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Abstract

International agri-food trade has expanded rapidly during the past decades and changed considerably in structure with important implications especially for developing economies. One of the main environmental concerns regarding international trade is about the exploitation and redistribution of water resources. In this paper we use the virtual water approach for analyzing the relation between global agri-food trade, its structure and virtual water flows in the period of 1986 to 2011. Specifically, for five world regions we calculate growth rates of interregional trade values and virtual water volumes, the contribution of different product groups to trade and the economic water efficiency of imports and exports. Our findings show that over time trade values have generally increased more rapidly than virtual water volumes. In Africa and South America virtual water exports have roughly quadrupled since 1986. In all regions staples and industrial products account for the largest share in virtual water trade. The recent shift towards high-value exports is beneficial for developing countries from a regional water efficiency perspective due to high trade values and low associated virtual water volumes. Water efficiency of trade has increased in all regions since 2000 and export water efficiency is especially high in Europe.

Key Words: virtual water trade; food trade; international trade; environmental impact; economic development

JEL classification: F18, F64, Q17, Q27, Q56

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1 Introduction

International trade in agricultural and food products has increased sharply during the past decades, mainly du to increased trade liberalization, urbanization and changing diets. Between 1985 and 2011 the total value of agricultural exports has tripled in real terms, from around 250 billion USD to more than 750 billion USD, measured in constant 1990 prices (FAO, 2014a). Whereas European countries still account for the largest share of world food exports, other regions are increasingly included in global trade and especially agri-food exports from low- and middle-income countries in Africa, Asia and South America are expanding rapidly. The sharp expansion of agri-food trade coincides with important changes in the structure of trade (Aksoy, 2005). Globally, high-value food products (including fruits, vegetables, and products from animal origin) are gaining importance in total agri-food trade; their share in total agri-food export value increased from 32% in 1980 to 41% in 2010 (FAO, 2014a). At the same time, the importance of staple food products such as cereals and of traditional tropical commodities such as coffee and cocoa in overall food trade has decreased. The structure of agri-food exports changed most dramatically in low- and middle-income economies where high-value products replaced tropical commodities as main agri-food export category (Maertens et al., 2012; World Bank, 2007; Aksoy, 2005, Diop and Jaffee, 2005). The expansion of agri-food trade and the changing trade pattern have important implications, especially for developing countries (Reardon et al., 2009; Pingali, 2007; Aksoy and Beghin, 2005).

Studies mainly point to positive welfare implications for developing economies. It has been argued that globalization in general and participation in international trade in particular leads to economic growth and poverty reduction in developing countries (Dollar and Kraay, 2004). Trade in high-value food products has been argued to be particularly promising for fostering agricultural growth and rural development in low-income countries because of high revenues (relative to lower-value staple food and raw commodity exports) and labor-intensive production systems (Maertens et al., 2012; Aksoy and Beghin, 2005). Most of the evidence on the beneficial effects of high-value trade comes from micro-economic studies. Recent empirical research has documented that the participation of farmers – smallholder farmers in particular – in high-value export chains increases household and farm income (Rao and Qaim, 2011, Miyata et al., 2009); reduces risk and income variability (Ramaswami et al., 2009); increases farm productivity (Rao et al., 2012); spurs technology adoption and improves product quality (Dries and Swinnen, 2004); and alleviates poverty and food insecurity (Maertens and Swinnen, 2009; Minten et al., 2009).

Others have expressed concerns about expanding and changing global agri-food trade, especially about the increasing dependency of low-income countries, mainly from Africa, on imports of staple food products (Christiaensen and Devarajan, 2013). This might pose a threat to food security in these countries, especially in the light of the 2008 food price spikes and the increased price volatility in food markets. In addition, increased reliance on staple food imports diverts investments away from domestic food sectors, which jeopardizes the much needed upgrading and modernization in staple and domestic food supply chains in developing countries (Minten et al., 2013; Reardon et al., 2012; Rakotoarisoa, 2011; Diao et al., 2010; Pingali, 2007).

