Disaggregating agricultural water flows in the world

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Water resources are growingly transferred embodied in products internationally traded. These water displacements often involve global inequalities that need to be addressed by setting consumption and production responsibilities. Although Multi-Regional Input Output models are powerful tools to assess the interrelations among countries and sectors in global supply chains, the lack of sufficiently disaggregated sectorial data in the empirical applications may entail a notable drawback for assessing some regional problems. This is particularly important when studying water resources, since agriculture accounts for 70% of water consumption all over the world. Therefore, in this paper we will try to join bilateral trade data on agricultural products with WIOD multiregional tables. This will allow us to analyze water consumption trends and to deepen into different productive specializations that could be triggering the increasing global water consumption happened from 1995 to 2009. Although this process was more intense in developed countries in the past, emerging areas cannot be neglected since their development entails a growing pressure on water resources. By applying a Structural Decomposition Analysis that will divide the sample into groups depending on the level of income of countries, we aim to explain water consumption trajectories on the basis of water intensities variations, changes on domestic or imported technologies and trends in demand patterns. Preliminary results seem to indicate an increase in virtual water trade chiefly due to the great boost of demand during these years. Changes in water intensities would be responsible for a partial moderation of water consumption increase in both high and low income countries. Finally, technological changes in low income nations would boost water consumption.

We use the environmentally extended input-output approach to obtain the volume of water embodied in domestic production and in trade flows. The MRIO model allows us to calculate consumer and producer responsibilities of water consumption, distinguishing by regions and sectors. We use a structure of input-output table, based on the model of Isard (1951) and further explained in Miller and Blair (2009) and Cazcarro et al. (2010 and 2013). For the 41 regions it is possible to represent the multiregional matrix of technical coefficients $\mathbf{A}^{\oplus}$ and the Leontief inverse $\mathbf{L}^{\oplus}$, respectively, as:

$$\mathbf{A}^{\oplus} = \begin{bmatrix} \mathbf{A}_{1,1} & \mathbf{A}_{1,2} & \dots & \mathbf{A}_{1,41} \\ \mathbf{A}_{2,1} & \mathbf{A}_{2,2} & \dots & \mathbf{A}_{2,41} \\ \dots & \dots & \dots & \dots \\ \mathbf{A}_{41,1} & \mathbf{A}_{41,2} & \dots & \mathbf{A}_{41,41} \end{bmatrix}; \qquad \mathbf{L}^{\oplus} = \begin{bmatrix} \mathbf{L}_{1,1} & \mathbf{L}_{1,2} & \dots & \mathbf{L}_{1,41} \\ \mathbf{L}_{2,1} & \mathbf{L}_{2,2} & \dots & \mathbf{L}_{2,41} \\ \dots & \dots & \dots & \dots \\ \mathbf{L}_{41,1} & \mathbf{L}_{41,2} & \dots & \mathbf{L}_{41,41} \end{bmatrix} \quad (3.1)$$

Each matrix $\mathbf{A}_{rr}$ $(n \times n)$ which forms the main diagonal indicates the domestic technical coefficients in the region r. The off-diagonal matrices $\mathbf{A}_{rs}$ indicate the coefficients of the region of imported inputs from r. In this way, each characteristic element $a^{ij}{}_{rs}$ of the matrix $\mathbf{A}^{\oplus}$ expresses the quantity of output of sector i produced in r and consumed as input by sector j of region s, per unit of total output of sector j in s.

If we also define $\mathbf{w}_r$ (41×1) as the vector of coefficients of water consumption per output of region r, whose characteristic element $w^{i}{}_{r}$ indicates the quantity of water per unit of output of sector i in region r, we can estimate the consumption of water associated with the production of each region as follows:

$$\begin{bmatrix} \mathbf{\Omega_1} \\ \mathbf{\Omega_2} \\ \dots \\ \mathbf{\Omega_{41}} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{w}}_{1,1} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{2,2} & \dots & \mathbf{0} \\ \dots & \dots & \dots & \dots \\ \mathbf{0} & \mathbf{0} & \dots & \hat{\mathbf{w}}_{41,41} \end{bmatrix} \begin{bmatrix} \mathbf{L}_{1,1} & \mathbf{L}_{1,2} & \dots & \mathbf{L}_{1,41} \\ \mathbf{L}_{2,1} & \mathbf{L}_{2,2} & \dots & \mathbf{L}_{2,41} \\ \dots & \dots & \dots & \dots \\ \mathbf{L}_{41,1} & \mathbf{L}_{41,2} & \dots & \mathbf{L}_{41,41} \end{bmatrix} \begin{bmatrix} \mathbf{y}_{1,1} + \mathbf{y}_{1,2} + \dots + \mathbf{y}_{1,41} \\ \mathbf{y}_{2,1} + \mathbf{y}_{2,2} + \dots + \mathbf{y}_{2,41} \\ \dots \\ \mathbf{y}_{41,1} + \mathbf{y}_{41,2} + \dots + \mathbf{y}_{41,41} \end{bmatrix}$$

(3.2)

Where the $\mathbf{\Omega}_r$ are diagonalized, $\mathbf{y}_{rr}$ represents domestic final demand of r, and $\mathbf{y}_{rs}$ are imports from the region consumed by final demand of s. Thus, with the matrices $\mathbf{\Omega}_r$ we obtain the consumption of direct and indirect water necessary to meet the demands of each region for each sector. Finally, $\mathbf{y}_{rr}$ and $\mathbf{y}_{rs}$ can be decomposed into 5 accounts: Final consumption expenditure by households, final consumption expenditure by non-profit organisations serving households, final consumption expenditure by government, gross fixed capital formation and changes in inventories and valuables

World Input Output Database (Timmer et al., 2012) offers the MRIO table that reflects all exchanges taken place between countries and sectors. Merging it with direct water coefficients that indicate the volume of water necessary to produce a unit of product in each country, also taken from WIOD, we obtain the environmentally extended MRIO model.

$$\begin{bmatrix} \boldsymbol{\Omega}_{1,1} & \boldsymbol{\Omega}_{1,2} & \cdots & \boldsymbol{\Omega}_{1,41} \\ \boldsymbol{\Omega}_{2,1} & \boldsymbol{\Omega}_{2,2} & \cdots & \boldsymbol{\Omega}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \boldsymbol{\Omega}_{41,1} & \boldsymbol{\Omega}_{41,2} & \cdots & \boldsymbol{\Omega}_{41,41} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{w}}_{1,1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{2,2} & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{\mathbf{w}}_{41,41} \end{bmatrix} \begin{bmatrix} \mathbf{L}_{1,1} & \mathbf{L}_{1,2} & \cdots & \mathbf{L}_{1,41} \\ \mathbf{L}_{2,1} & \mathbf{L}_{2,2} & \cdots & \mathbf{L}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{L}_{41,1} & \mathbf{L}_{41,2} & \cdots & \mathbf{L}_{41,41} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{y}}_{1,1} & \hat{\mathbf{y}}_{1,2} & \cdots & \hat{\mathbf{y}}_{1,41} \\ \hat{\mathbf{y}}_{2,1} & \hat{\mathbf{y}}_{2,2} & \cdots & \hat{\mathbf{y}}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \hat{\mathbf{y}}_{41,1} & \hat{\mathbf{y}}_{41,2} & \cdots & \hat{\mathbf{y}}_{41,41} \end{bmatrix} \quad (3.3)$$

