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The Transboundary Impacts of Trade Liberalization and Climate Change on the Nile Basin Economies and Water Resource Availability

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Abstract A multi-country, multi-sector computable general equilibrium (CGE) model is used for the first time to evaluate the economic and water resource availability effects of trade liberalization (removal of import tariffs) and facilitation (reducing non-tariff barriers) under climate change in the Nile Basin. The analysis uses the GTAP 9 Database and the GTAP-W model that distinguishes between rainfed and irrigated agriculture and implements water as a factor of production directly substitutable in the production process of irrigated agriculture. A full trade liberalization and improved trade facilitation scenario is considered with and without climate change. The study reveals that trade liberalization and facilitation generates substantial economic benefits and enhances economic growth and welfare in the Nile basin. The effect of instituting a free trade policy on water savings is found to be limited, while climate change improves water supply and hence irrigation water use, enhancing economic growth and welfare in the basin.

Keywords Computable general equilibrium model · Climate change · Trade liberalization · Nile River Basin

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1 Introduction

Despite its extraordinary natural endowments and positive economic growth rates (WDI 2012), the Nile Basin, supporting the livelihood of 238 million people (NBI 2012) and characterized by one of the highest population growth rates in the world (FAO 2011), faces massive poverty, social instability, and environmental degradation. Population growth combined with increased agricultural and industrial development are putting mounting pressure on the Basin's water resources through increased storage and diversion of surface water in order to serve the growing demand for energy and food (e.g. Hammond 2013). According to recent data (FAO 2013), the water supply conditions in the Nile basin can be classified as 'scarce' for Egypt, Kenya and Rwanda, and 'stressed' for Eritrea, Burundi, Ethiopia and Sudan according to the Falkenmark (1989) indicator for water stress.

Uncertainties related to future climate change pose additional challenges for the water resource situation in the Nile basin. Several studies have addressed the sensitivity of the Nile basin to climate change (e.g. Yates and Strzepek 1998; Elshamy et al. 2009; Beyene et al. 2010).While it is not clear how precipitation patterns would change exactly across the basin in the long run (Elshamy et al. 2009), there is consensus that temperature will increase, which will inevitably result in higher evaporation rates and water demand (Conway 2005). Other impacts include a reduction in agricultural yields and increasing crop water requirements (Blackmore and Whittington 2008). A recent study on the hydrological impacts of climate change on the Nile River Basin predicts that precipitation and stream flow levels in the basin would increase in the short-term (2010–2039) and decrease in the medium (2040–2069) and long term (2070–2099)(Beyene et al. 2010).

With an annual water withdrawal of 55.5 km^3 and 13.8 km^3, respectively (Blackmore and Whittington 2008), Egypt and Sudan are the main users of the Nile waters. Irrigated agriculture accounts for 80% of water withdrawals in the basin (Karyabwite 2000; Bastiaanssen and Perry 2009; FAO 2011). However, upstream countries like Ethiopia have begun to consider using the Nile waters in an attempt to mitigate the effects of weather uncertainties on their economic development. With most of the Nile Basin countries already being classified as water scarce or water stressed, upstream water withdrawals would further intensify competition for the basin's scarce water resources.

In the face of potential conflict and regional instability, the Nile Basin countries have been seeking cooperative solutions through basin-wide dialogues, most recently in the form of the Nile Basin Initiative (NBI). Recent decades have furthermore witnessed increased efforts of the Nile Basin countries to facilitate a move towards liberalized trade. In addition to tariffs, non-tariff barriers such as delays and related costs in customs clearance, sanitary and phyto-sanitary measures, poor infrastructure, high transportation and communication costs limit trade among the Nile Basin economies. According to the World Bank (2011), it takes on average 30 days to export from a Nile basin country and as much as 32 days to import to a Nile Basin country. In contrast, it takes on average 11 days to export to and import from a high income OECD country.

In light of the foregoing discussion, an important policy and research question is how the interaction between trade liberalization and facilitation and climate change would modify water endowments and water use in the Nile Basin countries, and impact agricultural production and overall economic conditions. Neoclassical (Heckscher-Ohlin) theory of international trade posits that it is largely driven by differences in countries' resources endowments (Krugman and Obstfeld 1997; Farmer and Schelnast 2013). In its simplest form the theory would predict that countries tend to export goods whose production is intensive in factors which are abundantly available, and import those that are intensive in factors that are relatively scarce. Lowering trade barriers would therefore increase the production of commodities favored by factor endowment, so that freer trade increases the use of the abundant factor relative to the scarce factor of production. Although the general applicability of the Heckscher-Ohlin theory has been questioned in the case of scarce water resources (Ansink 2010), it remains a powerful hypothesis that will be empirically tested in this paper.