In addition, there are various environmental concerns related to expanding and changing global agri-food trade. The most widely discussed environmental issue in this respect is carbon emissions (Edwards-Jones et al., 2008; MacGregor and Vorley, 2006). The production as well as the transportation of food are important components of global carbon emissions which gave rise to studies quantifying the carbon footprint of traded products, including food (Peters et al., 2011; Hertwich and Peters, 2009). Research results indicate that on a global level food consumption accounts for 20% of greenhouse gas emissions (Hertwich and Peters, 2009) and that emissions are increasingly transferred from developing to developed countries through trade (Peters et al., 2011). A second environmental issue is the link between agri-food exports and the use of agro-chemicals. Some studies claim that increasing agricultural exports lead to increased use of pesticides and chemicals and thereby to adverse environmental effects (Longo and York, 2008; Murray, 1991). Others have argued that export-oriented agri-food production is not necessarily more pesticide intensive than agri-food production for domestic markets, and that the comparison between higher-value pest-susceptible export crops and lower-value pest-resistant staple crops is not straightforward (Galt, 2008). A third important environmental issue is the relation between agri-food trade and the exploitation of water resources – the subject of this paper. Agricultural production is intensive in water, accounting for around 70% of global freshwater withdrawals (UNESCO, 2014) and it has been estimated that 15% of the world's agricultural water use is for export products (Chapagain and Hoekstra, 2008). Hence, agri-food trade has important consequences for the global redistribution of water. A number of studies have quantified hypothetical water flows between trading nations using the virtual water (VW) concept developed by Hoekstra and Hung (2005). The notion of VW is based on the total volume of water that is consumed during the whole production process of a product and it has been estimated that there is an average VW flow of 1,600 billion m^3/year due to international trade (Hoekstra and Chapagain, 2008). Seventy-eight percent of this volume is related to trade in agricultural products. Studies have analyzed the quantities and efficiency of VW trade on a global scale, mostly focusing on a specific year or using average trade volumes (Chapagain et al., 2006; Yang et al., 2006; Hoekstra and Hung, 2005). These show that international agricultural trade saves huge amounts of water due to trade flows from water-efficient to water-inefficient regions (Chapagain et al., 2006) and that the main contribution to these savings comes from trade in wheat and maize (Yang et al., 2006). Dalin et al. (2012) assess global VW flows over time and conclude that water savings due to international trade have increased over time. Carr et al. (2013) assess the contribution of different commodity types to annual VW trade and find that the overall product composition remained relatively stable while total VW volumes have increased. Konar and Caylor (2013) focus on staple food trade in Africa, finding a positive correlation between VW imports and human development. However, water use efficiency (i.e. the physical output produced per unit of water input) of staple crop exports from African countries does not increase with exports, contrary to global trends. Duarte, Pinilla and Serrano (2014) show for the case of Spain that globalization has led to sharp increases in VW flows mainly due to increasing trade volumes and to a lesser extent due to a change towards more water-intensive products.

The aim of this paper is to examine the relation between the changing composition of global agri-food trade, VW water flows and VW trade efficiency. Examining this relation will reveal whether the changing pattern of food trade has contributed to more efficient water use at the global level, and in low- and middle-income countries in particular. We distinguish interregional agri-food trade patterns and VW flows for five world regions (Africa, Asia, Europe, Northern America and Southern America) and for four major product categories (animal products, high-value products, industrial products and staples) for the period of 1986 until 2011. This time span was chosen based on data availability but coincides with the period of major global trade increases and changes in trade patterns. We assess growth rates of trade values and related VW flows, the product composition of trade and the economic water efficiency of food imports and exports, i.e. the the money spent (earned) per unit of VW imported (exported). This analysis allows us to draw conclusions on the impact of expanding and changing global agri-food trade on global water resources and to derive which regions trade water most efficiently.

The article is organized as follows. In the next section the research results are presented. We first show interregional trade values and related VW flows for each of the five world regions in order to put the further results into context. This is followed by the annual growth rates of trade values and VW flows, and the product composition of trade. Finally, the annual water efficiency of interregional imports and exports is presented. Section 3 discusses the results and draws conclusions. In section 4 the methodology applied and the construction of the database are presented in detail.

2 Results

2.1 Interregional trade and VW flows

In Table 1 the total value of interregional agri-food exports and imports and the associated VW flows are given for five world regions: Africa, Asia, Europe, Northern America and Southern America. We show figures for 1986 and 2011, the first and the last year of the period covered by our study. Trade values have been taken from FAO (2014a) and converted into constant 1990 prices. VW flows have been calculated for each region as the sum of product trade flows multiplied with the respective annual product- and country-specific water footprint (WF) of production. WF values were adapted from Mekonnen and Hoekstra (2012, 2011) (see sections 4.1. and 4.2. for details). Figures need to be interpreted with care as the regions do not cover all countries and products – but do cover the same countries and products in different years – because of data limitations.