Estimates of water consumption allow us to know the embodied water in trade flows between regions and estimate their water footprints. The pressure of countries on the global water resources (which we associate with the blue and green WF consumption), comes from the domestic water consumptive use (W_{dom}), plus the embodied water in imports (virtual water imports, VWM), minus embodied water in exports (virtual water export, VWX). $\boldsymbol{\Omega}_{rr}$ is the matrix of the amounts of water that are used in production activities in region r to support region r final demand, while $\sum_{r,r\neq s}\boldsymbol{\Omega}_{rs}$ is the matrix of water consumed in other regions production to support region s final demand (VW imports of region s) and $\sum_{s,s\neq r}\boldsymbol{\Omega}_{rs}$ is the matrix of water consumed in r to support the final demands of other regions (VW exports of region r). Then, $\mathbf{e}'\boldsymbol{\Omega}_{rs}\mathbf{e}$ is the total amount of water consumed in region r to support its own final demand, this is the domestic component of the water footprint of region r. Similarly, $\sum_{r,r\neq s}\mathbf{e}'\boldsymbol{\Omega}_{rs}\,\mathbf{e}$ is the total VW import of region s, and $\sum_{s,s\neq r}\mathbf{e}'\boldsymbol{\Omega}_{rs}\,\mathbf{e}$ the total VW export of region r. Moreover, $\sum_{r}\mathbf{e}'\boldsymbol{\Omega}_{rs}\,\mathbf{e} = \mathbf{e}'\boldsymbol{\Omega}_{ss}\mathbf{e} + \sum_{r,r\neq s}\mathbf{e}'\boldsymbol{\Omega}_{rs}\,\mathbf{e}$ is the water footprint of region s and $\sum_{s}\mathbf{e}'\boldsymbol{\Omega}_{rs}\,\mathbf{e} = \mathbf{e}'\boldsymbol{\Omega}_{rr}\mathbf{e} + \sum_{s,s\neq r}\mathbf{e}'\boldsymbol{\Omega}_{rs}\,\mathbf{e}$ the water due to production in region r (in other words, the direct consumption of water in region r). The difference between this water and the water footprint of the region r, $\sum_{s,s\neq r}\mathbf{e}'\boldsymbol{\Omega}_{rs}\,\mathbf{e} - \sum_{r,r\neq s}\mathbf{e}'\boldsymbol{\Omega}_{rs}\,\mathbf{e}$, is nothing but the net export of water, which can be positive or negative and reveals the exporter or importer character of the region.

In the basis of relationship (3.3), we can decompose $\mathbf{y}_{rs}$ into two components representing the composition (given by C) and the size (scale, given by Y) of the final demand, which yields:

$$\begin{bmatrix} \mathbf{\Omega}_{1,1} & \mathbf{\Omega}_{1,2} & \dots & \mathbf{\Omega}_{1,41} \\ \mathbf{\Omega}_{2,1} & \mathbf{\Omega}_{2,2} & \dots & \mathbf{\Omega}_{2,41} \\ \dots & \dots & \dots & \dots \\ \mathbf{\Omega}_{41,1} & \mathbf{\Omega}_{41,2} & \dots & \mathbf{\Omega}_{41,41} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{w}}_{1,1} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{2,2} & \dots & \mathbf{0} \\ \dots & \dots & \dots & \dots \\ \mathbf{0} & \mathbf{0} & \dots & \hat{\mathbf{w}}_{41,41} \end{bmatrix} \begin{bmatrix} \mathbf{L}_{1,1} & \mathbf{L}_{1,2} & \dots & \mathbf{L}_{1,41} \\ \mathbf{L}_{2,1} & \mathbf{L}_{2,2} & \dots & \mathbf{L}_{2,41} \\ \dots & \dots & \dots & \dots \\ \mathbf{L}_{41,1} & \mathbf{L}_{41,2} & \dots & \mathbf{L}_{41,41} \end{bmatrix}$$

$$\begin{bmatrix} \hat{\mathbf{C}}_{1,1} & \hat{\mathbf{C}}_{1,2} & \dots & \hat{\mathbf{C}}_{1,41} \\ \hat{\mathbf{C}}_{2,1} & \hat{\mathbf{C}}_{2,2} & \dots & \hat{\mathbf{C}}_{2,41} \\ \dots & \dots & \dots & \dots \\ \hat{\mathbf{C}}_{41,1} & \hat{\mathbf{C}}_{41,2} & \dots & \hat{\mathbf{C}}_{41,41} \end{bmatrix} \begin{bmatrix} \hat{Y}_1 & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \hat{Y}_2 & \dots & \mathbf{0} \\ \dots & \dots & \dots & \dots \\ \mathbf{0} & \mathbf{0} & \dots & \hat{Y}_{41} \end{bmatrix} \quad (3.4)$$

In this context, SDA has been applied to equation (3.4) to synthesize the driving forces underlying the changes in water embodied in regional domestic and traded production. As it is well-known, this approach tries to separate a time trend of an aggregated variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998; Hoekstra and van den Bergh, 2002; Lenzen et al., 2001).