To investigate the impact of trade liberalization and facilitation among the Nile Basin countries coupled with climate change, this study adopts a computable general equilibrium (CGE) methodology. CGE models have been widely used to analyze various water related issues (e.g. Diao et al. 2005; Feng et al. 2007; Berrittella et al. 2007).Previous studies focusing on climate change impacts in the Nile basin analyzed primarily the economic effects of infrastructure development in specific parts of the Blue Nile, in particular Ethiopia and Egypt (e.g. Strzepek et al. 2008; Jeuland 2010; Block and Strzepek 2010; Kahsay et al. 2015).Only a few CGE models (e.g. Berrittella et al. 2008; Calzadilla et al. 2011a) have addressed the issue of trade liberalization and its effect on agricultural water use. Berrittella et al. (2008) use a global CGE model that treats water as a non-substitutable factor of production to estimate the impact of agricultural trade liberalization on water use. Their findings reveal that significant reductions in agricultural tariffs lead to relatively modest changes in regional water use. Patterns are furthermore found to be non-linear in that water use may go up for partial liberalization and may go down for more complete liberalization. Moreover, trade liberalization tends to reduce water use in water scarce regions, and increase water use in water abundant regions. Similar results are found by Calzadilla et al. (2011a), who assess the potential global impacts of climate change and trade liberalization on agricultural productivity.

This study contributes to these previous global studies in two important ways. First, it examines the relationship between trade liberalization, climate change and water use by applying a CGE analysis at a concrete river basin-scale, and secondly by taking into account the responses of both agricultural and non-agricultural water users (municipal and industrial water use). Another novelty is that it considers both tariff and non-tariff barriers to intra-Nile basin trade.

2 Modeling Framework and Data

The modeling framework applied for the study is the Global Trade Analysis Project (GTAP) model (Hertel 1997). GTAP is a static, multi-region, multi-sector CGE model of the world economy that examines all aspects of an economy through its general equilibrium feature. The GTAP model comprises accounting relationships, behavioral equations and global sectors required to complete the model. The GTAP model assumes perfectly competitive markets, constant returns to scale technology, a non-homothetic private demand system and a foreign trade structure characterized by the Armington (1969) assumption. Assuming weak separability, the production system is set up as a series of nested constant elasticities of substitution (CES) functions combined through elasticities of substitution (see Supplementary Material, section A).

The analysis uses the GTAP-W model (Calzadilla et al. 2010),which accounts for rainfed land, irrigated land and irrigation water as factors of production. The production factor water is substitutable with other factors of production (capital, labor) in the production process of irrigated agriculture.

The GTAP 9 Database is used for the study, more specifically the GTAP-Power 9 Database, an electricity-detailed extension of the GTAP 9 Database. For the purpose of the present study, the 140 regions in the GTAP-Power 9 Database are aggregated into eight regions: Egypt, Ethiopia, Sudan (including South Sudan), the Equatorial Lakes (EQL) region, Rest of East Africa, Rest of North Africa, Rest of Sub-Sahara Africa and Rest of the World (ROW).The four EQL countries covered in the GTAP 9 Database are Rwanda, Kenya, Tanzania and Uganda. In the GTAP 9 database, Sudan is aggregated into the Rest of Eastern Africa region. The SplitReg Program (Horridge 2011a) is employed to split off Sudan from the composite region based on the share of Sudan in the region's total value of endowments. The split database is verified using the GTAPAdjust Program (Horridge 2011b). Since the study focuses on water resources management of the Nile River Basin, the regional aggregation highlights the importance of the Eastern Nile region, where the overwhelming proportion of the Nile water resource is generated and used.