Africa is the region with the lowest agri-food export values and the lowest VW outflows. While African exports and imports, and associated VW flows, increased over the period 1986-2011, they remain low compared to the other regions. In Southern America, exports and VW outflows are 10 times higher than in Africa but imports and VW inflows are similar to Africa. VW outflows are the highest in Southern America, with almost 400 km^3 of VW outflow in 2011, while VW inflows are the highest in Asia, with 390 km^3 in 2011. Northern America ranks second in terms of VW outflows with 314 km^3 in 2011 but VW inflows are rather small. In Europe and Asia the VW inflows are substantially higher than the outflows. While the 2011 value of exports in Europe is almost twice as high as in Asia, the VW outflows from Europe are much lower than those of Asia.

[Table 1]

In Figure 1, we depict the growth in agri-food exports and associated VW outflows in the period 1986-2011 for the five regions. We use 1986 as the base year and index the export values and VW outflows in that year to 100%. The exports and VW flows for the other years are then expressed relative to the base year. In all regions export values have increased in real terms over the period 1986-2011with the sharpest increases since the year 2000. Related VW outflows have increased along with exports. Especially since 2005 onwards, the growth in VW outflows slowed downed in all regions and did not keep pace with the growth in export value that increased at a higher rate than VW outflows. The highest growth in agri-food exports and VW outflows happened in Africa and Southern America. In Africa, export values almost quadrupled between 1986 and 2011 while VW outflows increased almost fivefold. Africa is the only region where VW outflows increased more rapidly than the value of agri-food exports. In Southern America, export values more than quadrupled while VW outflows increased nearly fourfold. Most of the changes here happened after 2000. At first, VW outflows increased more rapidly than export values but this reversed in recent years. In Asia, a similar but less pronounced trend is observed with VW outflows growing faster than exports until 2000 and a reversal of this in recent years. Between 1986 and 2011 export values almost tripled and VW outflows increased by 228%. Europe and Northern America have experienced the slowest growth in agri-food exports and VW outflows. In both regions, exports more than doubled over the period while VW outflows increased with 40 to 50%.

[Figure 1]

In Figure 2, we depict the growth in agri-food imports and associated VW inflows in the period 1986-2011 for the five world regions. Again, we use 1986 as the base year and index the imports and VW inflows in that year to 100%, and express values for the other years relative to the base year. In all regions, import values and VW inflows have increased over the period 1986-2011. The strongest increases are observed in Asia, Southern America and Africa. In Asia, the import value more than quadrupled while VW inflows tripled. In Southern America, the import value more than tripled while VW inflows doubled. In both regions, import values grew more rapidly than VW inflows, especially in recent years. In Africa, both import values and VW inflows almost tripled. VW inflows grew at a higher rate than imports during the 1990s and early years 2000, but this difference disappeared in recent years. Europe and Northern America have experienced the slowest growth in agri-food imports (80 and 60% respectively) and VW inflows (30 and 40% respectively) in the period 1986-2011, and in both regions VW inflows have grown slightly less rapidly than import values.

[Figure 2]

2.2 Composition of trade and VW flows

In Figure 3, we show the product composition of exports and VW outflows for the different regions. The figure includes five year averages of export values and VW outflows for four different product categories: high-value products, staple crops, live animals and animal products, and industrial products. High-value products include fruits, vegetables, spices and nuts; staple crops include cereals, roots, tubers and pulses as well as animal feed; live animals and animal products include milk, eggs and meat; and industrial products include sugar crops, tea, coffee, tobacco, rubber, oils, fats and beverages. Non-food agricultural products, such as fibers, hides and skins are not included in the analysis. More detail on the product categorization is provided in section 4.3. As we are mainly interested in the composition of trade, we express export values and VW outflows for the four product groups as percentage of the total export value and of the total VW outflow for each region for the respective years using 5-year average values.

[Figure 3]

The composition of agri-food exports varies somewhat across regions. In Africa, Asia and Southern America industrial products account for the largest share of export value, around 50% in all three regions in 2007-2011. While that share remained more or less stable over the period 1987-2011 in Asia and Southern America, it decreased quite substantially in Africa, from 64% in the beginning of the period to 49% at the end. Especially in Africa, and to a lesser extent also in Asia, the importance of high-value exports increased over time; in the former case from 28% of the total export value in the years 1987-1991 to 38% in the period 2007-2011. During the same period, the share of staple crops in total exports decreased in Asia and Southern America. In the three regions, Africa, Asia and Southern America, the share of industrial products in VW outflows is substantially higher than its share in export value – this is also the case for staple crops but the difference is less pronounced – while for high-value products it is the other way around. In the high-income regions, Europe and Northern America, industrial products are important in total exports as well but in Europe also animal products are significant, accounting for around one quarter of total agri-food exports. In Northern America also staples are important, accounting for 37% of exports in 2007-2011. In these two regions, the importance of the different product categories in export value is more similar to their importance in VW outflows. Industrial products and staple crops are responsible for the largest share of export earnings (65% in Europe and 77% in Northern America in 2007-2011) and also for the largest share of VW outflows (75% in Europe and 89% in Northern America). In Northern America, the share of VW outflows related to staple crop exports has decreased tremendously between 1987-1991 (74%) and 2007-2011 (45%) while the share of VW outflows related to industrial products has doubled from 21% to 44%.

