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Intra-African Trade in Virtual Water: Trends and Drivers

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Introduction

Increasing intra-African trade is expected to have a wide range of benefits, including contributing to increased economic growth, employment, and food security. The African Continental Free Trade Area (AfCFTA), launched in 2021, will have potentially significant impacts on economic output and incomes when fully implemented. A recent study suggests that AfCFTA implementation will drive substantial employment growth, generating more than 7 million new jobs in manufacturing, public services, trade, and other services (World Bank 2020). Bouët, Laborde, and Traoré (2022) estimate that an ambitious implementation of the AfCFTA, which eliminates tariffs and significantly reduces nontariff measures, would increase Africa's gross domestic product (GDP) by 0.2 percent compared to baseline trends in the absence of the AfCFTA by 2035. Increased intra-African trade in agriculture could also contribute significantly to improving food security and nutrition, including by increasing dietary diversity, promoting food price stability, and boosting the availability of key micronutrients (Bonuedi, Kamasa, and Opeku 2020; Makochekanwa and Matchaya 2019; Odjo and Badiane 2018; Olivetti et al. 2023).

A further potential benefit of increased intra-African trade is its contribution to environmental sustainability and efficient use of scarce natural resources. The impacts of trade on the environment are complex. Although trade expends resources and contributes to greenhouse gas emissions, it could also contribute to sustainable resource use if it allows countries to specialize in production patterns according to their resource endowments and comparative advantage (Odjo, Traoré, and Zaki 2023). In the context of climate variability and water scarcity, trade could potentially help to minimize the negative impacts by moving commodities from areas with high water availability to water-scarce areas (Matchaya, Garcia, and Traoré 2023).

This chapter reviews overall trends in intra-African agricultural trade and, to assess the contribution of this trade to sustainability, takes a close look at its potential to address issues of water scarcity and contribute to efficient use of water resources. The chapter examines intra-African agricultural trade in virtual water—that is, the water content embedded in trade flows of agricultural products. Trade is most commonly measured in value terms, but the monetary value of a product does not always reflect the resources used to produce it. Trade flows expressed as virtual water trade (VWT) reflect both the specific water requirements of different crops and the varying crop yields obtained in different countries. Examining intra-African trade in virtual water terms and identifying the impact of countries' resource endowments and water productivity levels on VWT helps us to assess the contribution of intra-African trade to addressing water stress and scarcity in African countries and contributing to more efficient water use.

Water is a key resource for food security in Africa. Water availability is a significant constraint to agricultural productivity. Distribution of Africa's water resources is highly unequal (Xie et al. 2014), with ample water resources in some areas (for example, Central Africa) and pronounced water scarcity in others (notably North Africa). Intra-African agricultural trade in virtual water could thus be a means to allow countries with greater water scarcity or less productive use of water to import virtual water content from countries with greater water endowments or greater water productivity, rather than exhausting their own limited resources.

The chapter is organized as follows. The next section reviews intra-African agricultural trade in value terms, assessing overall trends over time and across regional economic communities (RECs) and countries. The third section examines trade trends in terms of virtual water content and explores the relationship between trade in value and trade in water content for selected crops. The fourth section carries out an econometric analysis to explore the determinants of VWT

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among African countries. Specifically, the analysis examines the impact of water productivity and water and land endowments as well as other factors on VWT at the continental level and among RECs and for specific commodity groups. The final section concludes.

Trends in the Value of African Agricultural Trade

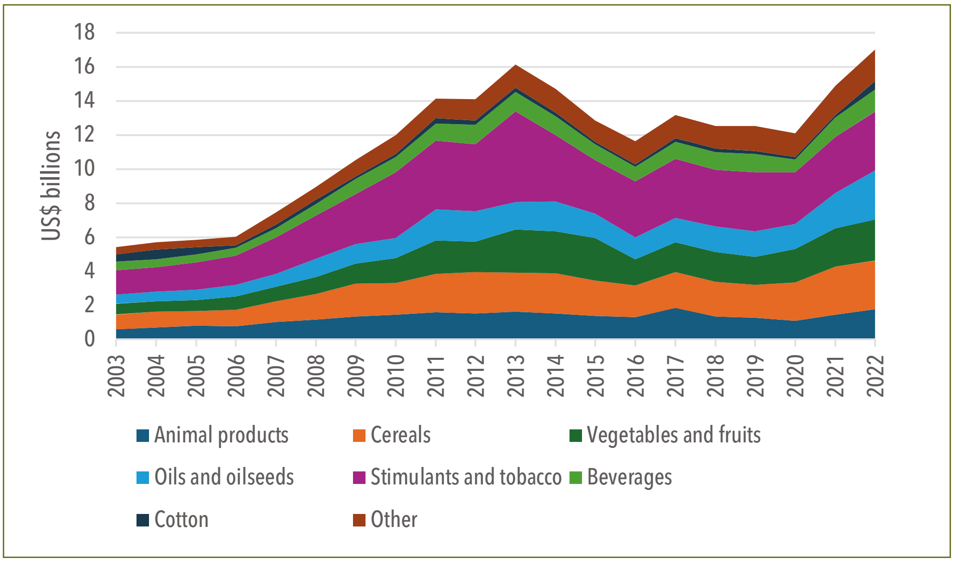
This section reviews current and recent patterns in intra-African agricultural trade measured in value terms as a backdrop to the subsequent examination of trade in virtual water terms. It should be noted that the trade data included in this chapter—both in terms of value and in terms of virtual water—include only formal trade. While there are no comprehensive continentwide data on informal trade in Africa, this trade is thought to constitute a significant share of cross-border flows, particularly for agricultural products (Bouët, Cissé, and Traoré 2020). A recent United Nations Economic Commission for Africa study estimates that Africa's informal trade represents 7 to 16 percent of formal trade at the continental level, and between 30 and 72 percent of formal trade between bordering countries (Gaarder, Luke, and Sommer 2021). Analyses of the content of informal trade suggest that perishable products are especially likely to be traded informally (Bensassi, Jarreau, and Mitaritonna 2019; Siu 2019) and that livestock products and cereals constitute a high share of informal trade (Afrika and Ajumbo 2012). Given the large share of informal trade in cross-border trade in agricultural products, all trade flows in the chapter should be considered substantial underestimates of actual intra-African agricultural trade.

Intra-African agricultural trade trends by product category

Figure 3.1 shows intra-African agricultural trade values during the 2003 to 2022 period, disaggregated by product category. The total value of intra-African agricultural trade rose sharply in the decade from 2003 to 2013, more than tripling from US$5.4 billion to $16.1 billion.[1] The value of trade then declined, before finally surpassing the 2013 value in 2022, when it reached $17.0 billion. This peak in the early 2010s followed by declining and later rising values reflects changes in global food prices (FAO 2024; Olivetti et al. 2023).

1 All figures in this chapter are in US dollars.

Figure 3.1 Intra-African agricultural exports by product category, 2003–2022 (current US$ billions)



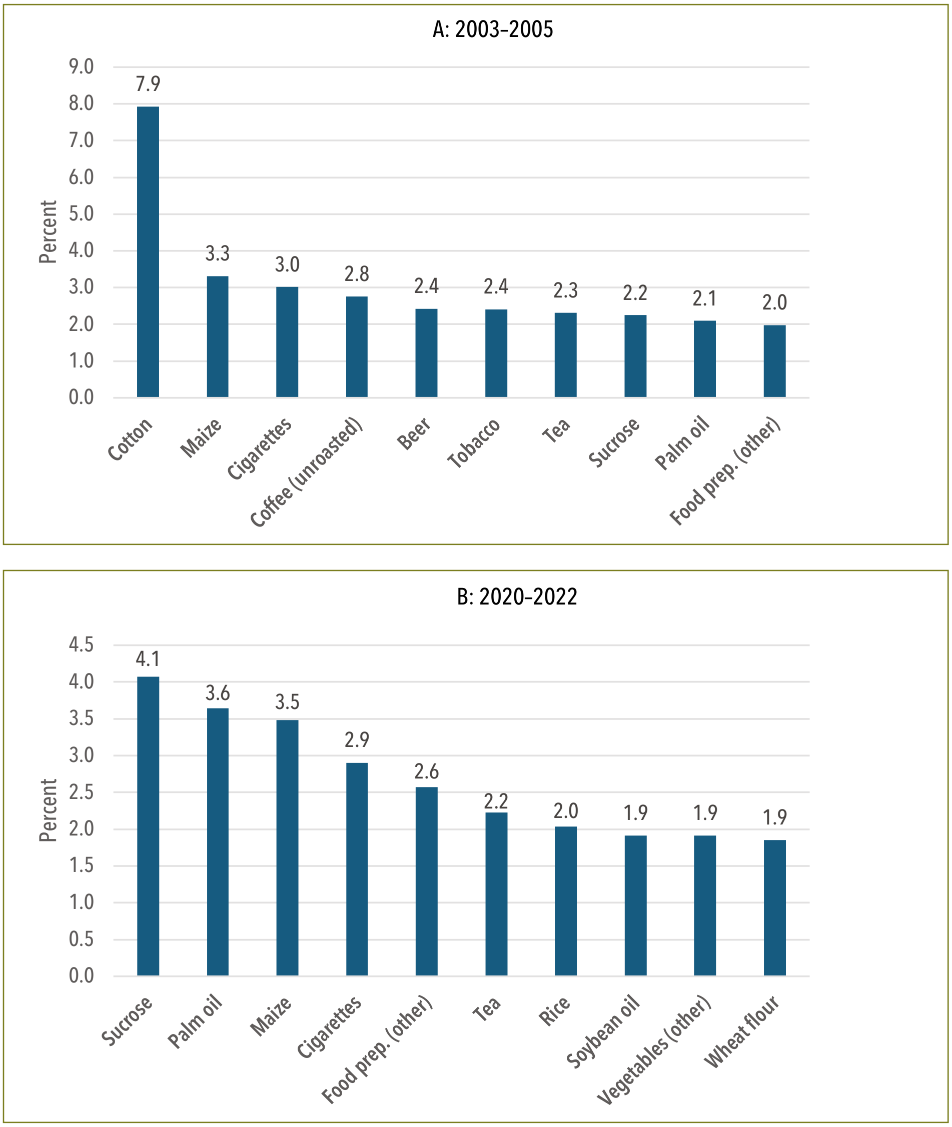
Source: 2024 AATM database.
Note: Product categories are aggregations of Harmonized System 2-digit level (HS2) categories, as detailed in Appendix 3.1.

The composition of intra-African agricultural trade in terms of product groups has shown moderate changes over time. Stimulants and tobacco—which comprises important cash crops including coffee, tea, sugar, and tobacco—is consistently the largest category, with an average share over the entire period of 27.1 percent of intra-African agricultural exports. However, its share has begun to decline in the last few years, reaching its lowest point in 2022 at 20.3 percent. Cotton has also shown declining importance in intra-African trade. Its share declined from 8.3 percent of intra-African exports on average during the 2003–2005 period to less than 3 percent of exports in all subsequent years. Along with the share, the overall value of intra-African cotton exports fell by around 3 percent per year between 2003 and 2022. These trends reflect the declining importance of cotton in Africa's global trade: as the continent's cotton production faces challenges, including low productivity and water stress, exacerbated by recent droughts, cotton subsidies in developed countries, and increasing international cotton price volatility, its global cotton exports have also declined significantly, and Africa has become a net importer of cotton (Sall, Odjo, and Zaki 2023). In contrast, the export shares of most food product categories remained the same or rose over the period. The share of oils and oilseeds rose moderately over the period, reaching its highest point of 16.9 percent of agricultural trade in 2022. The share of vegetables and fruits also rose slightly, while the shares of cereals and of animal products remained fairly stable over the period.

Figure 3.2 shows the top intra-African agricultural export products in the 2003–2005 and 2020–2022 periods at the more detailed HS6 product level. The figures show that intra-African trade has become slightly less concentrated over time. In 2003–2005, the top 10 products represented 30.5 percent of total intra-African exports, but by 2020–2022, their combined share had fallen to 26.6 percent. While the composition of top products has remained broadly similar over time, its evolution reflects the changes in categories discussed above. For example, cotton has decreased substantially in importance: it was no longer among the top 10 traded products in 2020–2022 (at 13th) despite ranking first and well above the other products in 2003–2005. Palm oil increased significantly in importance, rising from the ninth most traded product in 2003–2005 to second place in 2020–2022, and soybean oil entered the top 10 group of products in the latter period.