The 68 sectors in the GTAP-Power 9 Database are aggregated for the purpose of this study into 20 sectors, of which 8 are agricultural sectors and 12 non-agricultural sectors. Following Calzadilla et al. (2011b), the agricultural land endowment in the GTAP database is disaggregated into rainfed land, irrigable land, and irrigation water based on available IFPRI data. The relative share of rainfed and irrigated production in total production is used to split the land rent in the original GTAP database into a value for rainfed land and a value for irrigated land for each crop in each region. In a next step, the ratio of irrigated yield to rainfed yield is used to split the value of irrigated land into the value of irrigable land and the value of irrigation water. Due to the lack of data, the values for the elasticity of substitution between irrigated land and irrigation water used in this study are adapted from Calzadilla et al. (2011b).

According to the neoclassical theory of trade, comparative advantages determine the pattern of inter-industry trade among countries. Identifying the goods with revealed comparative advantage (RCA), i.e. inferred from observed trade patterns in each country, are expected to shed light on the structure of specialization of the Nile basin countries and the prospects of trade liberalization and climate change under changing economic and water scarcity conditions. RCA values computed based on an index proposed by Mukhopadhyay and Thomassin (2010) show that Egypt's comparative advantage is confined to manufactured goods (See Supplementary Material, Section B, Table B1. A value greater than 1 means that a country has a RCA in a particular sector. Ethiopia's comparative advantage lies in livestock and meat and for most of the period under consideration in vegetables and fruits, and oil seeds. For Sudan, the comparative advantage covers livestock and meat, rice, cereals and vegetables and fruits. The EQL region appears to have a comparative advantage in agricultural products, such as cereals and oilseeds, as well as manufactured goods. The fluctuations in the RCA values are related to the fluctuations in the volume and composition of exports of these countries. Trade barriers prevent countries to fully reveal their true comparative advantage in international trade. Bilateral tariffs on intra-Nile Basin trade exist for several agricultural products and manufactured goods, in particular between Egypt and Ethiopia and Ethiopia and the EQL region.

Irrigation water use varies considerably across crops and regions in the Nile Basin. According to the 2011 baseline data (See Supplementary Material, Section B, Table B2), Egypt is the major user of irrigation water in the Nile basin with an annual abstraction of 53.7 km^3. Sudan follows with 17 km^3 of water use in irrigated agriculture in the reference year. Irrigation water use in Ethiopia and the EQL region is much lower, standing at a mere 1.5 and 1.9 km^3 per year, respectively in 2011. Downstream countries Sudan and Egypt that use most of the Nile waters have relatively higher water intensity rates for most crops, measured both in terms of water use per unit of land and per unit of output.

3 Baseline and Policy Scenarios

Full trade liberalization and improved trade facilitation coupled with climate change until 2025 is considered for model implementation. Full trade liberalization involves elimination of import tariffs on intra-Nile Basin countries' trade. Although tariff liberalization is important in improving trade, the importance of other trade-related factors, such as transport and communication services, customs procedures, port efficiency, standards and technical regulations, etc. are equally important in enhancing trade performance. Hence, an improvement in non-tariff barriers in the form of trade facilitation is also considered.

Cumbersome trade procedures cause significant delays and constitute trade transaction costs to traders. Trade facilitation is incorporated into the GTAP model by splitting these trade transactions costs into two parts: the indirect trade transaction costs and a tax component capturing the direct costs (Fox et al. 2003; OECD 2003). The direct costs include costs incurred in providing information and documentation, customs fees, and direct charges for trade-related services, such as form-filling services, while the indirect costs are related to delays resulting from poor administration and infrastructure that cause burdensome and inefficient import-export procedures. Following Hertel et al. (2001) and Fox et al. (2003), this study models trade facilitation via a technical change in trading activities, which is considered appropriate for capturing the indirect cost component of trade transaction costs (OECD 2003). Indirect transaction costs are associated with higher costs and a melting down of the value of the good in proportion to the length of its transit time so that reducing delays related to inefficient trade procedures through trade facilitation would result in lower associated costs and hence lower prices of the traded goods.

The gains that would accrue from the implementation of trade facilitation among the Nile Basin countries is modeled using data about the amount of time required to import into a Nile Basin country from the World Bank (2011). Data on the cost of time in trade are from Minor and Tsigas (2008). The trade facilitation policy scenario assumes that the average time required to import to the Nile Basin countries (except Egypt) and hence the associated indirect cost of trade in the base year 2011 can be reduced to a global average. The average time required to import to Egypt, which is already very close to the OECD average, is assumed to converge to the OECD average in 2011. This implies a 8, 43, 44, and 16% increase of import-augmenting technical change in the various sectors in Egypt, Ethiopia, Sudan and the EQL region, respectively. The import-augmenting technical change effectively decreases the costs of importing goods. In the simulation we furthermore assume that trade facilitation can be achieved at no cost, although countries may have to invest for example in equipment to improve port handling and customs procedures and manpower. Direct trade transactions costs are not considered due to the lack of data on customs fees, port handling and other trade charges among the Nile basin countries.