In Figure 4, we show the product composition of imports and VW inflows for the different regions, using the same four product categories and 5-year average percentages as above. In Africa and Southern America staple imports represent the largest share of total agri-food import value and account for the largest share of VW inflows, followed by industrial products. In Asia, the importance of staple crops in total agri-food imports has decreased from 35% of the value in 1987-1991 to 26% in 2007-2011; and the importance in related VW inflows dropped from 59% to 34% over the same time period.

[Figure 4]

The share of industrial products has increased sharply between 1987 and 2011 and now accounts for the highest share of import value (45%) and VW inflows (49%) in Asia. Also in Northern America and Europe, industrial products account for the largest share of import value and VW inflows (71% in Northern America and 64% in Europe in 2007-2011). Moreover, high-value products account for around one third of the import value in both regions but only for a small share (around 10%) of the VW inflows.

2.3 Economic efficiency of VW flows

Figure 5 shows the economic water efficiency of agri-food trade for the five regions. It is calculated by dividing total annual trade values by the associated VW flows and is expressed in USD per m^3 of VW. For imports, the economic water efficiency describes the average amount of money spent per unit of VW inflow into a region. For exports it is the amount of money earned per unit of VW outflow. Some remarkable trends and patterns emerge in VW efficiency. First, in the period before 2000, water efficiency decreased or stayed stable over the years in all regions, for exports as well as for imports.

[Figure 5]

Since 2000, water efficiency of both imports and exports increased in all the regions. The strongest increases are observed for exports in Europe (water efficiency of exports increased from 0.33 USD/m^3 in 2000 to 0.58 USD/m^3 in 2011) and for imports in Northern America (water efficiency of imports increased from 0.27 USD/m^3 in 2000 to 0.44 USD/m^3 in 2011). In Africa, Asia and Southern America, the water efficiency of agri-food trade started to increase especially from 2005 onwards. Second, in Africa and Southern America, the VW efficiencies of imports and exports are very similar and follow a very similar trend over the years. For Europe and Northern America, this is not the case. In these regions large differences exist between water efficiency of exports and imports. Europe has a very high water efficiency of agri-food exports but has an efficiency of imports that is comparable to other regions. Specifically, Europe received 0.58 USD per m^3 of VW outflows in 2011 and paid only 0.25 USD per m^3 of VW inflows in the same year. The situation is reversed in Northern America where the price per unit of VW inflow is twice as high as the price received per unit of VW outflow (0.44 USD/m^3 vs. 0.22 USD/m^3 in 2011). Also in Asia water efficiency of imports is higher than that of exports but the difference is much less pronounced.

3 Discussion and conclusions

The results presented in the previous section provide interesting insights into the evolution and patterns of VW flows over time.

First, regarding the growth rates of trade values and VW flows we have shown that generally, interregional trade values have increased at a higher rate than related VW flows over time. Reasons for this are a more water-efficient production of exported products, a changing product composition, i.e. a shift towards products with higher trade values and a lower water intensity, or both. Growth rates have been especially high for VW outflows from Africa and Southern America where they raised fourfold between 1986 and 2011. This shows the increasing inclusion of these world regions in international agri-food trade which goes along with an increased use of water resources for the production of export goods. At the same time, import values and VW inflows have grown at a slower pace than exports in most world regions. Only in Asia import values and related VW inflows have grown at a higher rate than export values and VW outflows. This implies that Asia is increasingly relying on food imports and water inflows from other regions.

