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Analysis

A gravity model of virtual water trade

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ABSTRACT

This work investigates the determinants of bilateral 'virtual water trade (VWT) flows' by means of an estimated gravity model of trade applied to the services of the water embodied in the agricultural goods exchanged across countries. In line with the recent literature on the gravity model of trade, the paper presents a battery of estimation methods. The analysis shows that bilateral VWT flows are affected by the classical determinants of trade, by national water endowments, and by the level of pressure on water resources. These general findings are robust, even though some variation can be observed across the estimation methods and, in particular, when smaller subsamples of countries (such as continents and regional groups) are considered. This contributes to account for the mixed evidence in the literature on the importance of water endowments for the VWT flows.

1. Virtual Water Trade: A Brief Overview

Virtual water is commonly defined as the volume of water used to produce a certain commodity. As commodities are internationally traded, one can depict a network of fluxes of the water that is somehow 'embodied' in the goods exchanged across countries. This represents the core of the idea of virtual water trade (VWT), which this work aims to investigate empirically.

The idea of VWT, originally proposed by Allan (1997, 1998) in path-breaking contributions on the topic, refers to a number of economic concepts developed in the standard international trade literature, in particular within the Heckscher–Ohlin–Vanek (HOV) paradigm (see Heckscher, 1919; Ohlin, 1933; Samuelson, 1949; Vanek, 1968). This is justified by the fact that, as Reimer (2012) notices it, one can conceptualize the VWT 'flows' as the international exchanges of the *services of* the water embodied in the traded goods, in line with the idea of the factor content of trade accepted in international trade theory (Leamer, 1995; Davis and Weinstein, 2003).[1]

Probably because the virtual water concept does not originate within the economic literature, most studies provided at most suggestive results about the trade-related determinants of VWT 'flows' and one of the most important misunderstanding about VWT regards the role of water scarcity. The comparison of countries' absolute water endowments with the water content of their trade in goods (in particular of agricultural

[1] It is worth noticing that the terminology regarding virtual water (VW) remains controversial and we thank an anonymous reviewer for pointing this out. The term 'virtual' does not precisely account for the idea that the *services of* water (as well as the *services of* any other productive factor) are 'embodied' in the goods produced by using water (and other factors) among the productive inputs. Similarly, the locution 'virtual water trade' might improperly suggest that water is actually bought, sold and transferred across nations (see Merrett, 2003a,b); in fact, this expression is simply an abbreviation of the correct locution 'water content of international trade', that more closely reflects the HOV paradigm. In the remaining of the work, the expression 'virtual water trade' will be used as an abbreviation of 'water content of international trade', which in turn refers to the international transferring of the *services of* the water used as a productive factor. Similarly, for the sake of brevity, we shall use the terms VW 'imports' and VW 'exports' to refer, respectively, to the water content of imported and exported products.

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products) has led several authors to conclude about the existence of a paradox in the network of international VWT: countries endowed with little freshwater are net 'exporters' of virtual water, and vice versa. As noted by Ansink (2010), most studies have in fact mixed up the concepts of relative and absolute scarcity, thereby erroneously concluding in favour of the existence of the paradox. To assess properly whether water scarcity impacts on VWT 'flows' in line with relative factor abundance as predicted by the HOV theory, it is necessary to focus on the relative endowments of all productive factors across countries and on the relative factor-intensities of all (traded and non-traded) products. This exercise has been recently performed by Debaere (2014), who finds empirical evidence in favour of the hypothesis that water is indeed a source of comparative advantage along the HOV paradigm.[2] Although the water's impact on the export patterns of products appears less critical than that of other productive factors, countries that exhibit greater water availability do export more water-intensive goods. Moreover, Debaere (2014) finds that the share in world exports of water-abundant countries is larger the higher the water intensity of exported products.

The determinants of VWT 'flows', however, do not depend only on water endowments. Indeed, as suggested by Wichelns (2004), a large number of forces influence the production, the consumption and the exchanges of agricultural goods and of the services of water embodied in such goods: production technologies, domestic and international good prices, trade barriers, and the like. For instance, as shown by Kumar and Singh (2005), the quantity of available land is one of factors that limit the production of agricultural goods and, thus, the VW 'exports'. This suggests that to account for the observed network of VWT 'flows' one needs to identify as many of their determinants as possible. To approach the problem in this way, it is natural to look at the gravity model of trade, which relates product trade flows to the mass of the trading countries, their geographical distance and other possible factors characterising the trading partners. This empirical trade model, whose success is well established in the economic literature, represents a powerful and promising tool to study the causes of the international 'flows' of virtual water.[3] Our analysis of the bilateral VWT 'flows' follows the standard approach to estimate the gravity model of trade in the economic literature. Hence, we build on previous empirical trade studies (see, for instance, Head et al., 2010) and include in our estimations a number of country- and pair-specific variables that appear to be associated with bilateral trade in products. In addition, taking stock of previous works on aggregated VWT 'flows', we identify and test various possible water-related determinants of bilateral VWT 'flows'.