Climate change occurs in the future and hence impacts the future economy of the Nile basin countries. Climate change impacts are therefore evaluated relative to a future benchmark equilibrium derived assuming a future with no climate change. The dynamic GTAP model (Inachovichina and McDougall 2001) is employed to track the path of the world economy over time and obtain the future benchmark equilibrium dataset for the GTAP-W model. In the baseline scenario without climate change, the economies of the Nile basin countries are projected to grow on average between 4 (Egypt and Sudan) and 6% (Ethiopia and EQL) per year over the period 2011–2025 (Poncet 2006).

In estimating the economic impacts of climate change in the Nile basin, climate change related effects on (i) water resource endowment and (ii) irrigated and rainfed crop yields, as well as (iii) land endowment changes in irrigated and rainfed agriculture are taken into consideration. Future climate change impacts on stream flows and irrigation water supply in the Nile basin are based on data provided by Beyene et al. (2010). Using 11 general circulation models (GCMs) and the IPCC's A2 and B1 global emissions scenarios, Beyene et al. (2010) predict the impact of climate change on key climate variables, including temperature, precipitation and stream flow for the major sub-basins and the entire Nile basin over three time periods: 2010–2039, 2040–2069, and 2070–2099. They also provide predictions of climate change related changes in irrigation water releases from the High Aswan Dam (HAD). In this study, the impact of climate change on agriculture in the Nile basin is assessed for the two global emissions scenarios A2 and B1 in 2025. The year 2025is centered in the period 2010–2039 in Beyene et al. (2010) and represents the average for these 30-years. Short-term climate change impacts expected in the year 2025 are considered assuming that this period concurs with the time required to achieve free trade and improved trade facilitation in the Nile basin region. Changes in stream flow at the HAD and Lake Victoria are used to calculate the changes in water supply for Egypt and the EQL Region, respectively. Changes in irrigation water supply in Ethiopia and Sudan are based on climate induced changes in the Blue Nile flow at the border between Sudan and Ethiopia at El Diem.

Our estimates of yield responses to climate change in the Nile basin countries are based on climate change related changes in temperature and precipitation presented in Beyene et al. (2010) and their impact on crop yields based on estimates reported by Calzadilla et al. (2010b). We expect changes in precipitation to affect rainfed yields only, while changes in temperature influence both rainfed and irrigated yields. Changes in rainfed and irrigated land in the Nile basin countries are based on data from Nelson et al. (2010). Shocks related to the impacts of climate change are scaled by the size of irrigated and rainfed agriculture in each country that lies within the Nile basin (for a detailed overview of scenario assumptions, see Supplementary Material, Section B, Tables B3– B5).

Overall this results in five simulation scenarios. The first scenario represents trade liberalization and improved trade facilitation under current climate conditions. The second and third scenarios consider only the IPCC climate change scenarios A2 and B1, while the fourth and fifth scenarios couple trade liberalization and facilitation with the IPCC climate change scenarios A2 and B1, respectively. In all cases we adopt a small-country closure and assume fixed average world import prices since intra-Nile basin trade liberalization is not likely to influence world prices.

4 Simulation Results

Trade liberalization induces resource reallocation to sectors in each country where there is a comparative advantage. Production tends to improve in most agricultural sectors in Ethiopia and Sudan, while the manufacturing sector contracts in both countries (Table 1). The opposite is true for Egypt where the manufacturing sector expands while the agricultural sectors tend to decline or remain stable. The EQL region sees a substantial expansion in both the manufacturing sector and agricultural production. With the removal of bilateral tariffs and improvement in trade facilitation, the Nile basin economies thus adjust their economic structures according to their comparative advantages. Tariffs on intra-Nile countries trade have already been

Table 1 Percentage change in domestic production of agricultural and manufactured products in 2025 as a result of trade liberalization and climate change compared to the baseline scenario of no climate change and no trade liberalization