Second, considering the product composition of trade we have shown that staples and industrial crops account for the largest share of VW trade in all five regions and that the largest share of VW outflows from Africa, Asia, and Southern America is related to exports of industrial products. However, these products account for a relatively low share of export earnings which is a disadvantage for the exporting region from an economic water efficiency point of view. At the same time the importance of trade in high-value products is increasing especially in the three southern regions. While trade values of high-value products have expanded rapidly during the past decades, the related VW flows are relatively small. Hence, from a region-wide VW perspective, the recent shift towards promoting horticultural exports as a development strategy is not only beneficial from an economic point of view, but also from a water perspective. This is especially clear in the case of Africa, where earnings from high-value exports have increased from 28% of the total export value in the years 1987-1991 to 38% in the period of 2007-2011. The associated VW outflows only represent 8% of the total VW outflow in 1987-1991 and 18% in 2007-2011. However, it is important to keep national and production region-specific water availability in mind when formulating policy recommendations regarding increasing horticultural trade. Although high-value products are generally water-efficient, enough physical water resources need to be available in the production region in order to allow for a sustainable production.

Third, VW inflows to Africa, Asia and Southern America are mainly related to staple imports. The share of import value related to staples is considerably lower than the share of VW inflows making staples an advantageous import product from a water point of view. From this perspective, the pleas for decreasing the dependency of Africa and other low-income countries on staple food imports is not consistent with increasing the water efficiency of trade in these countries. Whereas the composition of imports has not changed much in Africa and Southern America over the studied period, in Asia the share of staple imports has decreased substantially between 1987 and 2011. At the same time, the share of industrial products in imports has nearly doubled. The composition of imports of Europe and Northern America has also remained relatively stable over time. The lion's share of VW inflows into these regions is due to imports of industrial products such as coffee and cacao which account for around half of the import value of these regions but are responsible for a relatively large share of associated VW flows. Trade in animal products accounts generally for a larger share in trade values than in VW trade. This picture would surely change when assessing VW flows in relation to physical quantities of the traded products because for many animal products the WF per ton is higher than the VW flow per USD. A striking example is beef with a global average WF of 15,415 m^3/ton (Mekonnen and Hoekstra, 2012). When considering trade values of cattle meat in 2011 (FAO, 2014a), the world average VW flow was 3,234 m^3/USD. Hence, the VW volume related to the physical quantity is five times higher than the VW volume related to the trade value.

Fourth, regarding overall economic water efficiency, a general trend of constant or decreasing water efficiency until 2000 can be observed for all five regions. From 2000 onwards, prices per

m^3 of water start increasing again. However, there are striking differences in water efficiency between regions. Generally, Asia, Africa and Southern America have a much lower water efficiency than Northern America and especially Europe. Differences between water efficiency of imports and of exports are also remarkable: Northern America and to a lesser extent Asia pay notably more per unit of imported VW than they receive per unit of VW exported. For Northern America this can be linked to its trade pattern which is comprised by relatively large shares of high-value imports with low related VW volumes. At the same time the share of staples imports is very low whereas on the other hand, exports are to a large extent comprised of staple crops with a low value per unit of VW. Contrary to Northern America, Europe has a much higher water efficiency of exports compared to imports, making its trade pattern very efficient from a regional water perspective. Considering agri-food exports, the price European countries receive per m^3 of VW is much higher than that of other regions, i.e. on average 0.4 USD/m^3 between 1986 and 2011 compared to 0.15 USD/m^3 in the other regions. This could be due to the product composition of European exports, including a relatively large share of animal products with a high value. Moreover, Europe is the only region where industrial products account for a larger share in export value compared to their share in VW outflows. This suggests that Europe is exporting industrial products with a higher value and lower VW content than other regions, for instance in the form of processed products in contrast to primary products. One example for this is coffee, where green coffee has a global average green and blue VW content of 15,365 m^3/ton and roasted coffee of 18,292 m^3/ton (Mekonnen and Hoekstra, 2011). However, the world market price of green coffee was 4,391 USD/ton in 2011 whereas roasted coffee was traded for more than twice the price of 9,903 USD/ton (FAO, 2014a). If European countries import green coffee and export the roasted product, this substantially increases the difference between economic water efficiency of imports and exports.

It is important to see these results in a broader context regarding water scarcity. When comparing physical water quantity as estimated by Gassert et al. (2013) and economic water efficiency of trade it becomes evident that trade patterns do not reflect the social value of water resources: Europe receives the highest price for its VW exports although it is the least water-scarce world region. Asia, on the other hand is generally very water-scarce but still pays more per unit of VW imported than it earns per unit of VW exported. This might be due to its trade pattern which consists to a large extent of industrial and staple exports that generally have a lower trade value and imports of more expensive animal products. Thus, Asia's trade pattern is to its disadvantage with respect to economic water efficiency. In Africa, water scarcity is especially occurring in the Northern African countries and in the Southern tip of the continent.