In a discrete schema, when we try to measure the changes in the dependent variable between two periods, *t-1* and *t,* there are different ways of solving this expression by way of exact decompositions, which leads to the well-known problem of the non-uniqueness of the SDA solution. In our case, if decomposition is based on four factors, we can obtain the following *4!* exact decompositions. In practice, as a "commitment solution", the average of all possible solutions is considered. Nevertheless, as Dietzenbacher and Los (1998) demonstrate, the simple average of the two polar decompositions runs as a good approximation to the average of the *4!* exact forms.

As departing point we obtain changes in matrix $\mathbf{\Omega}$ as difference of $\mathbf{\Omega_1}$ and $\mathbf{\Omega_0}$, i.e., $\mathbf{\Omega}$ in periods t_0 and t_1:

$$\Delta\mathbf{\Omega} = \mathbf{\Omega}_1 - \mathbf{\Omega}_0 = \mathbf{\widehat{w}_1 L_1 \widehat{C}_1 \widehat{Y}_1} - \mathbf{\widehat{w}_0 L_0 \widehat{C}_0 \widehat{Y}_0} \qquad (3.5)$$

Subsequently, we obtain the polar decompositions of the expression above:

$$\Delta\mathbf{\Omega} = \Delta\mathbf{\widehat{w} L_0 \widehat{C}_0 \widehat{Y}_0} + \mathbf{\widehat{w}_1} \Delta\mathbf{L \widehat{C}_0 \widehat{Y}_0} + \mathbf{\widehat{w}_1 L_1} \Delta\mathbf{\widehat{C} \widehat{Y}_0} + \mathbf{\widehat{w}_1 L_1 \widehat{C}_1} \Delta\mathbf{\widehat{Y}} \qquad (3.6)$$

$$\Delta\boldsymbol{\Omega} = \Delta\hat{\mathbf{w}}\mathbf{L}_1\hat{\mathbf{C}}_1\hat{\mathbf{Y}}_1 + \hat{\mathbf{w}}_0\Delta\mathbf{L}\hat{\mathbf{C}}_1\hat{\mathbf{Y}}_1 + \hat{\mathbf{w}}_0\mathbf{L}_0\Delta\hat{\mathbf{C}}\hat{\mathbf{Y}}_1 + \hat{\mathbf{w}}_0\mathbf{L}_0\hat{\mathbf{C}}_0\Delta\hat{\mathbf{Y}} \qquad (3.7)$$

Taking averages of (3.6) and (3.7) we obtain (3.8):

$$\begin{aligned}\Delta\boldsymbol{\Omega} = {} & \frac{1}{2}\left(\Delta\hat{\mathbf{w}}\mathbf{L}_0\hat{\mathbf{C}}_0\hat{\mathbf{Y}}_0 + \Delta\hat{\mathbf{w}}\mathbf{L}_1\hat{\mathbf{C}}_1\hat{\mathbf{Y}}_1\right) + \frac{1}{2}\left(\hat{\mathbf{w}}_1\Delta\mathbf{L}\hat{\mathbf{C}}_0\hat{\mathbf{Y}}_0 + \hat{\mathbf{w}}_0\Delta\mathbf{L}\hat{\mathbf{C}}_1\hat{\mathbf{Y}}_1\right) \\ & + \frac{1}{2}\left(\hat{\mathbf{w}}_1\mathbf{L}_1\Delta\hat{\mathbf{C}}\hat{\mathbf{Y}}_0 + \hat{\mathbf{w}}_0\mathbf{L}_0\Delta\hat{\mathbf{C}}\hat{\mathbf{Y}}_1\right) \\ & + \frac{1}{2}\left(\hat{\mathbf{w}}_1\mathbf{L}_1\hat{\mathbf{C}}_1\Delta\hat{\mathbf{Y}} + \hat{\mathbf{w}}_0\mathbf{L}_0\hat{\mathbf{C}}_0\Delta\hat{\mathbf{Y}}\right) \qquad (3.8)\end{aligned}$$