	Sector								
	Paddy	Wheat	Other cereals	Other crops	Vegetables & fruits	Oil seeds	Sugar crops	Livestock & meat	Manufactures
Trade liberalization and facilitation under current climate conditions									
Egypt	−0.1	−1.0	−0.2	−0.2	−0.2	−0.4	0.3	−0.3	1.6
Sudan (pre-2011)	−1.7	5.2	1.2	−14.8	−8.0	2.5	0.3	2.8	−5.9
Ethiopia	−2.9	−1.1	1.4	−3.6	2.4	−5.2	0.9	0.8	−1.1
EQL region	−0.7	−5.1	0.6	−2.1	0.1	0.2	0.0	0.0	4.9
No trade liberalization, only 2025A2 climate change									
Egypt	0.0	1.9	0.1	0.0	0.0	0.1	0.0	0.1	0.0
Sudan (pre-2011)	0.3	4.4	0.2	1.0	0.3	1.5	0.3	0.2	−0.1
Ethiopia	4.0	3.8	0.5	6.7	2.7	−7.1	0.7	−0.3	−1.3
EQL Region	1.8	4.1	1.5	5.7	−0.1	1.0	0.0	0.0	−0.7
No trade liberalization, only 2025B1 climate change									
Egypt	0.0	2.7	0.1	0.0	−0.1	0.2	0.1	0.1	0.0
Sudan (pre-2011)	0.3	4.5	0.2	1.0	0.3	1.5	0.3	0.2	−0.1
Ethiopia	4.1	3.8	0.5	6.8	2.7	−6.9	0.7	−0.3	−1.3
EQL region	2.4	7.3	1.6	6.5	1.1	1.2	0.2	0.1	−1.0
Trade liberalization plus future “2025A2” climate change									
Egypt	−0.1	0.8	−0.2	−0.2	−0.2	−0.3	0.4	−0.2	1.7
Sudan (pre-2011)	−1.2	9.5	1.4	−14.5	−8.3	4.2	0.6	3.0	−6.0
Ethiopia	1.4	3.0	1.8	2.9	5.2	−11.8	1.6	0.5	−2.5
EQL region	1.1	−1.3	2.1	3.4	0.0	1.2	0.0	0.0	4.2
Trade liberalization plus future “2025B1” climate change									
Egypt	−0.1	1.6	−0.1	−0.2	−0.3	−0.2	0.4	−0.2	1.6
Sudan (pre-2011)	−1.3	9.6	1.4	−14.5	−8.3	4.2	0.6	3.0	−5.9
Ethiopia	1.4	3.0	1.8	2.9	5.2	−11.6	1.5	0.5	−2.4
EQL region	1.7	1.7	2.2	4.1	1.2	1.4	0.1	0.1	3.8

eliminated for several agricultural sectors. As a result, complete elimination of the remaining tariffs would only have a limited (non-uniform) impact on sectoral output. The changes in sectoral output are therefore mainly due to lowering non-tariff barriers in the form of trade facilitation.

Climate change modifies the water and land endowments as well as crop yields in the Nile basin countries (Table 1). Climate change alone enhances production in most agricultural sectors in Sudan, Ethiopia and the EQL region. Expansion in agricultural production is more prominent in the wheat and oil seeds sector in Sudan, while paddy, wheat and other crops gain more in Ethiopia and the EQL region. Climate change has a negligible effect on agricultural production in Egypt, which relies heavily on irrigated agriculture. Agricultural production in Egypt remains stable across the agricultural sectors except for wheat where output increases by 1.9 to 2.7%. Results are similar for both the IPCC’s A2 and B1 scenarios.

Climate change coupled with trade liberalization and facilitation improves agricultural production in Ethiopia and the EQL region. The expansion in agricultural production in these countries is mainly due to climate change induced improvements in water and land endowments. In downstream Egypt where irrigated agriculture is already well developed, the predicted increase in water supply and the expected expansion in irrigated land due to climate change have little to no effect on agricultural production. In Sudan, climate change coupled with trade liberalization and facilitation results in mixed effects on agricultural production, enhancing output in most sectors and reducing production in some others.