There were several changes in relative importance of products within the category, including stimulants and tobacco. Sucrose, or table sugar, rose from 8th position in 2003–2005 to first in 2020–2022, while unroasted coffee declined in importance and disappeared from the top 10, declining from the 4th to the 17th most traded product. Intra-African exports of unprocessed tobacco decreased significantly between the two periods, dropping from the 6th most traded product to the 44th, but cigarettes maintained a position among the top products, rising from the 4th to the 3rd most traded product. Among other products, the trade share of beer decreased significantly between the two periods, while rice, other vegetables, and wheat flour increased their shares and entered the top 10 in the second period.

Figure 3.2 Top intra-African agricultural exports at HS6 level, 2003–2005 and 2020–2022, share in total value of intra-African agricultural exports (%)



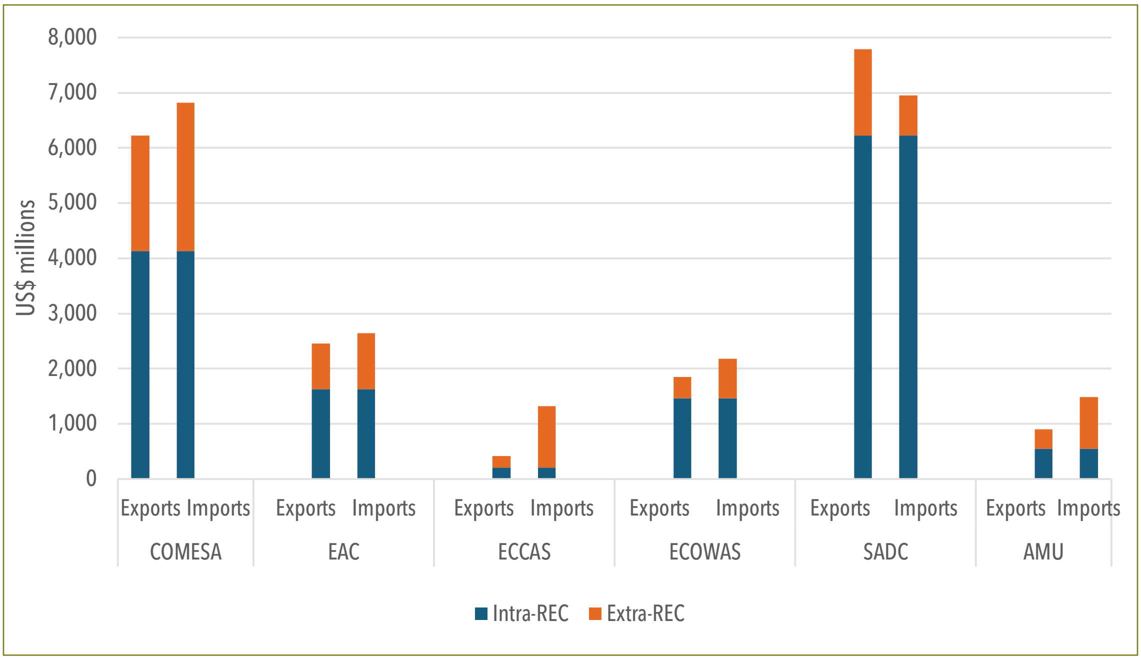
Source: 2024 AATM dataset.
Note: Shortened product names are listed in the figure. Harmonized System at the 6-digit level (HS6) codes and full product names are provided in Appendix 3.2.

Trade trends among regional economic communities and countries

We next examine patterns in the value of trade between regions and countries. Figure 3.3 shows trade between and within major RECs during the 2020–2022 period. The Southern African Development Community (SADC) is the largest player in intra-African trade in both exports and imports, followed by the Common Market for Eastern and Southern Africa (COMESA). SADC has a substantial intra-African agricultural trade surplus, with exports to other African RECs exceeding imports from other RECs by $834 million. This surplus corresponds to more than 10 percent of the value of SADC's total intra-African exports. Every other REC shows intra-African trade deficits, ranging from around 7 percent of the value of exports in the East African Community (EAC) to more than 200 percent of exports in the Economic Community of Central African States (ECCAS).

In addition to being the only REC where intra-African agricultural imports are more than double the exports, ECCAS stands out as the REC in which intra-REC trade accounts for the smallest share of its total intra-African agricultural trade. Member states of COMESA, EAC, the Economic Community of West African States (ECOWAS), and SADC trade with countries within their RECs at far greater levels than with countries outside their RECs. This is especially the case for SADC, where nearly 80 percent of intra-African exports and nearly 90 percent of intra-African imports are directed to or sourced from within the REC. In the Arab Maghreb Union (AMU), intra-REC exports exceed extra-REC exports, but countries import more from non-AMU countries than from countries within the REC. In ECCAS, extra-REC exports are slightly higher than intra-REC exports, while extra-REC imports are more than five times higher than imports from within the REC. Unlike the other RECs shown in the figure, AMU and ECCAS do not have functioning intra-REC free trade agreements: in AMU, political issues between member countries have impeded progress in regional integration; and in both AMU and ECCAS, tariff and nontariff barriers to intra-REC trade remain high (Baghdadi, Karray, and Zaki 2021; Efogo, Kane, and Ndoricimpa 2022). Their smaller shares of intra-REC trade may reflect the importance of free trade areas in facilitating intraregional trade (see also Aboushady, Ramzy, and Zaki 2023).

Figure 3.3 Intra-African agricultural trade values by REC, 2020–2022 average (current US$ millions)



Source: 2024 AATM database.
Note: AMU = Arab Maghreb Union; COMESA = Common Market for Eastern and Southern Africa; EAC = East African Community; ECCAS = Economic Community of Central African States; ECOWAS = Economic Community of West African States; REC = regional economic community; SADC = Southern African Development Community.

Table 3.1 lists the countries with the largest intra-African trade values, and Table 3.2 presents the countries with the largest intra-African agricultural trade surpluses and deficits during the 2020–2022 period—that is, countries with the highest and lowest net agricultural exports to the rest of the continent. The role of SADC in REC-level trends reflects the dominance of South Africa, which accounts for nearly a third of intra-African agricultural exports as well as 8.3 percent of imports. Unsurprisingly, South Africa also has the largest agricultural trade surplus with the rest of the continent. Three other SADC countries (Tanzania, Zambia, and Eswatini) are also among the top exporters and have sizable trade surpluses, while several others in the REC (Botswana, the Democratic Republic of the Congo [DRC], Lesotho, Mozambique, Namibia, and Zimbabwe) are top importers with large trade deficits. Outside of SADC, Egypt, Kenya, and Morocco, like South Africa, are top exporters as well as top importers. In Kenya and Egypt, exports exceed imports significantly. As shown in Table 3.2, for most of the countries with the largest trade surpluses, the surplus represents a small or moderate share of overall GDP; for example, Eswatini's agricultural trade surplus with Africa is equal to about 2 percent of its GDP, with smaller shares for all other countries listed. In contrast, several countries have significant deficits in terms of GDP, notably Lesotho with a deficit equivalent to 15.6 percent of GDP. Agricultural trade deficits in Botswana and Somalia reach 4.0 and 4.5 percent of GDP, respectively.

Table 3.1 Top 10 intra-African agricultural exporters and importers, 2020–2022 average

Top exporters			Top importers		
Country	**Export share (percent)**	**Export value (US$ millions)**	**Country**	**Import share (percent)**	**Import value (US$ millions)**
South Africa	30.2	4,424.8	South Africa	8.3	1,218.7
Egypt	8.8	1,292.5	Botswana	6.1	890.8
Kenya	7.1	1,041.4	Kenya	5.9	866.5
Tanzania	4.6	668.3	Zimbabwe	5.7	832.1
Zambia	3.8	561.1	Namibia	4.8	703.9
Ethiopia	3.4	504.2	Egypt	4.3	630.4
Côte d'Ivoire	3.3	484.1	Mozambique	4.3	626.9
Uganda	3.2	462.7	DRC	3.7	549.6
Eswatini	3.1	453.6	Morocco	3.7	536.7
Morocco	2.8	407.0	Lesotho	3.1	450.8
Top 10 Total	70.2	10,299.8	Top 10 total	49.8	7,306.4

Source: 2024 AATM database.
Note: DRC = Democratic Republic of the Congo.

Table 3.2 Top 10 intra-African agricultural trade surplus and deficit countries, 2020–2022 average

Country	**Net exports (US$ millions)**	**Surplus as share of GDP (percent)**	**Country**	**Net exports (US$ millions)**	**Deficit as share of GDP (percent)**
South Africa	3,206.1	0.8	Botswana	−720.7	4.0
Egypt	662.1	0.2	Zimbabwe	−524.0	2.0
Tanzania	429.8	0.6	DRC	−508.9	0.9
Côte d'Ivoire	285.8	0.4	Somalia	−439.7	4.5
Tunisia	219.8	0.5	Namibia	−424.6	3.5
Zambia	187.2	0.8	Libya	−401.8	0.9
Kenya	174.9	0.2	Lesotho	−345.8	15.6
Ethiopia	137.1	0.1	Mozambique	−343.2	2.1
Togo	105.0	1.3	Mali	−272.6	1.5
Eswatini	104.8	2.3	South Sudan	−184.9	

Source: 2024 AATM database; data on GDP from World Bank (2024).
Note: DRC = Democratic Republic of the Congo.

Because the production of agricultural products requires water, trade in agricultural products can be viewed as an exchange of virtual water resources between nations. In the next section, we investigate the patterns in virtual water exchange associated with the above-described intra-African agricultural trade flows.

Intra-African Virtual Water Trade

Virtual water trade (VWT) refers to the amount of water used to produce goods that are then traded internationally. Annual intra-African agricultural trade volumes are transformed from tons to VWT in m^3 per transaction, following the methodology in Chapagain and colleagues (2006) and Matchaya, Garcia, and Traoré (2023). To compute the water equivalent aggregated across all transactions, we multiply the specific water demand (SWD) of a commodity by the volume of the crop traded (CT_{ij}) from the i^{th} exporter to the j^{th} importer:

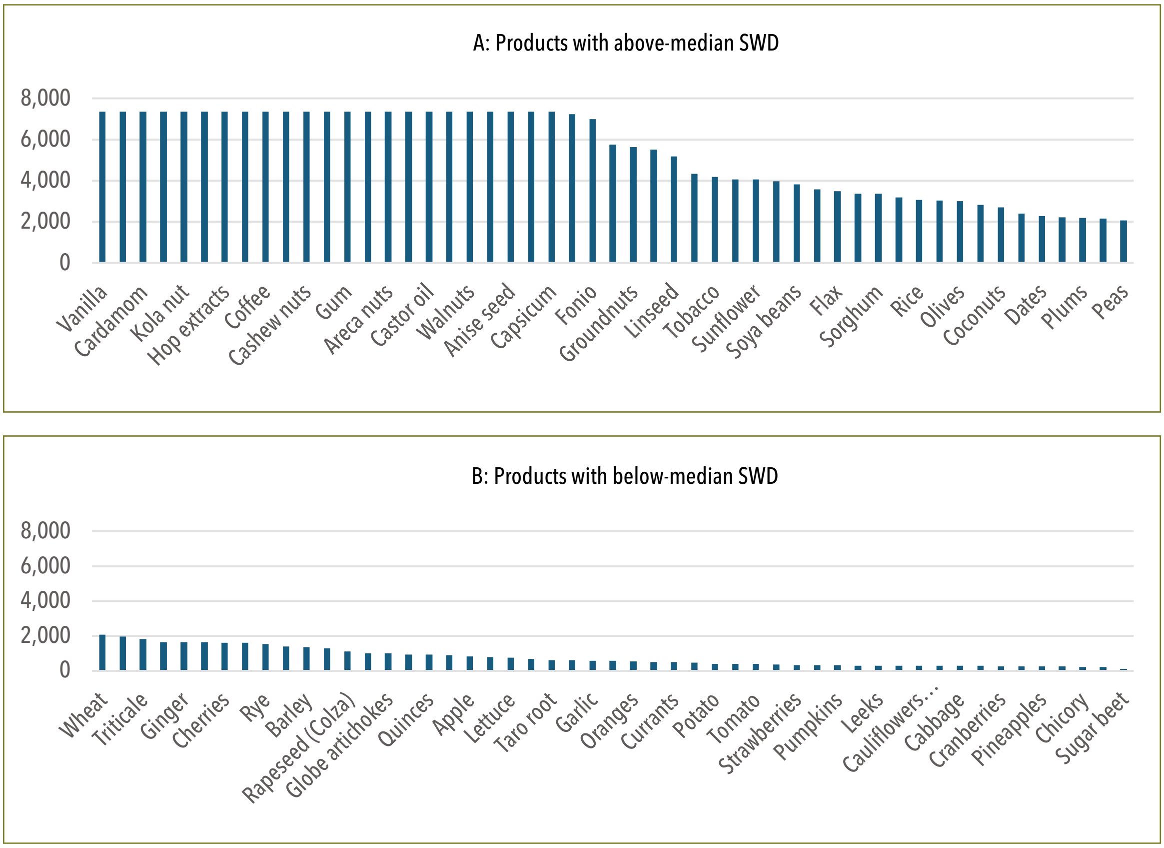
$$VWT_{ij} = CT_{ij} \cdot SWD \tag{1}$$