The opportunity cost of water used for the production of export commodities is thus very location specific. The same holds for Southern and Northern America, where the areas along the Pacific coast are extremely dry whereas the western side of the continent does generally not suffer from water stress. The relationship between agricultural trade patterns and water scarcity could be assessed in more detail with country- and watershed-specific studies, using the same methods as presented in this paper.

4 Material and Methods

4.1 Calculation of trade values, virtual water flows and water efficiency

First, annual values of exports and imports have been calculated per country by multiplying product-specific trade quantities with their respective trade values in real terms, only considering interregional trade. Then, the sum over all traded products p is taken. Country-level data have subsequently been summed up for all home countries $c_{h,r}$ belonging to world region r:

$$X_v(r,t) = \sum_{c_{h,r}} \sum_{p} x_q\left(c_{h,r}, c_f, p, t\right) \times x_v(c_{h,r}, c_f, p, t) \tag{1}$$

$$M_v(r,t) = \sum_{c_{h,r}} \sum_{p} m_q\left(c_{h,r}, c_f, p, t\right) \times m_v(c_{h,r}, c_f, p, t) \tag{2}$$

where X_v is the total value of exports from world region r in year t; x_q denotes the physical quantity of product p exported by home country $c_{h,r}$ to foreign country c_f in year t and x_v is the value of the respective transaction. In the same way, the total value of imports M_v for each world region has been calculated.

Second, the VW content of agricultural commodities that are traded between regions has been calculated following the approach of Hoekstra and Chapagain (2007). The volume of virtual water exports VWX from region r in a specific year t is obtained by multiplying the export quantities x_q of each country $c_{h,r}$ with the respective time- and product-specific water footprint of production $WF(c_{h,r}, p, t)$ and summing up over all export products and countries belonging to r. This can be expressed as:

$$VWX(r,t) = \sum_{c_{h,r}} \sum_{p} x_q(c_{h,r}, p, t) \times WF(c_{h,r}, p, t) \tag{3}$$

Similarly, the virtual water imports VWM of a region are calculated by summing up the national VWM of all countries belonging to r. VWM of $c_{h,r}$ in t are obtained by multiplying the imported quantities of agricultural commodities m_q with their product and time-specific WF of production in the country of origin c_f and summing over all products and partner countries:

$$VWM(r,t) = \sum_{c_{h,r}} \sum_{p,c_f} m_q(c_{h,r}, c_f, p, t) \times WF(c_f, p, t) \tag{4}$$

Growth rates of trade values and VW trade have been calculated using the year 1986 as the base year and indexing trade values and VW flows in that year to 100%. Trade values and VW flows for the other years are then expressed relative to the base year.

Lastly, we calculate the annual water efficiency of exports WEX and imports WEM of r by dividing the annual value of trade flows per region by the associated VW content:

$$WEX(r,t) = X_v(r,t)/VWX(r,t) \tag{5}$$

$$WEM(r,t) = M_v(r,t)/VWM(r,t) \tag{6}$$

4.2 Data sources

Data for our analysis were collected from two main sources. First, bilateral trade data of crops and livestock products come from FAO (2014a). These data include information on export and import quantities and values of crops, derived crop products and animal products. Also information on the trade partner country is provided. The FAOSTAT database only covers bilateral trade data between 1986 and 2011. Nonetheless, this is also the period of major global trade increases and changes in product patterns and thus suitable for our analysis. We focus on imports and exports of countries belonging to Africa, Asia, Europe, Northern America and Southern America and exclude trade data of countries belonging to the former USSR due to many years of missing values during the political transition. Moreover, Oceania is not considered in our analysis due to its limited importance in international agri-food trade. Due to political changes since 1986 we merged trade data from the Socialist Federal Republic of Yugoslavia and its former member states. The same procedure was applied for the Socialist Federal Republic of Yugoslavia and its former member states, Ethiopia and the People's Democratic Republic of Ethiopia, Germany and the Federal Republic of Germany. Missing trade data have been replaced by linear interpolation for all countries which had less than 10 years of missing data. Countries with more than 10 years of missing data have been excluded from analysis leading to a final set of 86 countries reporting imports and export. The number of trade partner countries is higher than this as the reporting countries might still export to or import from countries that are not included in our database with their own imports and exports. Trade quantities for live animals that were reported as the number of heads have been converted to tonnes based on their global average weight provided by Mekonnen and Hoekstra (2012) and FAO (2003). Moreover, trade values have been converted to constant USD of 1990 based on the consumer price index.