Free intra-Nile Basin trade and improved trade facilitation enhances bilateral trade in the basin substantially (Fig. 1). The total increase in intra-Nile basin exports due to trade liberalization and facilitation is in the order of USD 35 billion (price level 2011). Much of the improvements in intra-Nile exports (62%) is achieved by Egypt and Sudan, which are expected to gain about USD 10.6 and 11.1 billion respectively due to an expansion of their exports to other Nile basin countries. The export increase for Ethiopia and the EQL region is relatively lower with USD 4.1 and 9.1 billion, respectively. Paddy, wheat and manufactured goods account for about 70% of the expansion in intra-Nile exports from all the Nile basin countries. The results indicate that Egypt and the EQL region achieve relatively higher exports of manufactured products, while Sudan and Ethiopia gain more from agricultural exports. This corresponds with the expectation that the countries specialize in products favored by their resource endowments. Changes in the pattern of intra-Nile trade are essentially driven by trade liberalization and facilitation. Climate change has hardly any effect on trade between the Nile countries (Fig. 1).

Irrigation water use tends to decline or remain stable in most of the agricultural sectors across the Nile basin countries due to trade liberalization and facilitation (Table 2). In Sudan and Ethiopia, irrigation water use falls in some sectors and rises in others, while the simulation results show that irrigation water use remains more or less stable in most of the agricultural sectors in Egypt and the EQL region. Total irrigation water use increases by 0.14 km^3 in Egypt, decreases by 0.35 km^3 in Sudan and remains stable in Ethiopia and the EQL region, amounting to an overall decline of 0.17 km^3 in basin-wide irrigation water use (Table 3). Thus, eliminating tariffs on and improving non-tariff barriers to intra-Nile Basin countries' trade has a limited impact on overall water use. Climate change induced improvements in irrigation water availability and hence productive land endowments allow the Nile basin countries to increase irrigation demand substantially and tend to improve water use in most agricultural sectors in the basin countries (Table 2). The effect of climate change only on irrigation water use in the basin is substantial (3.35–4.75 km^3) due to enhanced water endowments induced by the wetter climate predicted for the basin. Egypt increases its irrigation water use most (2.48–3.85 km^3), followed at a distance by Sudan (0.73 km^3). In the upstream countries, where irrigated

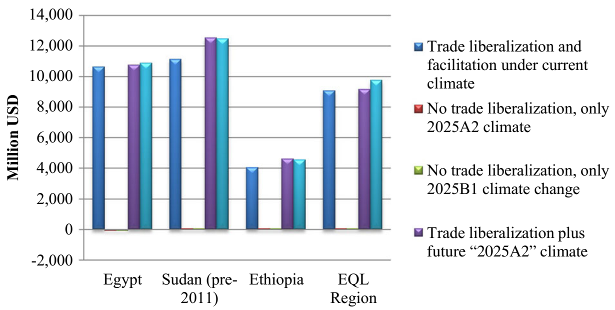

Fig. 1 Change in intra-Nile countries exports in 2025 as a result of trade liberalization and climate change compared to the baseline scenario of no climate change and no trade liberalization

Table 2 Percentage change in the demand for irrigation water across agricultural sectorsin 2025 as a result of trade liberalization and climate change compared to the baseline scenario of no climate change and no trade liberalization

	Sector						
	Paddy	Wheat	Other cereals	Other crops	Vegetables & fruits	Oil seeds	Sugar crops
Trade liberalization and facilitation under current climate conditions							
Egypt	0.3	−0.3	0.2	0.5	0.2	0.1	0.7
Sudan (pre-2011)	−0.7	5.1	0.8	−11.6	−4.7	0.7	2.3
Ethiopia	−2.2	−0.7	1.6	−2.8	1.9	−3.6	0.7
EQL region	0.2	−3.7	1.0	−1.1	0.9	0.8	0.8
No trade liberalization, only 2025A2 climate change							
Egypt	3.8	8.2	3.9	8.7	2.5	3.9	4.2
Sudan (pre-2011)	4.0	7.5	3.1	4.8	5.5	3.0	5.3
Ethiopia	7.6	7.4	−0.3	9.8	17.2	−10.9	15.8
EQL region	−2.3	7.8	18.5	5.8	−7.2	1.9	−7.5
No trade liberalization, only 2025B1 climate change							
Egypt	6.0	12.1	5.9	12.9	4.3	6.1	6.3
Sudan (pre-2011)	4.1	7.7	3.2	4.9	5.5	3.1	5.3
Ethiopia	7.7	7.5	−0.2	10.0	17.1	−10.7	15.4
EQL region	−1.0	11.1	19.3	7.4	−5.9	3.0	−6.6
Trade liberalization plus future “2025A2” climate change							
Egypt	4.2	7.9	4.1	9.3	2.7	4.0	4.9
Sudan (pre-2011)	3.4	12.8	3.9	−7.7	0.4	3.9	8.1
Ethiopia	5.7	7.0	1.3	6.8	19.2	−14.2	16.4
EQL region	−2.2	3.9	19.8	4.6	−6.4	2.7	−6.8
Trade liberalization plus future “2025B1” climate change							
Egypt	6.4	11.7	6.2	13.5	4.5	6.2	7.0
Sudan (pre-2011)	3.5	12.9	4.0	−7.7	0.4	4.0	8.2
Ethiopia	5.8	7.1	1.4	7.0	19.2	−14.0	15.9
EQL region	−0.9	7.1	20.6	6.2	−5.1	3.9	−5.9