We are not the first to recognise that the gravity model of trade is a useful tool to investigate bilateral VWT 'flows'. However, previous attempts to perform such kind of empirical analysis have mainly focused either on simplified specifications (Konar and Caylor, 2013) or on country-specific empirical relationships (Tamea et al., 2014) which, by definition, prevent from drawing general conclusions on the systemic determinants of VWT 'flows'. In this work, instead, we shall proceed in accordance with the standard approach used in the trade literature, with a view to identifying a specification of the gravity model that strikes a balance between parsimony and fit.

It is worth anticipating that we shall not venture into a normative evaluation of the ability of the international exchanges of the services of water to ameliorate global water efficiency.[4] Nor we shall discuss any welfare and policy implications because, as argued by Boelens and Vos (2012), the ultimate impact of water-related policies on the welfare of the population and, specifically, on the poor is very complex and calls for a very sophisticated and comprehensive kind of analysis which this work does not intend to undertake.

The remainder of the article proceeds as follows. In Section 2 we shall discuss the candidate determinants of VWT 'flows' and in Section 4 we shall illustrate the measures and the data to operationalize them. The specification of the gravity model of trade will be presented in Section 3. Sections 5 and 6 will offer the main empirical results. Some robustness checks will be illustrated in Section 7, where we shall also discuss the estimates for a number of restricted sub-samples of countries. Section 8 will conclude.

2. The Candidate Determinants of the International Flows of Virtual Water

As mentioned in Section 1, several researchers (probably reminiscent of the HOV theory) have studied the relationship between water endowments and product trade flows in the attempt to determine to what extent water availability impacts on the water content of international trade. In doing so, some confusion has emerged: while the HOV model predicts that goods intensive in water are exported by countries with relatively abundant endowments of such factor, many authors have instead tested whether water abundance is positively related to net 'exports' of virtual water. This approximation can be correct, but only under certain conditions: it is only when factor prices and good prices equalise or when trade is balanced (see Ansink, 2010; Reimer, 2012) that the factor content of trade (i.e., the factor volumes embodied in the traded goods) is such that a country surely 'exports' (the services of) its more abundant factor. The equalisation of good and factor prices, however, is unlikely to hold, especially in the case of agricultural products; furthermore, in the real world, net trade exchanges are hardly balanced.

By focusing on crops that are intensive in water, a number of authors provide evidence in favour of a relationship between scarce water endowments and net VW 'imports': Novo et al. (2009) look at Spanish grain trade and Yang et al. (2003) investigate cereal imports in African and Asian countries. Similarly, Yang and Zehnder (2007) find that the intensification of water scarcity is an important factor in explaining the increase in food imports in the Southern and Eastern Mediterranean countries. Short of a test on the entire set of traded goods and trading countries, however, these findings on VWT 'flows' represent at most a *prima facie* evidence regarding the application of the HOV theory to the water content of international trade. In fact, other studies reach opposite conclusions. Kumar and Singh (2005), for instance, extend the analysis to a large set of countries and find no statistically significant relationship between net VWT 'flows' and water scarcity. The very same relationship between scarce water endowments and net VW 'imports' found by Yang et al. (2003) holds only below a certain level of water endowment (whereby cereal imports increase exponentially with the decline in per capita water resources availability). Other studies reach conclusions at variance with the hypothesis that countries with scarce water endowments are net importers of the services of water and find

[2] Debaere (2014) exploits the cross-sectional variation across 134 countries and 206 sectors, and estimates the impact of various interaction terms – between sectors' factor intensities (where the factors are water, capital, land and high-skilled work) and countries' production resources – on the national gross sectoral exports to the rest of the world. This approach applies the notion of supermodularity (see Costinot, 2009) to capture the sources of comparative advantage, which depend on the sectoral variation of factor intensities and on the national variation in relative factor abundances.

[3] On the gravity model of trade see, among others, Anderson (1979), Anderson and van Wincoop (2003), Baier and Bergstrand (2009), Bergstrand (1985), Eaton and Kortum (2001), Feenstra et al. (2001), Santos Silva and Tenreyro (2006), Helpman et al. (2008), Chaney (2008), Anderson (2011) and Head and Mayer (2014).

[4] The reason is twofold. First, we do not estimate how the water management efficiency affects bilateral trade flows; this Ricardian dimension of trade, which is partially captured either by domestic GDP per capita or by the country-fixed effects in the estimation, is not the object of our empirical analysis. Second, the theoretical relationship between the water content of trade and global water efficiency is far from straightforward.