where VWT_{ij} is the water equivalent aggregated across all transactions, CT is in tons, and SWD (cubic meters per ton) is the commodity's water requirement (cubic meters per ha) divided by the crop yield (tons per ha). The total VWT is the sum of all virtual water for all crops traded from the i^{th} exporter to the j^{th} importer. This approach is consistent with the methodology used by Tamea and colleagues (2014). The crops' water requirements are documented in Hoekstra and Hung (2002), SWDs are available in Mekonnen and Hoekstra (2010), and the yields are taken from FAO (2023). Many factors, including technological advances, affect crop yields. Hence, the current average yield for each crop in each country is used to compute the weighted average SWD where crop water requirement data are available. In a few cases where SWD are absent from Mekonnen and Hoekstra (2010), we use the older crop water requirements from Hoekstra and Hung (2002), as there are no databases with recent data for crop water requirements across countries. Although these data are old, the use of current productivity parameters to calculate SWD ensures that the SWD estimates are not distant from reality.

The results of the SWD calculations are presented in Figure 3.4, which illustrates the large variability in water demand among crops traded within the continent.[2] SWD ranges between less than 100 m^3 per ton and more than 7,000 m^3 per ton. Vegetables are among the least water-intensive crops, while the most water-intensive are perennial crops.

2 See also Chapter 5, this volume, which uses these estimations of SWD to assess which traded products are the most affected by climate change.

Figure 3.4 Specific water demand by crop (cubic meters per ton)

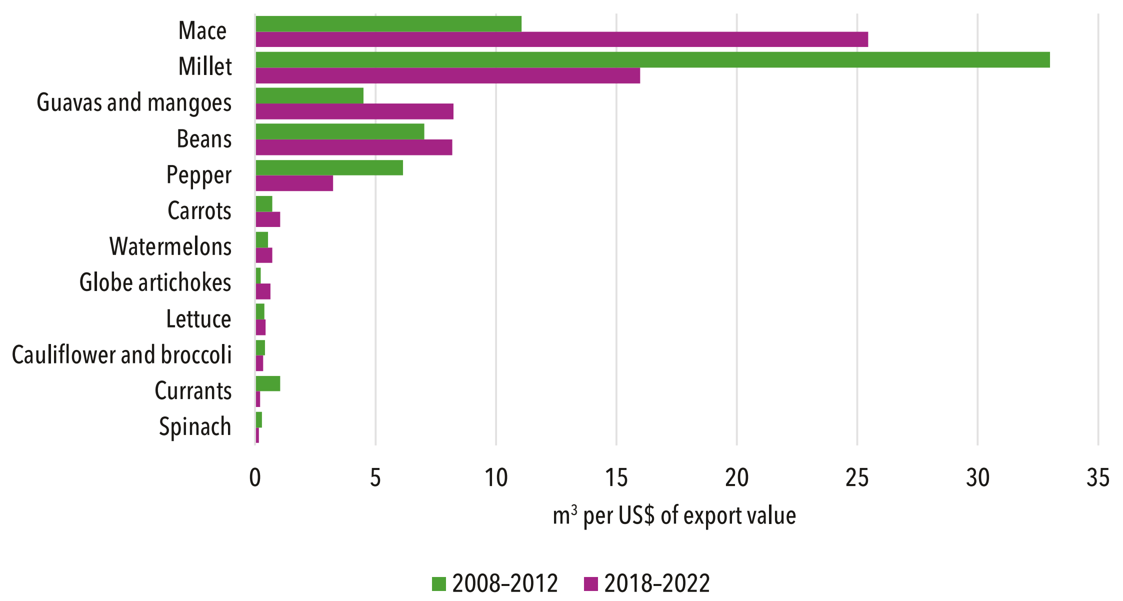


Source: Authors' calculations.
Note: SWD = specific water demand.

The remainder of this section examines the patterns of virtual water transfers among Africa's regions and countries through trade in a dozen selected crops. The selected crops are those for which trade quantity data and necessary conversion parameters are available to enable estimation of the water hidden in every bilateral intra-African trade flow. Processed food products are not included in the analysis due to a lack of data on their water requirements. We start with a comparison of the volumes of virtual water associated with intra-continental export of individual crops, and then explore the leading virtual water trading regions and countries for every selected crop.

Figure 3.5 presents the volumes of virtual water traded across the continent per US dollar of export value for the different crops. Of the crops under analysis, mace and millet are the largest virtual water movers across Africa, while spinach and currants are the lowest. For every one dollar of mace export revenue, 25 m^3 of hidden water are moved, on average, from one place to another within the continent in recent years (an average over 2018–2022). The corresponding number for millet is 16 m^3, but only 0.16 and 0.21 m^3 for spinach and currants, respectively. In other words, for the same economic benefit, intra-African trade in mace and millet entails a higher water footprint than trade in other selected crops. It is worth noting that the volume of intra-African VWT per US dollar of export value decreased between 2008–2012 and 2018–2022 for some crops, including most notably millet and pepper. For instance, the volume of virtual water exported with every US dollar of millet exports decreased from an average of 33 m^3 in 2008–2012 to 16 m^3 in 2018–2022. Conversely, the volume increased for other crops, including mace (from 11 to 25 m^3) and beans (from 7 to 8 m^3). Next, we examine the main routes of virtual water flows in relation with intra-African trade in each crop.

Figure 3.5 Ratio of intra-African virtual water trade to the corresponding export value, for selected crops, 2008–2022 average (cubic meters per US dollar)



Source: Authors' calculations from AATM database.

The role of different countries and regions in VWT could potentially be influenced by the availability of water resources. Table 3.3 categorizes African countries by the degree of water stress—that is, the ratio of water demand to renewable water supply. Many African countries have high water stress, including those in North Africa, Sahelian countries, some East African countries, and those around the Kalahari and Namibian deserts, as well as South Africa, which also faces considerable physical water scarcity. At the regional level, North Africa has the highest share of countries with high levels of water stress, followed by Southern Africa and East Africa. Most Central African countries have abundant water resources, and nearly all are classified in the low water stress category.

Table 3.3 Country grouping by degree of water stress

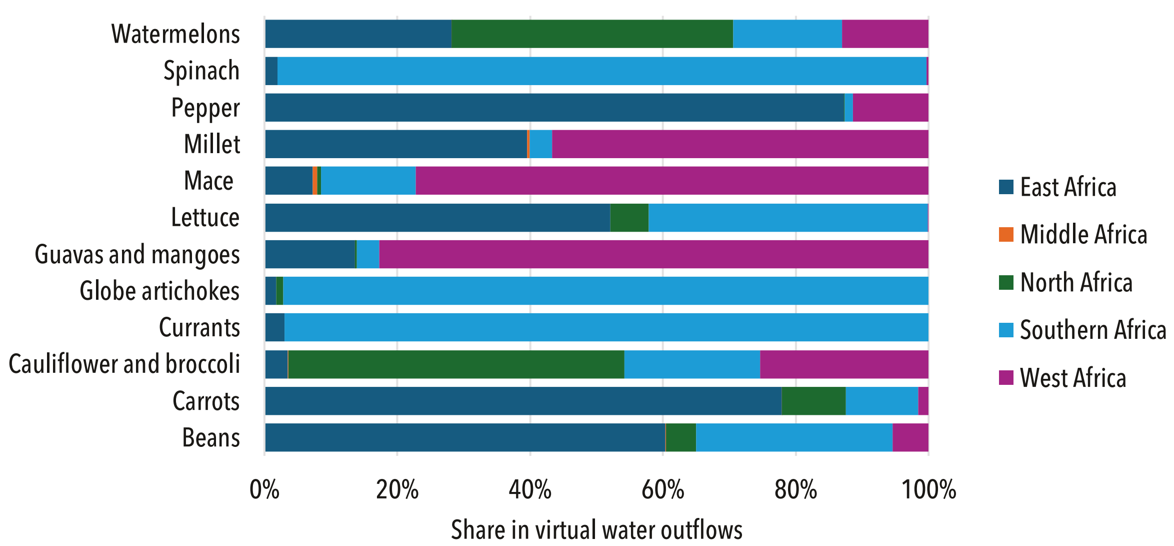
Low water stress (<10 percent)		Low-medium (10–20 percent) and medium (20–40 percent) water stress	High (40–80 percent) and extremely high (>80 percent) water stress
Benin	Guinea-Bissau	**Low-medium**	**High**
Burundi	Kenya	Angola	Algeria
Cameroon	Liberia	Burkina Faso	Djibouti
Central African Republic	Madagascar	Somalia	Eritrea
Chad	Malawi	South Sudan	Morocco
Côte d'Ivoire	Mali	Sudan	Niger
DRC	Mozambique	Tanzania	
Equatorial Guinea	Nigeria	**Medium**	**Extremely high**
Eswatini	Republic of the Congo	Lesotho	Botswana
Ethiopia	Rwanda	Mauritania	Egypt
Gabon	Sierra Leone	Senegal	Libya
Gambia	Togo	Zimbabwe	Namibia
Ghana	Uganda		South Africa
Guinea	Zambia		Tunisia

Source: Authors' computations from World Resources Institute (2023) data.
Note: Water stress measures the ratio of water demand to renewable water supply. Water stress categories are those used by the World Resources Institute and are based on thresholds defined in previous literature (see Gassert et al. 2014 and Kuzma et al. 2023 for more details). DRC = Democratic Republic of the Congo.

Although the data appear to categorize many of the countries as less water stressed, within-country realities can vary. For example, Kenya falls within the low water stress category at the national level but has counties with high levels of local water stress (WRI 2023).

Figure 3.6 and Table 3.4 break down the volume of intra-African VWT related to each crop into leading source regions and countries for the 2018–2022 period. A broad pattern of specialization exists among Africa's regions with respect to their contributions to the hidden water outflows associated with each crop's trade. East Africa is the leading source of intra-African virtual water transfers related to trade in pepper, carrots, and beans. Madagascar, Ethiopia, and Tanzania emerge as the leading sources of hidden water trade in these three crops, respectively. Southern Africa, and particularly South Africa, is the dominant exporter of water embedded in intracontinental trade in spinach, globe artichokes, and currants, which are among the crops with the lowest volumes of hidden water trade per US dollar of export value. West Africa dominates the export of virtual water in intra-African trade of guavas and mangoes, mace, and millet, the crops with the largest volumes of virtual water transfer per US dollar of export value (Figure 3.5). North Africa contributes the largest shares of hidden water associated with the trade of watermelons and of cauliflower and broccoli across the continent. No significant transfer of virtual water originates in Central Africa to the rest of the continent, despite the region's abundant water resources. This recalls the relatively small share of ECCAS in intra-African trade in value terms (Figure 3.3). Trade in lettuce is associated with hidden water outflows from East and Southern Africa. In short, West Africa tends to specialize in crops that move the largest volumes of virtual water per unit of export value, while the reverse applies to Southern Africa. This may be related to the relatively high water stress of several Southern African countries (Table 3.3). However, further investigation with a larger set of crops is needed to confirm these patterns.