As long term effects of development on environment seem to be different regarding the economic features of regions, we have classified countries depending on their level of per capita gross domestic product, dividing the sample into high and low-middle income countries. Thus, it will possible to observe the different effects depending on countries classification. Therefore, applying this classification to water intensities, we obtain:

$$\begin{bmatrix} \hat{\mathbf{w}}_{1,1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{2,2} & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{\mathbf{w}}_{41,41} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{w}}_{\mathbf{1,1}} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{H,H} & \cdots & \mathbf{0} \\ \cdots & \cdots & \mathbf{0} & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \\ \cdots & \cdots & \hat{\mathbf{w}}_{H+1,H+1} & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{\mathbf{w}}_{L,L} \end{bmatrix} \quad (3.9)$$

In which *n* is the number of total countries (*n=1…41)* that comprises the two subsamples; i.e., h high income countries (h*=1,2,…,h)* and *n-h* low income countries (l=*h+1,h+2,…,l).* h consists of 29 countries and l consists of 11 countries plus ROW.

Accordingly, we obtain the intensity effect (IE) as expressed in the following equation, (3.10):

$$\begin{aligned}\mathrm{IE} & = \frac{1}{2}\left(\Delta\hat{\mathbf{w}}_{\mathbf{H}}\mathbf{L}_1\hat{\mathbf{C}}_1\hat{\mathbf{Y}}_1 + \Delta\hat{\mathbf{w}}_{\mathbf{H}}\mathbf{L}_0\hat{\mathbf{C}}_0\hat{\mathbf{Y}}_0\right) + \frac{1}{2}\left(\Delta\hat{\mathbf{w}}_{\mathbf{L}}\mathbf{L}_1\hat{\mathbf{C}}_1\hat{\mathbf{Y}}_1 + \Delta\hat{\mathbf{w}}_{\mathbf{L}}\mathbf{L}_0\hat{\mathbf{C}}_0\hat{\mathbf{Y}}_0\right) \\ & = \mathrm{IEH} + \mathrm{IEL} \qquad (3.10)\end{aligned}$$

Thus, the intensity effect (IE) can be decomposed into:

- Intensity effect of high income countries (IEH), which quantifies the contribution of changes in high income countries water intensities to water consumption trends.

$$\mathrm{IEH} = \frac{1}{2}\left(\Delta\hat{\mathbf{w}}_{\mathbf{H}}\mathbf{L}_1\hat{\mathbf{C}}_1\hat{\mathbf{Y}}_1 + \Delta\hat{\mathbf{w}}_{\mathbf{H}}\mathbf{L}_0\hat{\mathbf{C}}_0\hat{\mathbf{Y}}_0\right) \qquad (3.11)$$

- Intensity effect of low income countries (IEL), which identifies the impact of changes in water intensities of low-middle income countries on water consumption trajectories.

$$\text{IEL} = \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}_{\mathbf{L}}\mathbf{L}_{\mathbf{1}}\widehat{\mathbf{C}}_{\mathbf{1}}\widehat{\mathbf{Y}}_{\mathbf{1}} + \Delta\widehat{\mathbf{w}}_{\mathbf{L}}\mathbf{L}_{\mathbf{0}}\widehat{\mathbf{C}}_{\mathbf{0}}\widehat{\mathbf{Y}}_{\mathbf{0}}\right) \qquad (3.12)$$

Secondly, we obtain technology effect that links variations in water consumption with changes in the technology of production.

$$\text{TE} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{1}}\Delta\mathbf{L}\widehat{\mathbf{C}}_{\mathbf{0}}\widehat{\mathbf{Y}}_{\mathbf{0}} + \widehat{\mathbf{w}}_{\mathbf{0}}\Delta\mathbf{L}\widehat{\mathbf{C}}_{\mathbf{1}}\widehat{\mathbf{Y}}_{\mathbf{1}}\right) \qquad (3.13)$$

Regarding this effect, note that, for each country, the technological effect can be also separated into changes in domestic technology (domestic technology effect), changes in imported technology from low income areas (backward technology effect from low) and variations in imported technology from high income countries (backward technology effect from high). The different blocks in matrix $\mathbf{\Delta L}$ approximate these effects.

As it is well known, we can describe production as a chain of processes that, departing from some primary inputs generates intermediate inputs used in subsequent processes until the generation of final demand. This is the basis of the vertically integrated production. When this production chain is established in a multiregional input-output model, the different countries and technologies contribute to the generation of the final demand of a country, and technological changes along the entire production chain will condition the volume of water embodied in a specific final demand.