agriculture is limited, the impact of climate change on irrigation water use is found to be negligible. An increase in water use due to climate change only is more pronounced for the IPCC’s B1 scenario than the IPCC’s A2 scenario. Trade liberalization and facilitation combined with climate change increase water allocation across sectors substantially in all the Nile basin countries, but mainly due to climate change.

Trade liberalization, trade facilitation and climate change are expected to result in changes in the basin’s industrial and municipal water use as well. To examine these changes, we took the output of the water services sector as a proxy for raw water use by the municipal and industry sectors (Table 3).

Municipal and industrial water use tends to increase slightly in Egypt, Ethiopia and Sudan. In the EQL region, municipal and industry water use tend to remain more or less stable. Overall, the effect of trade liberalization and facilitation on municipal and industrial water use is negligible (0.023 km^3 in the whole basin). Similar results are observed for trade liberalization plus climate change, except for Egypt where water use decreases slightly and the EQL region where water use increases slightly. Results for climate change only reveal that municipal and industrial water use remains more or less stable in all the Nile basin countries. Combining the results for municipal, industrial and irrigation water demand in Table 3 reveals that total water savings in the basin due to trade liberalization and trade facilitation are negligible. However, climate change increases irrigation water demand and hence water use in the basin.

Table 3 Change in municipal and industrial water use in the Nile Basin countries as a result of trade liberalization and facilitation

	Municipal and industry water use in benchmark equilibrium (km^3/year)*	Change in output of municipal and industrial water use (%)	Change in municipal and industry water use (km^3)	Change in irrigation water use (km^3)**
Trade liberalization and facilitation under current climate conditions				
Egypt	9.30	0.06	0.006	0.14
Sudan (pre-2011)	1.03	0.85	0.009	−0.35
Ethiopia	0.86	0.76	0.007	0.02
EQL region	2.85	0.07	0.002	0.01
Total	14.04		0.023	−0.17
No trade liberalization, only 2025A2 climate change				
Egypt	9.30	−0.03	−0.003	2.48
Sudan (pre-2011)	1.03	0.08	0.001	0.73
Ethiopia	0.86	−0.03	0.000	0.20
EQL region	2.85	0.07	0.002	−0.07
Total	14.04		0.000	3.35
No trade liberalization, only 2025B1 climate change				
Egypt	9.30	−0.05	−0.005	3.85
Sudan (pre-2011)	1.03	0.08	0.001	0.74
Ethiopia	0.86	−0.03	0.000	0.20
EQL region	2.85	0.12	0.003	−0.04
Total	14.04		−0.001	4.75
Trade liberalization plus future “2025A2” climate change				
Egypt	9.30	0.03	0.003	2.63
Sudan (pre-2011)	1.03	0.92	0.009	0.35
Ethiopia	0.86	0.74	0.006	0.22
EQL region	2.85	0.15	0.004	−0.05
Total	14.04		0.023	3.15
Trade liberalization plus future “2025B1” climate change				
Egypt	9.30	0.02	0.002	4.01
Sudan (pre-2011)	1.03	0.92	0.009	0.36
Ethiopia	0.86	0.74	0.006	0.22
EQL region	2.85	0.21	0.006	−0.03
Total	14.04		0.024	4.56

*Calculated based on water use data from AQUASTAT (FAO 2015)