Second, the national average water footprint (WF) of production of a wide number of crops, derived crop products, animals and livestock products has been estimated by Mekonnen and Hoekstra (2011, 2012). It measures the amount of water required for producing one ton of an agricultural product under specific spatial circumstances and can be subdivided into consumptive water use (i.e. water lost to the atmosphere due to evapotranspiration or water incorporated in the final product) and the amount of water required to assimilate pollutants to a maximum allowed level. The former can furthermore be divided into green (rainwater) and blue water (surface and ground water). The water needed to assimilate pollutants is called grey water (2011). For our calculations we focus on consumptive water use, i.e. the sum of the green and blue WF which together account for 90% of the global WF of crop production (2011) and for 93.4% of global animal production (2012). For 195 nations both WF for crops and livestock products are available from Mekonnen and Hoekstra (2011, 2012). Additionally, we have calculated the WF for the USSR, the SFR Yugoslavia and Czechoslovakia as the unweighted average of the WF of its member countries and used the WF of Serbia and Montenegro for the states of Serbia and Montenegro, respectively. In cases where country-specific WF information for a certain product was missing, we used the global average value. This allows the inclusion of VW flows related to re-exports and re-imports of products from countries that are not the original producers of a product. The WF is expressed in m^3 of water per ton of a product and is obtained for crops by dividing evapotranspiration (m^3/ha) by yield (t/ha). As Mekonnen and Hoekstra (2011) use average yield data from 1996-2005, we follow Duarte, Pinilla, and Serrano (2014) and adjust the WF of crop products to annual changes in yields for our reference period:

$$WF(c,p,t) = WF(c,p)\frac{Y(c,p)}{Y(c,p,t)} \tag{7}$$

where $WF(c,p,t)$ is the water footprint for country c of producing product p in year t. In our analysis, t ranges from 1986 to 2011. $WF(c,p)$ is the national average WF as provided by Mekonnen and Hoekstra (2011) and $Y(c,p)$ the average yield used by them. $Y(c,p,t)$ is the yield of product p in country c and year t and has been obtained from FAO (2014a).

As trade data are reported in FAO commodity codes and WF data mainly according to Harmonized System (HS) codes, we have converted the classification of the WF dataset using conversion tables provided by FAO (2014b). In cases where multiple HS codes correspond to one FAO code the average WF was taken. After merging trade and WF data our final database includes trade data of 256 crop, livestock and derived products according to the FAO classification.

A limitation regarding data availability is due to the FAO (2014a) bilateral trade database: Export and import quantities and values reported by different trading partners do not correspond which leads to considerable differences between total annual exports and total imports in some years.

4.3 Classification of products and countries

For analyzing the VW trade patterns we have subdivided the traded commodities into four major categories. All agricultural and food products are classified by FAO (2014b) into 20 commodity groups. We have used these pre-defined groups and further classified them into four major categories: First, high-value products such as fruits, vegetables, spices and nuts which are of growing importance in the trade pattern of many developing countries. Second, staple crops including cereals, roots, tubers and pulses. These crops constitute a large share of the daily diet in many countries but do generally have a lower trade value. Third, we grouped live animals and animal products such as milk, eggs and meat into one category named animal products. The fourth group, industrial products, subsumes a variety of traditional agricultural commodities such as sugar crops, tea and coffee, tobacco, rubber, oils and fats and beverages. Non-food products, such as fibers, hides and skins are not included in the analysis.

Countries are grouped into five geographical regions being Africa, Asia, Europe, Northern America and Southern America (including Central America and the Caribbean). The final dataset includes trade data of 86 countries of which 18 are in Africa, 17 in Asia, 30 in Europe, 2 in Northern America and 19 in Southern America.

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Table 1: Total interregional agri-food trade values (billion USD, constant 1990 prices) and associated VW flows (km³) per region, 1986 and 2011.

	Export value		VW outflows		Import value		VW inflows	
	1986	**2011**	**1986**	**2011**	**1986**	**2011**	**1986**	**2011**
Africa	2.20	8.05	8.13	38.84	6.41	19.93	36.00	96.88
Asia	9.96	29.20	66.23	150.80	22.28	96.18	130.11	390.17
Europe	21.02	50.08	60.59	85.19	40.56	64.36	195.17	259.77
N-America	28.28	70.61	204.55	314.93	23.55	43.32	72.68	99.50
S-America	19.17	89.05	105.78	397.72	5.02	16.85	32.51	76.07

Figure 1: Growth in agri-food export value and VW outflows per region. Values are indexed to the base year 1986.