Thus, changes in $\Delta\mathbf{L}$ for a country *s,* can be decomposed into changes in inputs domestically produced (DD) (changes in the domestic technology used to produce inputs that can be used in other countries, but are eventually embodied in its domestic final demand, which will comprise the so-called internal and mixed effects) and changes in the backward effect (DB), that is, changes in technologies of other countries that produce the inputs necessary to meet the final demand of country s. This backward effect can be further decomposed identifying the contribution of high income areas (DBH) and low income countries (DBL). For the whole model, these components can be expressed as follows:

$$\Delta\mathbf{L} = \begin{bmatrix} \mathbf{D}_{1,1} & \mathbf{D}_{1,2} & \cdots & \mathbf{D}_{1,41} \\ \mathbf{D}_{2,1} & \mathbf{D}_{2,2} & \cdots & \mathbf{D}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{D}_{41,1} & \mathbf{D}_{41,2} & \cdots & \mathbf{D}_{41,41} \end{bmatrix} =$$

$$\begin{bmatrix} \mathbf{D}_{1,1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{D}_{2,2} & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{D}_{41,41} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \mathbf{D}_{1,2} & \cdots & \mathbf{D}_{1,41} \\ \mathbf{D}_{2,1} & \mathbf{0} & \cdots & \mathbf{D}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{D}_{41,1} & \mathbf{D}_{41,2} & \cdots & \mathbf{0} \end{bmatrix} =$$

$$= \mathbf{DD} + \mathbf{DBH} + \mathbf{DBL} \qquad (3.14)$$

Thus, we obtain technology effect:

$$\mathrm{TE} = \frac{1}{2}\left(\hat{\mathbf{w}}_{\mathbf{0}}\mathbf{DD}\hat{\mathbf{C}}_{\mathbf{1}}\hat{\mathbf{Y}}_{\mathbf{1}} + \hat{\mathbf{w}}_{\mathbf{1}}\mathbf{DD}\hat{\mathbf{C}}_{\mathbf{0}}\hat{\mathbf{Y}}_{\mathbf{0}}\right) + \frac{1}{2}\left(\hat{\mathbf{w}}_{\mathbf{0}}\mathbf{DBH}\hat{\mathbf{C}}_{\mathbf{1}}\hat{\mathbf{Y}}_{\mathbf{1}} + \hat{\mathbf{w}}_{\mathbf{1}}\mathbf{DBH}\hat{\mathbf{C}}_{\mathbf{0}}\hat{\mathbf{Y}}_{\mathbf{0}}\right) + \frac{1}{2}\left(\hat{\mathbf{w}}_{\mathbf{0}}\mathbf{DBL}\hat{\mathbf{C}}_{\mathbf{1}}\hat{\mathbf{Y}}_{\mathbf{1}} + \hat{\mathbf{w}}_{\mathbf{1}}\mathbf{DBL}\hat{\mathbf{C}}_{\mathbf{0}}\hat{\mathbf{Y}}_{\mathbf{0}}\right) = \mathrm{DTE} + \mathrm{BTEH} + \mathrm{BTEL} \qquad (3.15)$$

Accordingly, water consumption changes due to changes in technology can be explained on the basis of:

- Domestic technology effect (DTE), which quantifies the contribution of changes in inputs produced domestically to water consumption trends.

$$\mathrm{DTE} = \frac{1}{2}\left(\hat{\mathbf{w}}_{\mathbf{0}}\mathbf{DD}\hat{\mathbf{C}}_{\mathbf{1}}\hat{\mathbf{Y}}_{\mathbf{1}} + \hat{\mathbf{w}}_{\mathbf{1}}\mathbf{DD}\hat{\mathbf{C}}_{\mathbf{0}}\hat{\mathbf{Y}}_{\mathbf{0}}\right) \qquad (3.16)$$

- Backward technology effect from high income countries (BTEH), which measures to what extent changes in inputs produced in high income areas and imported by countries affect water consumption trajectories.

$$\mathrm{BTEH} = \frac{1}{2}\left(\hat{\mathbf{w}}_{\mathbf{0}}\mathbf{DBH}\hat{\mathbf{C}}_{\mathbf{1}}\hat{\mathbf{Y}}_{\mathbf{1}} + \hat{\mathbf{w}}_{\mathbf{1}}\mathbf{DBH}\hat{\mathbf{C}}_{\mathbf{0}}\hat{\mathbf{Y}}_{\mathbf{0}}\right) \qquad (3.17)$$