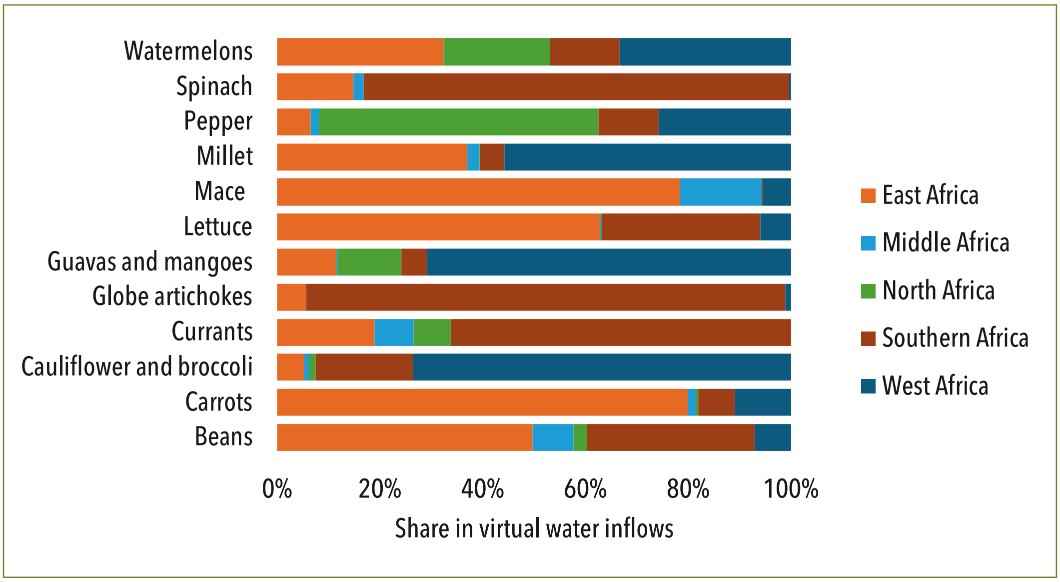
Figure 3.6 Regional breakdown of intra-African virtual water outflows, by selected crop, 2018–2022 average



Source: Authors' calculations from AATM database.

Figure 3.7 presents the breakdown of the volume of intra-African virtual water transfers associated with each crop's trade by destination regions for the 2018–2022 period. East Africa is the main destination of water transfers embedded in carrots, mace, and lettuce traded across Africa, and the region is also the primary source of virtual water exported through carrots and lettuce across Africa (as shown in Figure 3.6). Hence, the water-stressed region of East Africa dominates intracontinental inflows and outflows of the virtual water traded through carrots and lettuce, which are among the least water-intensive crops (see Figure 3.4). The same trend is observed in Southern Africa. Southern Africa is the leading destination of virtual water transfers related to globe artichokes, currants, and spinach, which predominantly originate in the same region (Figure 3.6). Hence, trade in virtual water embodied in these three crops mostly occurs within the region. For instance, Table 3.4 indicates that South Africa is the primary source of virtual water flows through exports of currants, and Lesotho is their primary destination. Similarly, the virtual water transfers associated with the trade of guavas, mangoes, and millet predominantly occur within West Africa, which also receives the bulk of water embodied in traded quantities of cauliflower and broccoli. North Africa receives the largest share of water embodied in traded pepper and retains part of embedded water flows in intracontinental trade of watermelons. In short, Figure 3.7 reveals that VWT between African countries generally occurs through intraregional flows, that is, originating and ending in the same region. This pattern is similar to that presented in Figure 3.3, which shows higher levels of intra-REC agricultural trade than extra-REC trade in value terms.

Figure 3.7 Regional breakdown of intra-African virtual water inflows, by selected crop, 2018–2022 average



Source: Authors' calculations from AATM database.

Table 3.4 Leading intra-African exporter and importer of virtual water, by selected crop, 2018–2022 average

Crop	Top exporter	Share in crop virtual water export (%)	Top importer	Share in crop virtual water import (%)
Beans	Tanzania	22.8	South Africa	25.8
Carrots	Ethiopia	55.3	Somalia	53.4
Cauliflower and broccoli	Morocco	48.1	Mauritania	46.3
Currants	South Africa	96.7	Lesotho	27.1
Globe artichokes	South Africa	97.1	Botswana	93.0
Guavas and mangoes	Côte d'Ivoire	66.9	Ghana	33.9
Lettuce	South Africa	42.0	Djibouti	34.4
Mace	Nigeria	77.2	Uganda	72.3
Millet	Tanzania	32.8	Kenya	31.7
Pepper	Madagascar	57.0	Sudan	25.3
Spinach	South Africa	97.5	Lesotho	31.5
Watermelons	Morocco	21.2	Mauritania	21.2

Source: Authors' calculations from AATM database.
Note: "Share in crop virtual water export/import" refers to the share of the country's export/import of the crop in total intra-African trade of the crop in virtual water terms.

This examination of trade in virtual water terms demonstrates that VWT patterns differ across commodities as well as regions and countries. However, further analysis is necessary to identify the determinants of these patterns. A key benefit of looking at trade through the lens of water content is the possibility of assessing whether and to what extent countries' water endowments influence their exports and imports of virtual water, and thus whether trade in virtual water helps to increase water use efficiency. In the next section, we examine this question by investigating the determinants of trade in virtual water.

Econometric Analysis of the Determinants of Bilateral Trade in Virtual Water

As demonstrated in the previous section, patterns in intra-African trade in virtual water differ across countries and commodities. A study of the trade in agriculture commodities and the VWT that flows from it should provide insights into whether factor endowments explain trade or whether other determinants matter. The Heckscher-Ohlin (Leamer 1995) and Rybczynski (1955) theorems, which relate trade to the factors used to produce traded products, imply that international trade can save water globally or regionally if a water-intensive commodity is traded from an area of high water abundance to an area with water scarcity. According to Hoekstra (2010), global use of water in agriculture could be reduced by 5 percent through international VWT. Dalin et al. (2012) find that the VWT associated with international food trade increases global water use efficiency and contributes to water resource savings. A nation can preserve its domestic water resources by importing a water-intensive product instead of producing it domestically.

Export of agricultural products entails expending national water resources, whereas import of agricultural products saves national water resources (Chapagain et al. 2006). Water-abundant countries could profit from their abundance of water resources by producing water-intensive products for export. VWT between nations and even continents could thus be used as an instrument to improve regional water use efficiency and to achieve water security in water-scarce regions of the world (Shi, Liu, and Pinter 2014). Despite the potential of the virtual water concept to help societies achieve some level of water security through trade, empirical research in this area in Africa is limited.

Focusing on Brazil, da Silva et al. (2016) find that the nature and magnitude of virtual water movements depend on the specific crops studied. Fracasso (2014) suggests that bilateral VWT is determined by economic variables as well as by water endowments and the level of pressure on water resources. However, Feng and colleagues (2014) report the opposite, finding that water-scarce areas in northern China export water-intensive products to water-abundant southern China. Similar observations in China have been explained by three possibilities, including low costs for water use, differing climate conditions and water management practices, and economic and other government policies (Feng et al. 2014; Guan and Hubacek 2007; Islam and Susskind 2013; Zhuo, Mekonnen, and Hoekstra 2016). In SADC, Matchaya, Garcia, and Traoré (2023) find that VWT in cereals varies with distance, as well as with water endowments.

This section weighs in on this debate by analyzing bilateral VWT (exports and imports), considering economic variables and sociocultural and geographical factors, in addition to water-related aspects of agricultural production. It uses a large database of more than 75,000 observations of trade transactions for African countries, which was not available to many previous studies.

Materials and methods

Data sources

The analysis uses data drawn from the AATM database for annual trade transactions involving more than 100 unprocessed agricultural commodities (listed in Appendix 3.3) for the 55 African Union member states for the 2003–2022 period. Data on processed products are not included in this analysis due to challenges in calculating their virtual water content. The production database of the Food and Agriculture Organization (FAO) of the United Nations provides data on crop production, hectares planted, and arable land and yields, and the FAO publishes statistics on crop water requirements (FAO 2023). GDP, population, proportion of the population with access to water, and exchange rate data are obtained from the World Development Indicators (World Bank 2024). Data for the dummy variables related to common borders, membership in regional groupings, language, and distance between commercial capitals are taken from the database of the Centre d'Études Prospectives et d'Informations Internationales (CEPII),[3] while data on water stress by country are from the World Resources Institute.[4] Data on conflicts are taken from the database by Davies et al. (2024), data on international water treaties are from the Oregon State University website,[5] and variables for AfCFTA ratification are derived from information available at Tralac.[6]

Virtual water trade

The VWT variable is the key variable for the analysis. Annual traded volumes are transformed from tons to VWT in cubic meters per transaction, as described in the preceding section, following the methodology in Chapagain and colleagues (2006) and Matchaya, Garcia, and Traoré (2023).

A trade matrix is constructed on export values between pairs of countries for each of the 55 African countries for all of the more than 100 commodities considered. The commodities are also grouped into four main categories (cereals, fruits, nuts, and vegetables) to permit further group-level analysis. This is important because analysis at the individual specific commodity level would encounter problems of insufficient data for some years. The matrix of the quantities of VWT thus consists of 55 countries, each with 100 commodities recorded over 20 years, and more than 110,000 observations, which reduce to 75,000 once other data quality checks are applied. Our focus is on the total VWT between each pair of countries; hence, both bilateral exports from and imports to each country are considered in line with Matchaya, Garcia, and Traoré (2023). This differs from Lenzen et al. (2013), who focus on virtual water imports only. Finally, all the continuous variables are converted into natural logarithms for ease of interpretation and to lessen the influence of heteroscedasticity in the analysis.

Gravity model specification

The classical gravity model is widely used in estimation of international trade (Anderson and Van Wincoop 2003; Bensassi, Jarreau, and Mitaritonna 2019; Head and Mayer 2014; Kamin 2022; Melitz and Toubal 2014; as well as Matchaya, Garcia, and Traoré 2023), but its application in understanding the flow of virtual water among nations has been limited (Dang et al. 2015; Matchaya, Garcia, and Traoré 2023; Tamea et al. 2014). We adopt the formulation in Matchaya, Garcia, and Traoré (2023) to model the bilateral trade process (as detailed in the technical note in Appendix 3.4). The dependent variable is bilateral VWT. We examine the impact on VWT of variables associated with water and other natural resource availability in the exporting and importing country, including the ratio of water productivity of the exporter and importer, the ratio of freshwater withdrawals of the exporter and importer, the ratio of the degree of water stress of the exporter and importer, and the ratio of exporter's and importer's available farmland. We also include variables that represent the ease or difficulty of trade and other economic factors explaining trade flows, including the distance between trading partners, the ratio of the exporter's and importer's GDP per capita, the exchange rate between the exporter and importer, and variables capturing whether exporters are landlocked, as well as the existence of a common border, language, or colonizer between the trading partners. We also include language similarity, as this is found to influence trade (Melitz and Toubal 2014); existence of

3 www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp
4 www.wri.org/insights/highest-water-stressed-countries
5 https://transboundarywaters.ceoas.oregonstate.edu/international-freshwater-treaties-database
6 www.tralac.org/documents/resources/booklets/5388-the-afcfta-a-tralac-guide-11th-ed-may-2024/file.html

present and/or past conflict within the trade dyad, as wars can influence the amount and pace of trade (Kamin 2022); and common membership in a REC, as well as common membership in water treaties/transboundary water agreements in the form of river basin organizations, as these are also key for trade, since lack of cooperation on water use could limit production and tradable surpluses (Gbandi 2024).[7]

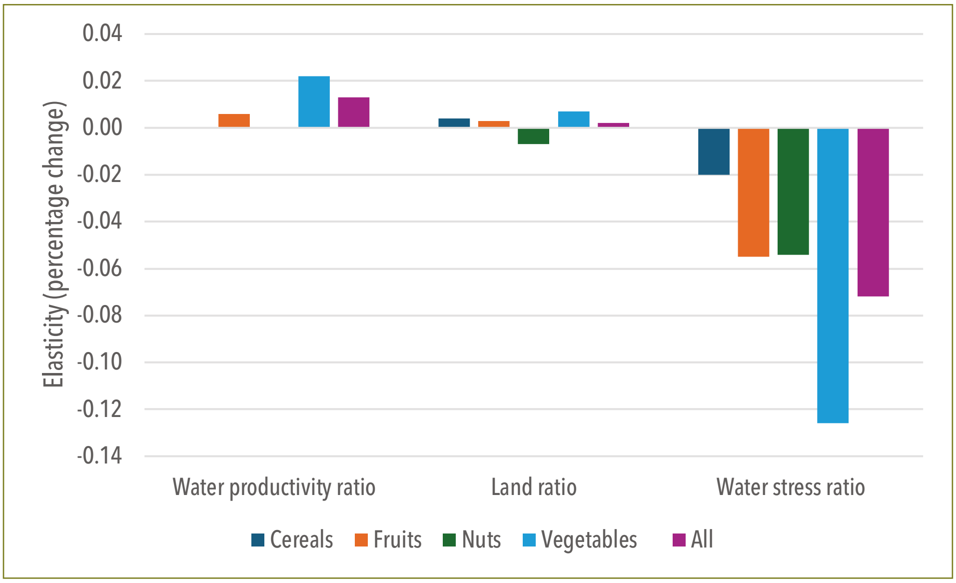
Results

Appendix 3.5 and Appendix 3.6 present the regression results, and Figures 4.8 and 4.9 summarize results for variables of interest. Many of the results are significant and are in line with previous studies (Kamin 2022; Matchaya, Garcia, and Traoré 2023; Melitz and Toubal 2014; Tamea et al. 2014), suggesting that the models have the capacity to identify important drivers of VWT. The discussion of the regressions focuses on the different RECs and different commodity groups to tease out the heterogeneous effects of water stress and endowments on these different groups. This is important because policy prescriptions are likely to vary across RECs and commodity groups, depending on the specific drivers of trade in each region and commodity category. Where the focus is on REC trade (Appendix 3.6), the analysis focuses on intra-REC trade only.

