2012; Vanham et al., 2013). In this paper, we will use the bottom-up methodology that, according to Feng et al. (2011), "has become one of the most popular approaches in water footprinting studies due to its simplicity and relatively good data availability". It allows us to study global virtual

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water flows of agricultural and food products in a highly disaggregated way.

Whereas many of these studies focus on the short term, to our knowledge there are few papers empirically addressing global virtual water trade flows over the long run (Clark et al., 2015; Tamea et al., 2014). From our viewpoint, the long-term approach is essential to assess the relationship between economic growth and natural resources, addressing the historical trajectories and feedbacks. This seems particularly important in the period studied, when the second wave of globalization took place. This long-term process has entailed an outstanding economic and commercial integration that has resulted in growing exchanges of factors and products that embody large volumes of water. The analysis of the environmental implications of globalization processes in the long term, from an economic perspective, is in our view one of the main contributions and innovations of our study. The broad sample considered, including a large number of products and countries, is another of the strong points of the paper. The high level of disaggregation allows us to go deeper into the explanation of virtual water trade in the long run. It is important to highlight that we estimate virtual water trade flows for a long period, but we also explain and quantify the factors behind these trends using an economic approach.

Thus, this paper assesses the trends in virtual water transfers in the world from 1965 to 2010, a period of intense internationalization that led to important environmental impacts. To that end, we analyze global trends paying special attention to those areas that exert the largest pressures on those domestic water resources that are exported, studying the amount and direction of global virtual water flows. We obtain and quantify those factors, driving the path followed by virtual water imports and exports. By means of a Decomposition Analysis (DA), trends in water exchanges are explained on the basis of changes in the volume of trade, in the product–trade composition, in the origin of flows, and in the main commercial countries dealing with agricultural and food products. DA has been utilized in other studies that explain the determinants of changes in virtual water trade flows (Duarte et al., 2014a,c; Kondo, 2005).

The intended contribution of the paper is the analysis of the effects that economic integration, trade expansion, specialization patterns, etc. and the historical factors occurring in the world, have had on the environment, from a long-term perspective, and particularly on an indicator of water pressures. Hence, this study is concerned with the relationship between globalization and natural resources, through the case study of water. To our knowledge, hitherto, water resources have been primarily analyzed from a short-term perspective, while we contribute to the scarce existing literature on virtual water trade flows in the long run (Clark et al., 2015), offering an analysis of the pressures on global water resources from an economic perspective. Our work builds on the prior literature describing water embodied in production and trade (Hoekstra and Chapagain, 2008; Hoekstra and Hung, 2005; Zhan-Ming and Chen, 2013).

The following section addresses the main methodological aspects and explains the data, Section 3 deals with the main findings of our work, Section 4 contains a discussion of the results, and Section 5 presents our main conclusions.

2. Materials and methods

2.1. Methodological aspects

As a first step, we estimate virtual water trade flows following the methodology proposed by Hoekstra and Hung (2005). For a country c in year t virtual water exports $VWX(c,t)$ can be obtained as:

$$VWX(c,t) = \sum_{p} d_p^c(c,p,t)x_p^c(c,p,t) \quad (1)$$

With x_p^c being the quantity of product p exported (Tonnes) and d_p^c a coefficient indicating the volume of water necessary to produce a tonne of each commodity in the exporting country, i.e., water footprint (m^3/Tonne). d_p^c will distinguish between green or blue water.

For a country c, virtual water imports are the sum of the water embodied in the imported goods coming from all countries z.

$$VWM(c,t) = \sum_{pz} d_p^Z(z,p,t)m_p^z(z,p,t) \quad (2)$$

With m_p^z being the bilateral import flow from country z to country c (Tonnes) and d_p^Z representing the water required in country z to produce p (m^3/Tonne). Calculating the difference between virtual water exports and virtual water imports, we get the virtual water trade balance for each country c, as in Hoekstra et al. (2011):

$$VWB(c,t) = VWX(c,t) - VWM(c,t) \quad (3)$$

Second, we apply a Decomposition Analysis (DA) to obtain the factors driving virtual water export and import changes in the world, following the approach applied by Duarte et al. (2014a,c) for the case study of Spain. Embodied water in exports can be explained on the basis of four elements, obtaining:

$$VWX(c,t) = \sum_{p} w_{cpt}\frac{x_{cpt}}{x_{ct}}\frac{x_{ct}}{x_t}x_t \quad (4)$$

The former expression, for country c can be obtained as follows:

$$VWX(c,t) = \mathbf{w}'_{\mathbf{ct}}\mathbf{X}_{\mathbf{ct}}s_{ct}x_t \quad (5)$$

With $\mathbf{w}'_{\mathbf{ct}}$ being a row vector of the water footprint per \$ of product in m^3/\$ (US dollars) in country c, $\mathbf{X}_{\mathbf{ct}}$ is a vector showing the share that each product represents in total exports of country c in period t (product composition of the trade flow). s_{ct} is a scalar with the percentage of the country in total exports (country shares) and x_t is the total value of exports in the world in year t in US dollars (scale). Note that to be able to aggregate trade flows in the DA it is necessary to express the water footprints in m^3/\$ instead of m^3/tonne.

For the whole world economy:

$$VWX(t) = \mathbf{w}'_{\mathbf{t}}\mathbf{X}_{\mathbf{t}}\boldsymbol{s}_t x_t \quad (6)$$

With $\mathbf{w}'_{\mathbf{t}}$ being a vector of water footprints per product and country, $\boldsymbol{X}_t$ a matrix of the share of product exports per country, $\boldsymbol{s}_t$ a vector showing the country shares in total world exports, and x_t the total volume of world exports.

Regarding imports, virtual water imports can be explained on the basis of five drivers: product water footprints, the origin of flows, product composition of the trade flow, country shares, and the scale of trade.

$$VWM(c,t) = \sum_{p,z} w_{cpzt}\frac{m_{cpzt}}{m_{cpt}}\frac{m_{cpt}}{m_{ct}}\frac{m_{ct}}{m_t}m_t \quad (7)$$

or in matrix form,

$$VWM(c,t) = \mathbf{w}'_{\mathbf{czt}}\mathbf{M}_{\mathbf{czt}}\mathbf{m}_{\mathbf{ct}}r_{ct}m_t \quad (8)$$

with $\mathbf{w}'_{\mathbf{czt}}$ being a row vector of the embodied water per product in each of the countries z, from which country c imported, measured in m^3/\$ (US dollars). $\mathbf{M}_{\mathbf{czt}}$is a matrix that includes, for each product p, the percentage bought by c from each country z. $\mathbf{m}_{\mathbf{ct}}$ is a vector of product import composition in country c (with information on