- Backward technology effect from low income countries (BTEL), which explains the relationship between changes in inputs produced in low income regions imported by countries and water consumption variations.

$$\mathrm{BTEL} = \frac{1}{2}\left(\hat{\mathbf{w}}_{\mathbf{0}}\mathbf{DBL}\hat{\mathbf{C}}_{\mathbf{1}}\hat{\mathbf{Y}}_{\mathbf{1}} + \hat{\mathbf{w}}_{\mathbf{1}}\mathbf{DBL}\hat{\mathbf{C}}_{\mathbf{0}}\hat{\mathbf{Y}}_{\mathbf{0}}\right) \qquad (3.18)$$

Finally, demand is decomposed into:

- Composition effect, which studies changes in water consumption as a result of variations on the composition of demand by products.

$$\mathrm{CE} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{L}_{\mathbf{1}}\Delta\widehat{\mathbf{C}}\widehat{\mathbf{Y}}_{\mathbf{0}} + \widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{L}_{\mathbf{0}}\Delta\widehat{\mathbf{C}}\widehat{\mathbf{Y}}_{\mathbf{1}}\right) \quad (3.19)$$

- Scale effect, which quantifies how much of the change in water consumption is due to changes in the volume of final demand.

$$\mathrm{SE} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{L}_{\mathbf{1}}\widehat{\mathbf{C}}_{\mathbf{1}}\Delta\widehat{\mathbf{Y}} + \widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{L}_{\mathbf{0}}\widehat{\mathbf{C}}_{\mathbf{0}}\Delta\widehat{\mathbf{Y}}\right) \quad (3.20)$$

All the components presented below are obtained in a matrix fully disaggregated by country and sector, aggregating the data only for the final presentation of the results. In this regard, all the components can be particularized by sector, country or group of countries, generating important information in the identification of national footprints and their evolution.

In the empirical analysis, we use MRIO tables data from the World Input Output Database (WIOD) (see WIOD, 2012 and Dietzenbacher et al., 2013 for more information on methodology). This database offers economic information for 35 economic sectors in 40 countries and a region called Rest of the World (ROW) from 1995 to 2009. We have chosen 1995 and 2009 to be able to compare and explain trends on water resources in the largest possible time horizon. IO tables are expressed in current monetary units and in previous year prices. Thus, in order to accurately make the comparison between these two years, it was necessary to deflate 2009 data, i.e., we express 2009 MRIO table in constant 1995 prices. Since the new data does not fulfill the requirement of equal sum of totals in rows and columns, once we deflate 2009 economic data, the next step involves applying a GRAS adjustment; a generalization of RAS proposed by Junius and Oosterhaven (2003) and improved by Lenzen et al. (2007). This approach allows working with matrixes containing positive and negative values, so that adjustment it is possible despite negative values. Moreover, we use WIOD data on water consumption distinguishing its color (green, blue and grey) and sector. In the case of green water, WIOD only offers information of the direct consumption of water in one sector, agriculture. Nevertheless green water represents about 78% of global crop production water footprint (Mekonnen and

Hoekstra, 2011) and 87.2% of global animal production water footprint (Mekonnen and Hoekstra, 2012).

Countries are classified depending on their level of per capita income into two groups, low-middle income countries and high income countries. This has been done following the criteria of the World Bank (2013). Therefore, we consider as high income countries those who have a per capita gross national income equal or more than $12,476. On the contrary, low-middle income areas are under $12,476.

Furthermore, following the Statistical classification of economic activities in the European Community (NACE Rev. 2), the Agriculture, Forestry and Fishing in the Multiregional Input-Output tables from WIOD is disaggregated into approximately 14 agricultural sub-sectors. Therefore, it will be necessary to obtain information on the composition of production, exports and imports in each of the 41 countries. On the one hand, data on agricultural domestic production are taken from the Food and Agriculture Organization (FAO, 2014). On the other hand, the product composition of bilateral trade flows among countries is obtained on the basis of the data taken from UN COMTRADE database (2014).

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