Figure 3.8 and Appendix 3.5 to this chapter show the effects of water endowments on VWT across all key commodity groups. Studying the effects across different commodity groups is useful because demand for agricultural commodities may be heterogenous, and their response to various factors may also differ. Studying them separately can offer insights that pooled regression may hide. The signs and statistical significance of the coefficients for the variables of interest (water stress variables) are consistent across all commodity-based regression estimates. A central focus of this study is to gain insight into which factors affect VWT. Variables directly related to water and land are of particular interest. The coefficient on the degree of water stress for the exporter and the degree of water stress for the importer evaluated as a ratio is negative, as well as statistically significant at both the 5 and 1 percent levels across all commodity groups (Figure 3.8). The negative and significant coefficients on exporters' and importers' degree of water stress suggests that countries with low water endowments import more virtual water, whereas those with high water endowments tend to export more. Water therefore is a limiting factor in international trade, and trade can be used to ameliorate the effects of water stress in a country.

7 Water cooperation is relatively well established in Africa, particularly in Africa south of the Sahara, with functioning agreements covering most major river basins (UN and UNESCO 2021). Such transboundary water agreements facilitate the management of shared water bodies by multiple countries.

Figure 3.8 Impacts of natural resource-related variables on virtual water trade by commodity



Source: Authors' construction from regression results.

Note: Only results significant at the 1 or 5 percent levels are shown. All variables are constructed as logarithms of the ratio of exporter and importer values. The values shown by the bars represent elasticities of virtual water trade (that is, the percentage change in virtual water trade expected to result from a 1 percent increase in the value of the variable). Results for freshwater withdrawals are significant at the 1 percent level but are omitted due to low magnitudes.

Across the commodity categories, it is clear that water availability affects production of cereals, nuts, fruits, and vegetables, and thus trade, differently. For example, a 1 percent increase in the ratio of the water stress index between the exporter and the importer is associated with reduction in VWT of −0.13 percent for vegetables, −0.05 percent for nuts, −0.06 percent for fruits, and −0.02 percent for cereals. For all the commodities, a 1 percent increase in the ratio of water stress leads to a -0.07 percent reduction in VWT through those commodities, at the continental level. Thus, there are differences in trade sensitivities across commodity groups following an increase in water stress, with vegetables most affected, followed by nuts and fruits. The variation in impacts of water stress on trade depending on the commodity, with the largest impacts on trade in vegetables, can be explained by the different water sensitivities of these crops, which affect their production (FAO 2012). Our results recall da Silva et al. (2016), who also identify differential impacts of drivers of VWT depending on the commodity concerned.

Other measures of water availability—including freshwater withdrawals and water use productivity—also support the important role of water endowments in VWT. Generally, an increase in the ratio of freshwater withdrawals between exporters and importers (implying more withdrawals by the exporter) is associated with an increase in trade across all the commodity types. This result implies that an increase in water withdrawals among importers is associated with a reduction in virtual water imports, likely because the resultant production reduces the need for virtual water imports. Again, where the ratio in water productivity between exporter and importer is high, implying that exporters have higher withdrawals, VWT generally increases. A 1 percent increase in the ratio of water productivity for exporters and importers is associated with a 0.01 percent increase in all VWT. The effect varies by crop type, such that a 1 percent increase in the ratio of water productivity leads to a 0.02 percent trade increase for vegetables and a 0.01 percent increase for fruits. Similarly, an increase in the exporter–importer ratio of land allocated to agriculture generally positively drives VWT. These results are significant at the 5 and 1 percent levels, implying that land endowments are also important for trade dynamics across the different commodity groups.

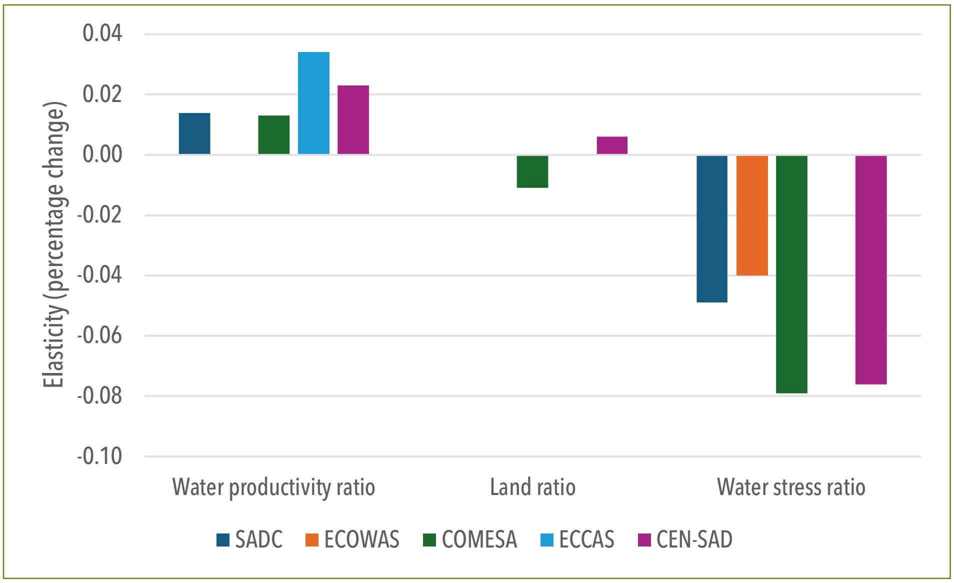
Thus, virtual flows of water through the trade in crops are affected by the amount of arable land and availability of water. That is, it appears as if arable land and water endowments, if all else is the same, provide the ability to produce for export, that is, specialization and agricultural trade, as trade theory suggests. This implies that irrigation expansion could bring about increases in marketable surpluses that can be exported from countries where arable land and water are available to countries where water and land are scarce (see Matchaya, Garcia, and Traoré 2023).

As discussed previously, other key variables that explain bilateral trade include the distance between the bilateral partners and their purchasing and production power. The logarithm of distance is negative and significant at the 5 and 1 percent levels across all commodity groups (except for cereals), underscoring the importance of transport and storage infrastructure as well as other trade facilitation factors that undermine the smooth and timely flow of commodities. Countries that are contiguous tend to trade more in virtual water, underscoring the importance of not only distance but also other cultural similarities. Although the common official languages do not appear to systematically positively influence trade in virtual water, likely because these areas are spread far apart and may not trade despite similar languages, trade is influenced more positively by local native languages. Countries with a common colonizer appear to trade more because transaction costs of trade are lower. Across the continent, being landlocked encourages intra-African trade. Countries that belong to the same REC trade more because trade restrictions are generally lower for members. Similarly, common membership to the AfCFTA is associated with more bilateral trade, but as this agreement is not yet fully operational, this result should be interpreted with caution, and more studies are needed once it is fully operational. Underscoring the importance of water in trade, common membership in water treaties is also associated with more bilateral trade, likely because such treaties simplify water use within basins, which leads to marketable surpluses. It is interesting to note that wars appear to have a mixed effect on commodity trade within Africa, likely because while wars undermine production and market access in some places, conflicts may increase the need for trade in search of resources to finance the war (Cali 2015).

An increase in the exporter–importer income ratio is associated with increased VWT. The logarithm of the exchange rate between the exporter and the importer is generally positive, implying that countries tend to export more when their currencies are relatively weaker and import more with stronger currencies. This finding also implies that under certain conditions, a depreciation improves the exporter's competitiveness.

Figure 3.9 and Appendix 3.6 show the effects of water endowments on VWT within six RECs. Studying trade by region is important because some policies are region specific, and the findings can have applications at that level of administration. Water endowments also vary across regions, with some RECs experiencing more significant water stress than others. Among the RECs analyzed here, the Community of Sahel-Saharan States (CEN-SAD) has the largest share of countries with high water stress, followed by SADC and COMESA; ECOWAS and ECCAS countries have the least water stress (see Table 3.3). It is important to understand how intra-REC VWT varies across regions in relation to water endowments. The signs and statistical significance of the coefficients for the variables of interest (water stress, water withdrawals, and water productivity variables) are mostly consistent across all REC-based regression estimates. The coefficients on the ratio of the degree of water stress for the exporter and importer are negative and statistically significant at the 5 and 1 percent levels across all the RECs, except for the Intergovernmental Authority on Development (IGAD) and ECCAS, where the coefficient on the degree of water stress was either not estimable due to low within-REC variation for this variable or was not significant. The negative and significant coefficients on the ratio of the degree of water stress suggest that countries with low water endowments import more virtual water, whereas those with high water endowments tend to export more virtual water; and, in fact, trade is negatively affected by water scarcity.

Figure 3.9 Impacts of natural resource-related variables on virtual water trade by REC



Source: Authors' construction from regression results.
Note: Only results significant at the 1 or 5 percent levels are shown. All variables are constructed as logarithms of the ratio of exporter and importer values. The values shown by the bars represent elasticities of virtual water trade (that is, the percentage change in virtual water trade expected to result from a 1 percent increase in the value of the variable). Results for freshwater withdrawals are significant at the 1 percent level but are omitted due to low magnitudes. CEN-SAD = Community of Sahel-Saharan States; COMESA = Common Market for Eastern and Southern Africa; ECCAS = Economic Community of Central African States; ECOWAS = Economic Community of West African States; REC = regional economic community; SADC = Southern African Development Community.

Across the RECs, it is clear that water availability affects trade in SADC, ECOWAS, COMESA, IGAD, ECCAS, and CEN-SAD differently. For example, a 1 percent increase in the ratio of water stress index is associated with a 0.08 percent reduction in virtual water exports in CEN-SAD, 0.07 percent in IGAD, 0.08 percent in COMESA, 0.04 percent in ECOWAS, and 0.05 percent in SADC. In IGAD, the coefficients are not statistically significant. Thus, there are differences in trade sensitivities across REC groups following an increase in water stress, with CEN-SAD, COMESA, and SADC most affected. The higher sensitivity of these RECs to additional water stress may be related to the already high levels of water stress among many North, East, and Southern African countries (see Table 3.3).

Water is therefore a limiting factor again in intraregional trade, and trade can be used to ameliorate the effects of water stress in a region. The variation in the effects across RECs also suggests that there are unexploited opportunities to reduce the impacts of water scarcity within regional blocs through trade between blocs.

Similarly, land endowments are important for trade dynamics across the different RECs. Other measures of water availability, including freshwater withdrawals and water use productivity, also support the important role of water endowments in VWT. Generally, an increase in freshwater withdrawals among importers is associated with a reduction in virtual water imports across all RECs, likely because the resultant production reduces the need for virtual water imports. A 1 percent increase in the ratio of water productivity for exporters and importers is associated with notable percentage increases in VWT as follows: SADC, 0.01 percent; COMESA, 0.01 percent; ECCAS, 0.03 percent; and CEN-SAD, 0.02 percent. The same factors, including common membership to water treaties, contiguity, native languages, land lockedness, common AfCFTA membership, and common colonizers, are all important in determining VWT at the REC level as well.