Figure 2: Growth in agri-food import value and VW inflows per region. Values are indexed to the base year 1986.

Figure 3: Importance of different product groups in export values and VW outflows (%). Average shares over 5-year periods are given.

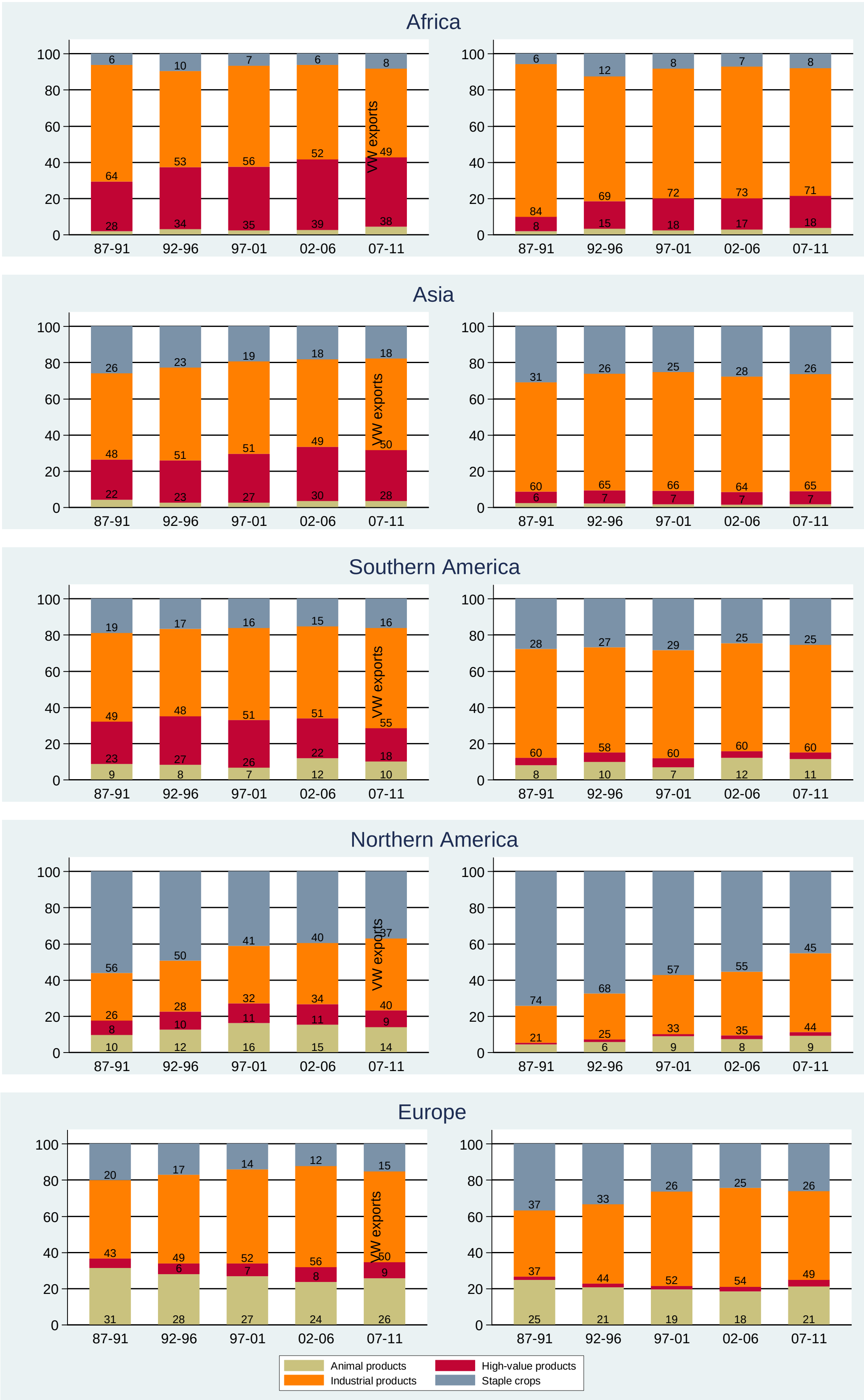
Africa
Asia
Southern America
Northern America
Europe
VW exports
87-91
92-96
97-01
02-06
07-11
Animal products
High-value products
Industrial products
Staple crops

Figure 4: Importance of different product groups in import values and VW inflows (%). Average shares over 5-year periods are given.

Figure 5: Water efficiency of exports and imports (USD/m³) per region.