The magnitude of the statistically significant elasticities is often around 0.01 percent or greater, except for water withdrawals. These elasticities are comparable to other studies on impacts of virtual water on agriculture trade and, given the scale of current trade flows, imply economically significant impacts. Therefore, these results are significant from both a statistical and a policy perspective.

Conclusions

This chapter reviewed intra-African agricultural trade trends in terms of value and virtual water and analyzed the determinants of VWT. The analysis of trade trends by value shows that the level of trade has begun to increase again after stagnating throughout the mid-2010s. The commodity composition of trade has changed moderately over time, with a sizable but declining share of cash crops such as stimulants, tobacco, and cotton, and increasing shares of oilseeds and oils, vegetables, and fruits. Most RECs trade more within their regions than with the rest of Africa, reflecting the importance of intra-REC free trade agreements in facilitating intraregional trade.

An analysis of the relationship between trade in value terms and trade in virtual water terms for selected crops shows that some products are characterized by much higher water use per dollar of exports than others. Millet and mace have the highest impact on water use of the examined crops, followed by guavas and mangoes and beans. West Africa tends to specialize in crops that move the largest volumes of virtual water per unit of export value, while the reverse holds true of Southern Africa. As was observed for trade in value terms, most VWT is intraregional, with trade originating and ending in the same region.

This chapter has explored the factors that characterize agricultural VWT associated with intra-African trade in unprocessed commodities, as in Matchaya, Garcia, and Traoré (2023). The principal research question was whether such agricultural trade reflects relative water availabilities in member states or whether other factors drive agricultural trade, such that VWT flows in the opposite direction, from water-scarce countries to water-abundant countries.

The results on water stress and endowment variables support the argument that management of water resources through intraregional trade can reduce the mismatch in water availability and water scarcity (see also Matchaya, Garcia, and Traoré 2023). Both the availability of arable farmland and water availability as well as water stress in the exporting country affect export of virtual water in a manner that indicates that high water endowments encourage trade flows to areas of low water endowments. High water stress discourages exports, while low water stress encourages exports, and high water stress encourages imports of virtual water. These results are consistent for most commodity groups and RECs studied. Given the poor quality of water infrastructure in many parts of Africa, facilitating virtual water exports is a key strategy for reducing the impacts of differential water availability within the continent. Country- and regional-level policies and strategies that support irrigation systems and/or improvement in water management practices for crop production could have the desired effect in terms of moving water from where it is relatively abundant to where it is scarce. This finding therefore can be very useful for climate change adaptation.

The significance of the coefficient on distance, a proxy for transportation costs, suggests that efforts to reduce the cost of transport, storage, and related marketing costs could improve commodity trade and the flow of virtual water within and across RECs. The commodity- and REC-level results suggest that distance matters particularly in SADC and ECCAS and for vegetable trade, perhaps owing to vegetables' perishability; thus, trade facilitation would be beneficial for commodity trade and especially for vegetable trade in those areas, likely because vegetables are more perishable than the other crops.

Thus, there is a clear role for trade policy in each REC to reduce the impacts of water insecurity through trade. Countries that are water stressed can lessen the effects of the scarcity through imports of water-intensive commodities. This knowledge can be very beneficial in guiding anticipatory action in preparation for water-related crises. For example, where dry spells are predicted for a region with some precision, the affected areas can consider switching to producing more low water–intensive crops and prepare to import more water-intensive commodities.

Further, understanding the potential impact of an impending water crisis, or indeed macroeconomic instability, can inform the targeting of safety nets and reduce the impact of such crises on poverty and livelihoods. Given that many African countries experience high levels of water scarcity, it would be beneficial in the long term for countries to make efforts to reduce water stress, for example through water conservation measures or improved water use efficiency. Reduced water stress would in turn lessen the influence of water stress on bilateral trade. Regional integration as well as transboundary water cooperation are also very important in encouraging bilateral trade in Africa, and it is important that these both be encouraged or strengthened.

On a broad level, the chapter's findings call for further efforts to facilitate intra-African trade in order to increase the contribution of trade to alleviating the impacts of water scarcity. Constraints to intra-African trade include the poor quality of transport and market infrastructure, inefficient and lengthy border procedures, harassment and corruption, and other tariff and nontariff barriers, all of which increase the cost of trade; lack of knowledge about trade regulations and limited compliance capacity; and lack of transparency about product quality, which lowers consumers' confidence in local products. Addressing these issues would help to strengthen the positive contribution of intra-African trade to enhancing the efficient use of natural resources.

It should be noted that the commodity coverage of this chapter's examination of the virtual water content of trade is limited by data availability. Developing methodologies to accurately estimate the virtual water content of processed products is an important area for future research. In addition, comprehensive data on informal trade are essential to provide a more complete picture of intra-African trade. Despite this limitation, the chapter provides initial evidence on the role of water endowments in driving intra-African trade, and the potential for trade to address issues of water scarcity on the continent.

References

Aboushady, N., M. Ramzy, and C. Zaki. 2023. "Which Agreements Boost Agricultural Trade in Africa?" In *Africa Agriculture Trade Monitor 2023,* eds. S. Odjo, F. Traoré, and C. Zaki, 16–52. Kigali: AKADEMIYA2063; Washington, DC: International Food Policy Research Institute (IFPRI).

Afrika, J.-G.K., and G. Ajumbo. 2012. "Informal Cross-Border Trade in Africa: Implications and Policy Recommendations." *AfDB Africa Economic Brief* 3 (10): 1–13.

Anderson, J.E., and E. Van Wincoop. 2003. "Gravity with Gravitas: A Solution to the Border Puzzle." *American Economic Review* 93 (1): 170–192.

Baghdadi, L., Z. Karray, and C. Zaki. 2021. "The Arab Maghreb Union: Regionalization without Integration." In *Africa Agriculture Trade Monitor 2021,* eds. A. Bouët, G. Tadesse, and C. Zaki, 165–198. Kigali: AKADEMIYA2063; Washington, DC: IFPRI.

Bensassi, S., J. Jarreau, and C. Mitaritonna. 2019. "Regional Integration and Informal Trade in Africa: Evidence from Benin's Borders." *Journal of African Economies* 28 (1): 89–118.

Bonuedi, I., K. Kamasa, and E.E.O. Opoku. 2020. "Enabling Trade across Borders and Food Security in Africa." *Food Security* 12: 1121–1140.

Bouët, A., B. Cissé, and F. Traoré. 2020. "Informal Cross-Border Trade in Africa." In *Africa Agriculture Trade Monitor 2020*, eds. A. Bouët, S. P. Odjo, and C. Zaki, 117–149. Washington, DC: IFPRI.

Bouët, A., D. Laborde Debucquet, and F. Traoré. 2022. "The AfCFTA: The Need for Ambitious Implementation." In *Africa Agriculture Trade Monitor 2022*, eds. A. Bouët, S.P. Odjo, and C. Zaki, 140–171. Kigali: AKADEMIYA2063; Washington, DC: IFPRI.

Cali, M. 2015. *Trading Away from Conflict: Using Trade to Increase Resilience in Fragile States*. Washington, DC: World Bank.

Chapagain, A.K., A.Y. Hoekstra, H.H.G. Savenije, and R. Gautam. 2006. "The Water Footprint of Cotton Consumption: An Assessment of the Impact of Worldwide Consumption of Cotton Products on the Water Resources in the Cotton Producing Countries." *Ecological Economics* 60 (1): 186–203.

Dalin, C., M. Konar, N. Haasaki, A. Rinaldo, and I. Rodriguez-Iturbe. 2012. "Evolution of the Global Virtual Water Trade Network." *Proceedings of the National Academy of Sciences* 109 (16): 5989–5994.

Dang, Q., X. Lin, and M. Konar. 2015. "Agricultural Virtual Water Flows within the United States." *Water Resources Research* 51 (2): 973–986.

da Silva, V.P., S.D. de Oliveira, A.Y. Hoekstra, J.D. Neto, J.H.B.C. Campos, C.C. Braga, and L.E. Araújo. 2016. "Water Footprint and Virtual Water Trade of Brazil." *Water* 8 (11): 517.

Davies, S., G. Engström, T. Pettersson, and M. Öberg. 2024. "Organized Violence 1989-2023, and the Prevalence of Organized Crime Groups." *Journal of Peace Research* 61 (4).

Efogo, F.O., G.Q. Kane, and A. Ndoricimpa. 2022. "Regional Trade Integration in the Economic Community of Central African States." In *Africa Agriculture Trade Monitor 2022*, eds. A. Bouët, S. Odjo, and C. Zaki, 171–214. Kigali: AKADEMIYA2063; Washington, DC: IFPRI.

FAO (Food and Agriculture Organization of the United Nations). 2012. *Crop Yield Response to Water*. Rome: FAO.

FAO. 2019. Aquastat database. Accessed January 11, 2019. www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

FAO. 2023. FAOSTAT database. http://faostat.fao.org. Accessed July 2024

FAO. 2024. "World Food Situation: FAO Food Price Index." Accessed July 2024. www.fao.org/worldfoodsituation/foodpricesindex/en/

Feng, K., K. Hubacek, S. Pfister, Y. Yu, and L. Sun. 2014. "Virtual Scarce Water in China." *Environmental Science and Technology* 48 (14): 7704–7713.

Fracasso, A. 2014. *A Gravity Model of Virtual Water Trade.* Trento, Italy: School of International Studies, University of Trento.

Gaarder, E., D. Luke, and L. Sommer. 2021. *Towards an Estimate of Informal Cross-Border Trade in Africa*. Addis Ababa: United Nations Economic Commission for Africa (UNECA).

Gassert, F., M. Luck, M. Landis, P. Reig, and T. Shiao. 2014. "Aqueduct Global Maps 2.1: Constructing Decision-Relevant Global Water Risk Indicators." WRI Working Paper. World Resources Institute, Washington, DC.

Gbandi, T. 2024. "Necessary Evil: Water Treaties and International Trade." *Review of World Economics.* doi: 10.1007/s10290-024-00533-9

Guan, D., and K. Hubacek. 2007. "Assessment of Regional Trade and Virtual Water Flows in China." *Ecological Economics* 61 (1): 159–170.

Hanck, C., A. Martin, M. Gerber, and M. Schmelzer. 2024. *Introduction to Econometrics with R*. Essen, Germany: University of Duisburg-Essen.

Head, K., and T. Mayer. 2014. "Gravity Equations: Workhorse, Toolkit, and Cookbook." In *Handbook of International Economics Vol. IV*, eds. G. Gopinath, E. Helpman, and K. Rogoff, Chapter 3, 131–195. Amsterdam: Elsevier.

Hoekstra, A.Y. 2010. "The Water Footprint of Animal Products." In *The Meat Crisis: Developing More Sustainable Production and Consumption*, eds. J. D'Silva and J. Webster, 22–33. London, UK: Earthscan.

Hoekstra, A.Y., and P.Q. Hung. 2002. *Virtual Water Trade: A Quantification of Virtual Water Flows Between Nations in Relation to International Crop Trade.* Value of Water Research Report Series No. 11. Delft, the Netherlands: IHE Delft Institute for Water Education.

Islam, S., and L. Susskind. 2013. *Water Diplomacy: A Negotiated Approach to Managing Complex Water Networks.* New York: RFF Press, Routledge.

Kamin, K. 2022. "Bilateral Trade and Conflict Heterogeneity: The Impact of Conflict on Trade Revisited." Kiel Working Paper No. 2222. Kiel Institute for the World Economy, Kiel, Germany.

Khayat, S.H. 2019. "A Gravity Model Analysis for Trade Between the GCC and Developed Countries." *Cogent Economics & Finance* 7 (1): 1703440.

Kuzma, S., M.F.P. Bierkens, S. Lakshman, T. Luo, L. Saccoccia, E. H. Sutanudjaja, and R. Van Beek. 2023. *Aqueduct 4.0: Updated Decision-Relevant Global Water Risk Indicators*. Technical Note. Washington, DC: World Resources Institute.

Leamer, E.1995. *The Heckscher-Ohlin Model in Theory and Practice*. New Jersey: International Economics Section, Department of Economics, Princeton University.

Lenzen, M., D. Moran, A. Bhaduri, K. Kanemoto, M. Bekchanov, A. Geschke, and B. Foran. 2013. "International Trade of Scarce Water." *Ecological Economics* 94: 78–85.

Makochekanwa, A., and G. Matchaya. 2019. "Regional Trade Integration in Eastern and Southern Africa." In *Africa Agriculture Trade Monitor 2019*, eds. A. Bouët and S.P. Odjo, 133–163. Washington, DC: IFPRI.

Matchaya, G., R.J. Garcia, and F. Traoré. 2023. "Does Bilateral Trade in Cereals within SADC Reflect Virtual Trade in Water between Countries with Different Water Endowments?" *Water International* 48 (6): 759–782.

Mekonnen, M.M., and A.Y. Hoekstra. 2010. *The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products*. Value of Water Research Report Series No. 47. Delft, the Netherlands: UNESCO-IHE Delft.

Melitz, J., and Toubal, F. 2014. "Native Language, Spoken Language, Translation and Trade."

Journal of International Economics 93 (2): 351–363.

Odjo, S., F. Traoré, and C. Zaki. 2023. "Overview and Recent Challenges." In *Africa Agriculture Trade Monitor 2023*, eds. S. Odjo, F. Traoré, and C. Zaki, 6–16. Kigali: AKADEMIYA2063; and Washington, DC: IFPRI.

Odjo, S.P., and O. Badiane. 2018. "The West African Trade Outlook: Business-as-Usual Compared with Alternative Options." In *Africa Agriculture Trade Monitor 2018*, eds. O. Badiane, S.P. Odjo, and J. Collins, 131–151. Washington, DC: IFPRI.

Olivetti, E., J. Collins, S. Odjo, and D. Laborde. 2023. "Intra-Africa Agricultural Trade: Recent Trends and Nutritional Content." In *Africa Agriculture Trade Monitor 2023*, eds. S. Odjo, F. Traoré, and C. Zaki, 53–88. Kigali: AKADEMIYA2063; and Washington, DC: IFPRI.

Reina Caballero, J., J. Crespo Cuaresma, K. Fenz, J. Zellmann, T. Yankov, and A. Taha. 2024. "Gravity Models for Global Migration Flows: A Predictive Evaluation." *Population Research and Policy Review* 43 (2): 29.

Rybczynski, T.M. 1955. "Factor Endowments and Relative Commodity Prices." *Economica* 22 (88): 336–341.

Sall, L.M., S. Odjo, and C. Zaki. 2023. "Competitiveness of the Cotton Value Chain in Africa." In *Africa Agriculture Trade Monitor 2023*, eds. S. Odjo, F. Traoré, and C. Zaki, 89–129. Kigali: AKADEMIYA2063; Washington, DC: IFPRI.

Santos, J.M.C., and S. Tenreyro. 2010. "On the Existence of the Maximum Likelihood Estimates in Poisson Regression." *Economics Letters* 107: 310.

Shi, J., J. Liu, and L. Pinter. 2014. "Recent Evolution of China's Virtual Water Trade: Analysis of Selected Crops and Considerations for Policy." *Hydrology and Earth System Sciences* 18 (4): 1349–1357.

Siu, J. 2019. "Trade Costs, Trade Facilitation, and Formalisation of Trade: Evidence from One-Stop-Border-Posts in Uganda." IGC Working Paper F-43435-UGA-1. International Growth Centre, London.

Tamea, S., J. Carr, F. Laio, and L. Ridolfi. 2014. “Drivers of the Virtual Water Trade.” *Water Resources Research* 50 (1): 17–27.

UN (United Nations) and UNESCO (United Nations Educational, Scientific and Cultural Organization). 2021. *Progress on Transboundary Water Cooperation: Global Status of SDG Indicator 6.5.2 and Acceleration Needs*. Paris: UN and UNESCO.

World Bank. 2020. *The African Continental Free Trade Area: Economic and Distributional Effects*. Washington, DC: World Bank.

World Bank. 2024. World Bank Development Indicators Database. Accessed May 22, 2024. https://databank.worldbank.org/source/world-development-indicators

WRI (World Resources Institute). 2023. Aqueduct 4.0 Current and Future Country Rankings [Dataset]. Accessed July 14, 2024. www.wri.org/data/aqueduct-40-country-rankings

Xie, H., L. You, B. Wielgosz, and C. Ringler. 2014. “Estimating the Potential for Expanding Smallholder Irrigation in Sub-Saharan Africa.” *Agricultural Water Management* 131 (1): 183–193.

Zhuo, L., M.M. Mekonnen, and A.Y. Hoekstra. 2016. “The Effect of Inter-Annual Variability of Consumption, Production, Trade and Climate on Crop-Related Green and Blue Water Footprints and Inter-Regional Virtual Water Trade: A Study for China (1978-2008).” *Water Research* 94 (1): 73–85.

Appendix 3.1

Table A3.1 Composition of commodity groups

Commodity group	HS2 code	HS2 description
Animal products	01	Animals, live
	02	Meat and edible meat offal
	04	Dairy produce; birds' eggs; natural honey; edible products of animal origin, not elsewhere specified or included
	05	Animal originated products, not elsewhere specified or included
	16	Meat, fish, or crustaceans, mollusks, or other aquatic invertebrates, preparations thereof
	41	Raw hides and skins (other than fur skins) and leather
	43	Fur skins and artificial fur, manufactures thereof
	50	Silk
	51	Wool; fine or coarse animal hair; horsehair yarn and woven fabric
Cereals	10	Cereals
	11	Products of the milling industry: malt, starches, inulin, wheat gluten
	19	Preparations of cereals, flour, starch or milk; pastrycooks' products
Vegetables and fruits	07	Vegetables and certain roots and tubers, edible
	08	Fruit and nuts, edible; peel of citrus fruit or melons
	14	Vegetable plaiting materials: vegetable products not elsewhere specified or included
	20	Preparations of vegetables, fruit, nuts, or other parts of plants
Oil and oilseeds	12	Oilseeds and oleaginous fruits; miscellaneous grains, seeds, and fruit; industrial or medicinal plants; straw and fodder
	15	Animal or vegetable fats and oils and their cleavage products; prepared animal fats; animal or vegetable waxes
	33	Essential oils and resinoids; perfumery, cosmetic, or toilet preparations
Stimulants and tobacco	09	Coffee, tea, maté, and spices
	17	Sugars and sugar confectionery
	18	Cocoa and cocoa preparations
	24	Tobacco and manufactured tobacco substitutes
Beverages	22	Beverages, spirits, and vinegar
Cotton	52	Cotton

Commodity group	HS2 code	HS2 description
Other	06	Trees and other plants, live; bulbs, roots, and the like; cut flowers and ornamental foliage
	13	Lac; gums, resins, and other vegetable saps and extracts
	21	Miscellaneous edible preparations
	23	Food industries, residues and wastes thereof; prepared animal fodder
	29	Organic chemicals
	35	Albuminoidal substances; modified starches; glues; enzymes
	38	Chemical products n.e.c.
	53	Vegetable textile fibers; paper yarn and woven fabrics of paper yarn

Note: n.e.c. = not elsewhere classified.

Appendix 3.2

Table A3.2 HS6 codes and full HS6 product descriptions for top intra-African products

HS6 code	Long name	Short name
70999	Vegetables, edible, n.e.c. in Chapter 7, fresh or chilled	Vegetables (other)
090111	Coffee, not roasted or decaffeinated	Coffee (unroasted)
090240	Tea, black; (fermented) and partly fermented tea, in immediate packings of a content exceeding 3 kg	Tea
100590	Cereals; maize (corn), other than seed	Maize
100630	Cereals: rice, semi-milled or wholly milled, whether or not polished or glazed	Rice
110100	Wheat or meslin flour	Wheat flour
150710	Vegetable oils: soya-bean oil and its fractions, crude, whether or not degummed, not chemically modified	Soybean oil
151190	Vegetable oils: palm oil and its fractions, other than crude, whether or not refined, but not chemically modified	Palm oil
170199	Sugars: sucrose, chemically pure, in solid form, not containing added flavoring or coloring matter	Sucrose
210690	Food preparations; n.e.c. in item no. 2106.10	Food prep. (other)
220300	Beer, made from malt	Beer
240110	Tobacco (not stemmed or stripped)	Tobacco
240220	Cigarettes, containing tobacco	Cigarettes
520100	Cotton, not carded or combed	Cotton

Note: n.e.c. = not elsewhere classified.

Appendix 3.3

Table A3.3 List of unprocessed agricultural commodities considered in the gravity analysis

Commodity	HS6 code	Commodity	HS6 code	Commodity	HS6 code	Commodity	HS6 code
Potato	070110	Pistachios	080251	Capsicum	090421	Groundnuts	120241
Potato	070190	Pistachios	080252	Vanilla	090510	Groundnuts	120242
Tomato	070200	Macadamia	080261	Cinnamon	090611	Linseed	120400
Garlic	070320	Macadamia	080262	Cinnamon	090619	Rapeseed (colza)	120510
Leeks	070390	Kola nut	080270	Cloves	090710	Rapeseed (colza)	120590
Cauliflowers and broccoli	070410	Areca nuts	080280	Mace	090811	Sunflower	120600
Cabbage	070490	Plantains	080310	Mace	090821	Palm nuts	120710
Cabbage	070511	Bananas	080390	Carda-moms	090831	Cotton	120721
Lettuce	070519	Dates	080410	Anise seed	090921	Cotton	120729
Chicory	070521	Figs	080420	Cumin	090931	Castor oil	120730
Chicory	070529	Pineapples	080430	Anise seed	090961	*Sesamum*	120740
Carrots	070610	Avocados,	080440	Ginger	091011	Mustard	120750
Sugar beet	070690	Guavas and mangoes	080450	Wheat	100111	Safflower	120760
Cucumber	070700	Oranges	080510	Wheat	100119	Poppy	120791
Peas	070810	Citrus, other	080520	Wheat	100191	Sugar beet	120910
Beans	070820	Grapefruits	080540	Wheat	100199	Rye	120925
Asparagus	070920	Citrus, other	080550	Rye	100210	Veg., other	120991
Aubergines	070930	Citrus, other	080590	Rye	100290	Hop cones	121010
Capsicum	070960	Grapefruits	080610	Barley	100310	Poppy	121140
Spinach	070970	Watermelons	080711	Barley	100390	Sugar beet	121291
Globe artichokes	070991	Watermelons	080719	Oats	100410	Locus bean	121292
Olives	070992	Pawpaws	080720	Oats	100490	Sugar cane	121293
Pumpkins	070993	Apples	080810	Maize	100510	Chicory	121294

Commodity	HS6 code	Commodity	HS6 code	Commodity	HS6 code	Commodity	HS6 code
Cassava	071410	Pears	080830	Maize	100590	Cereals, other	121300
Potato, sweet	071420	Quinces	080840	Rice	100610	Gum	130120
Yams	071430	Apricots	080910	Rice	100620	Gum	130190
Taro root	071440	Cherries	080921	Rice	100630	Hop extracts	130213
Yautia	071450	Cherries	080929	Rice	100640	Veg., other	140190
Cassava	071490	Peaches	080930	Sorghum	100710	Cocoa	180100
Coconuts	080111	Plums	080940	Sorghum	100790	Cocoa	180200
Coconuts	080112	Strawberries	081010	Wheat	100810	Tobacco	240110
Coconuts	080119	Raspberries	081020	Millet	100821	Cotton	520100
Cashew nuts	080131	Currants	081030	Millet	100829	Cotton	520210
Cashew nuts	080132	Cranberries	081040	Canary	100830	Cotton	520291
Almonds	080211	Kiwifruit	081050	Fonio	100840	Cotton	520299
Almonds	080212	Coffee	090111	Triticale	100860	Flax	530110
Hazelnuts	080221	Coffee	090112	Cereals, other	100890	Flax	530121
Hazelnuts	080222	Tea	090210	Soya beans	120110		
Walnuts	080231	Tea	090220	Soya beans	120190		
Walnuts	080232	Pepper	090411	Ground-nuts	120230		

Appendix 3.4

Technical Note

In its basic formulation, the gravity model considers the sizes of trading partners and the distances between them as important (Fracasso 2014; Head and Mayer 2014). We adopt the formulation in Matchaya, Garcia, and Traoré (2023) to model the bilateral trade process. Thus, in Equation (2), size and distance assume a multiplicative form:

$$VWT_{ij} = G \cdot S_i^{\beta} \cdot S_j^{\alpha} \cdot \Phi_{ij}^{\gamma} \qquad (2)$$

where VWT_{ij} represents bilateral trade transactions between the i^{th} exporting country to the j^{th} importing country. Bilateral trade between exporter and importer are specified as VWT flows. G is the gravitational constant. S refers to the size of the economy, measured as total real GDP in per capita terms, or S_i and S_j in the exporting and importing country, respectively.

We introduce a further modification to the gravity model by including income per capita rather than absolute incomes, in line with Reina et al. (2024) as well as Khayat (2019), among others. This deviates from Matchaya, Garcia, and Traoré (2023) and is justified on the basis that per capita income may matter more for trade than just absolute incomes. The variables that represent the ease or difficulty with which the i^{th} exporting country accesses the market of the j^{th} importing country and other economic factors explaining trade flows are included in Φ_{ij}. This includes distance, common border or language, and other economic or policy variables affecting export supply or import demand. There are also variables that account for water treaties, the African Continental Free Trade Agreement, conflict, common native languages, and common regional economic community memberships. These variables are identified from literature cited previously as useful in bilateral trade determination (see Anderson and Van Wincoop 2003; Benassi, Jarreau, and Mitaritonna 2019; Head and Mayer 2014; Kamin 2022; Matchaya, Garcia, and Traoré 2023; Melitz and Toubal 2014).

The total volume of bilateral trade in the commodities between the i^{th} exporting country and the j^{th} importing country is converted into VWT_{ij}. The continuous variables are converted into natural logarithms and the variables tested for stationarity. The base model is expressed as Equation (3) for each bilateral VWT pairing over time t:

$$\begin{aligned} lnVWT_{ijt} = {} & lnG + \gamma lnDist_{ij} + \beta lnGDPPc_{ijt} + \gamma_1 lnWatp_{ijt} + \gamma_2 lnAFL_{ijt} + \gamma_3 lnER_{ijt} + \qquad (3) \\ & \gamma_4 Contiguity_{ij} + \gamma_5 Common\_Language_{ij} + \gamma_6 Common\_Colonizer_{ij} + \gamma_7 Landlocked_{ij} + \\ & \gamma_8 lnWAI_{ijt} + \gamma_9 lnWaS_{ij} + \gamma_{10} WaTT_{ijt} + \\ & \gamma_{11} AfCFTA_{ij} + \gamma_{12} War_{ijt} + \gamma_{13} SREC_{ijt} + \gamma_{14} NativLang_{ij} + \delta_t + \varepsilon_{ijt} \end{aligned}$$

where each variable is defined as listed in Table A3.4. In this model, δt represents years dummies that control for unobservables that evolve over time but are constant across entities (see Hanck et al. 2024). We run a classical gravity model because we are interested in identifying the effects of variables that change by exporter and importer and that are not time variant (this is why we do not include bilateral fixed effects that control for the endogeneity of trade agreements). Finally, it is also possible that some of our estimates may be biased downward because we do not control for intranational trade flows.

Table A3.4 Variable names and units

Variable	Description	Unit
VWT_{ijt}	Cubic meters of water traded	Cubic meters
$Dist_{ij}$	Distance between trading partners' cities	Km
$GDPPc_{iit}$	Ratio of real income per capita exporter for exporter and importer	
$Watp_{ijt}$	Ratio of water productivity for exporter and importer	
AFL_{ijt}	Ratio of available farmland for exporter and importer	
ER_{ijt}	Exchange rate between exporter and importer	Local currency to $
$Contiguity_{ij}$	Whether countries share a border = 1	Dummy variable
$Common\_Language_{ij}$	Whether pair share official language = 1	Dummy variable
$Common\_Colonizer_{ij}$	Whether pair was colonized by same country = 1	Dummy variable
$Landlocked_{ij}$	Whether pair is landlocked = 1	Dummy variable
WAI_{ijt}	Ratio of fresh water withdrawals by exporter and importer	Cubic meters
WaS_{ij}	Ratio of water stress index for exporter and importer	
$WaTT_{ijt}$	1 for common water treaty	Dummy variable
$AfCFTA_{ij}$	1 if common AfCFTA ratification	Dummy variable
War_{ijt}	1 if both countries are/were at war	Dummy variable
$SREC_{ijt}$	1 if shared REC	Dummy variable
$NativLang_{ij}$	1 for similar native language	Dummy variable
δt	Years dummies	Dummy variables

Estimating Equation (3) by ordinary least squares (OLS) assumes that the functional form of the model is known, and that the distribution of errors follows an OLS-compatible form, which might not hold. Log-linearization can introduce an endogeneity bias in the presence of heteroskedasticity in the nonlinear, original form (Santos and Tenreyro 2010). Other factors within years and across countries may affect trade decisions (e.g., multilateral trade resistance terms idiosyncratic to country and time), which produced biased OLS estimates in the absence of sufficient control. Thus, Equation (3) is estimated by the Poisson pseudo maximum likelihood (PPML) method with years dummies to control for time unobservables (Head and Mayer 2014). Our results are produced following both the OLS and the PPML technique, but we present the PPML results because OLS results may exhibit inherent bias, as discussed previously.

Appendix 3.5

Table A3.5 Effect of water endowments on intra-Africa virtual water trade by key commodity groups

	PPML cereals	PPML fruits	PPML nuts	PPML vegetables	All trade
Log distance between countries	−0.004 (0.00)	−0.017** (0.01)	−0.013** (0.00)	−0.030*** (0.01)	−0.005** (0.00)
Log ratio exporter/ importer real GDP	0.000 (0.00)	0.016*** (0.00)	0.013*** (0.00)	0.020*** (0.00)	0.021*** (0.00)
Log ratio of exporter/ importer water productivity	0.002 (0.00)	0.006*** (0.00)	0.001 (0.00)	0.022*** (0.00)	0.013*** (0.00)
Log ratio exporter/ importer agricultural land	0.004** (0.00)	0.003** (0.00)	−0.007*** (0.00)	0.007*** (0.00)	0.002*** (0.00)
Log exporter/importer exchange rate	0.002* (0.00)	0.004*** (0.00)	0.007*** (0.00)	0.012*** (0.00)	0.008*** (0.00)
Log ratio exporter/ importer freshwater withdrawals	0.000*** (0.00)	0.000*** (0.00)	−0.000 (0.00)	0.000*** (0.00)	0.000*** (0.00)
Log ratio exporter/ importer degree of water stress	−0.020*** (0.00)	−0.055*** (0.00)	−0.054*** (0.01)	−0.126*** (0.01)	−0.072*** (0.00)
1 for contiguity	0.050*** (0.01)	0.094*** (0.01)	0.013 (0.01)	0.014 (0.01)	0.027*** (0.00)
1 for common official language	−0.019** (0.01)	0.008 (0.01)	−0.007 (0.01)	−0.029*** (0.01)	−0.019*** (0.00)
1 for native language similarity	0.030*** (0.01)	0.012 (0.01)	0.023** (0.01)	−0.003 (0.01)	0.042*** (0.00)
1 for common colonizer, post-1945	0.029*** (0.01)	0.016* (0.01)	0.026*** (0.01)	0.031*** (0.01)	0.034*** (0.00)
1 if landlocked	−0.003 (0.01)	−0.012 (0.01)	0.025*** (0.01)	−0.013 (0.01)	0.030*** (0.00)
1 for shared regional economic community	0.018*** (0.00)	0.021*** (0.00)	0.035*** (0.00)	0.022*** (0.01)	0.013*** (0.00)
1 for being member of the same water treaty	0.039*** (0.01)	0.003 (0.01)	0.043*** (0.01)	0.060*** (0.01)	0.052*** (0.00)
1 for ratification of AfCFTA	0.013* (0.01)	0.065*** (0.01)	0.045*** (0.01)	0.041*** (0.01)	0.034*** (0.00)
1 if both countries were/ are at war	−0.014* (0.01)	0.000 (0.01)	0.042*** (0.01)	−0.010 (0.01)	0.003 (0.00)
Constant	2.457*** (0.03)	2.130*** (0.05)	2.443*** (0.03)	2.515*** (0.06)	2.386*** (0.02)
Years dummies	Yes	Yes	Yes	Yes	Yes
N	11,702.0	16,117.0	6,316.0	8,239.0	60,799.0
R-squared	0.10	0.12	0.14	0.24	0.16

Note: AfCFTA = African Continental Free Trade Area; PPML = Poisson pseudo maximum likelihood.
* p < .10; ** p < .05; *** p < .01. Standard errors are in the parentheses.

Appendix 3.6

Table A3.6 Effect of water endowments on intraregional virtual water trade by key regional economic community (PPML estimates)

	SADC	ECOWAS	COMESA	IGAD	ECCAS	CENSAD
Log distance between countries	−0.015** (0.01)	0.003 (0.00)	−0.002 (0.00)	−0.108 (0.08)	−0.016* (0.01)	−0.021*** (0.00)
Log ratio exporter/ importer real GDP	0.032*** (0.00)	−0.022*** (0.01)	0.019*** (0.00)	−0.050 (0.06)	0.060*** (0.01)	0.010** (0.00)
Log ratio exporter/ importer water productivity	0.014*** (0.00)	0.004 (0.00)	0.013*** (0.00)	−0.036 (0.05)	0.034** (0.01)	0.023*** (0.00)
Log ratio exporter/ importer agricultural land	0.000 (0.00)	−0.006* (0.00)	−0.011*** (0.00)	0.019 (0.15)	−0.007 (0.00)	0.006*** (0.00)
Log exporter/ importer exchange rate	0.004*** (0.00)	0.006*** (0.00)	0.002 (0.00)	0.010 (0.01)	−0.033*** (0.01)	0.011*** (0.00)
Log ratio exporter/ importer freshwater withdrawals	0.000* (0.00)	0.000*** (0.00)	0.000*** (0.00)	−0.000 (0.00)	0.000*** (0.00)	0.000*** (0.00)
Ratio exporter/ importer degree of water stress	−0.049*** (0.01)	−0.040*** (0.01)	−0.079*** (0.01)	−0.068 (0.24)		−0.076*** (0.00)
1 for contiguity	0.056*** (0.01)	0.025** (0.01)	0.021** (0.01)	−0.055 (0.09)	−0.008 (0.05)	−0.001 (0.01)
1 for common official language	−0.018** (0.01)	−0.041 (0.03)	-0.014 (0.01)	0.298 (0.19)	−0.044 (0.05)	0.030*** (0.01)
1 for native language similarity	0.010 (0.01)	0.050*** (0.01)	0.074*** (0.01)		−0.012 (0.03)	0.041*** (0.01)
1 for common colonizer post-1945	0.061*** (0.01)	0.040 (0.03)	0.018** (0.01)	0.014 (0.07)	0.076 (0.04)	−0.028*** (0.01)
1 if landlocked	−0.014* (0.01)	0.072*** (0.01)	0.125*** (0.01)	0.272** (0.10)	−0.045* (0.02)	0.069*** (0.01)
1 for common water treaty	−0.005 (0.01)	0.047*** (0.01)	0.008 (0.01)	−0.040 (0.06)	0.121*** (0.02)	0.076*** (0.01)
1 for common AfCFTA ratification	0.024*** (0.01)	0.056*** (0.01)	0.035*** (0.01)	0.047** (0.02)	0.028 (0.02)	0.033*** (0.01)
1 if both countries are/were at war	−0.023*** (0.00)	0.114*** (0.02)	0.007 (0.01)		0.059 (0.04)	
Constant	2.511*** (0.04)	2.269*** (0.04)	2.352*** (0.04)	2.795*** (0.54)	2.371*** (0.05)	2.523*** (0.03)
Years dummies	Yes	Yes	Yes	Yes	Yes	Yes
N	21,529.0	9,578.0	10,897.0	1,949.0	1,414.0	16,032.0
R-squared	0.12	0.10	0.16	0.20	0.14	0.16

Note: AfCFTA = African Continental Free Trade Area; CEN-SAD = Community of Sahel-Saharan States; COMESA = Common Market for Eastern and Southern Africa; ECCAS = Economic Community of Central African States; ECOWAS = Economic Community of West African States; IGAD = Intergovernmental Authority on Development; PPML = Poisson pseudo maximum likelihood; SADC = Southern African Development Community. * p < .10; ** p < .05; *** p < .01. Standard errors are in the parentheses.