**Calculated based on the data presented in Table 2 and the Supplementary Material, Section B, Table B2

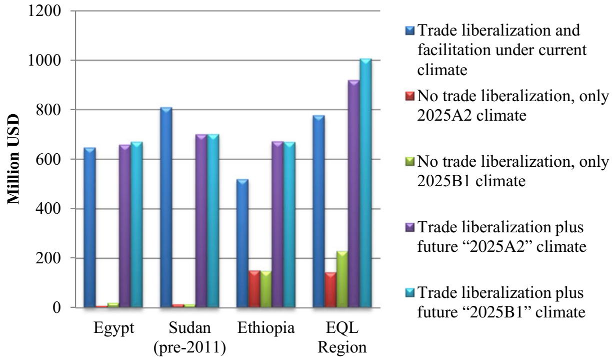

Fig. 2 Potential total welfare effects of trade liberalization and climate change across the Nile Basin countries

Overall, the basin-wide potential total welfare gain (net economic benefits) due to trade liberalization and facilitation are about USD 2.8 billion (Fig. 2). The total welfare gain rises to about USD 3 billion when trade liberalization and facilitation take place under climate change. The welfare effect due to trade liberalization alone is limited to USD 319 to 416 million. On average, Egypt, Sudan, Ethiopia, and the EQL region are expected to face a welfare gain of USD 401, 448, 433 and 616 million, respectively. These results are robust irrespective of changes in the substitution elasticity parameters (test results are available from the authors upon request).

5 Discussion and Conclusion

This study presents one of the first efforts to use a global CGE model to analyze the implications of trade liberalization on transboundary water resources management. Trade liberalization is modeled in a novel fashion in that both tariff and non-tariff barriers to intra-basin trade are considered under climate change in a multi-sector and multi-country CGE setting. Moreover, the study uses the latest GTAP database and employs official data in designing policy scenarios. The findings presented in this study indicate that the Nile Basin countries would potentially gain from multilateral trade liberalization and trade facilitation as resources are reallocated to sectors in each country where there is a comparative advantage. The findings suggest that trade liberalization and facilitation could result in structural adjustments in the Nile basin economies as their sectors grow according to their comparative advantages.

In view of the fact that tariffs on trade between Nile countries have already been eliminated for several sectors, implementing free basin-wide trade is expected to have limited economic and water resource implications compared to instituting improved trade facilitation in the basin. Climate change investigated in this study predicts a wetter Nile basin in the next decade and hence improves the water and land endowments of the Nile basin countries. Accordingly, climate change coupled with trade liberalization and facilitation further improves agricultural production and enhances economic growth and welfare. Climate change is, however, found to have little impact on the magnitude and pattern of intra-Nile trade.

The results found in this study are more or less consistent to the findings of previous studies. As in these other studies, we find that significant trade liberalization results in a modest decline in water use. Whereas Berrittella et al. (2008) and Calzadilla et al. (2011a) predict a decline in water use in water scarce regions, this study reveals that water use decreases in relatively water abundant Sudan and remains more or less stable in the other Nile basin countries. A possible explanation for this is that Sudan is more abundant in land than water, so that a shift in the pattern of production towards rainfed agriculture results in a decreased demand for irrigation water. The comparative advantages of the Nile Basin economies predicted by the model are found to be consistent with the RCA's observed in the UN comtrade and UNCTAD database over the period 2006–2010. Both the model results and the RCA data show that capital-abundant Egypt has a comparative advantage in manufactured products, while the comparative advantages of the remaining land-abundant Nile Basin economies lie in agricultural products. Only the EQL region has a comparative advantage in both.

Overall, while trade liberalization and facilitation may generate substantial basin-wide economic benefits, their impact on water savings in the basin is found to be limited. Free trade policy and trade facilitation alone are thus less likely to be a panacea for the looming longer term water scarcity conditions in the basin. However, freer trade policy coupled with other relevant policy measures, like improved irrigation efficiency and other water-saving measures as well as basin-wide infrastructure development, might help to alleviate future water scarcity conditions. Short-term climate change, as investigated here, modestly increases water supply and hence irrigation water use in the basin.

The results presented here have to be interpreted with the necessary care for a number of reasons and limitations surrounding this study. The static nature of the model constitutes one of the most important limitations of the study. A dynamic model would, according to theoretical expectations, yield bigger effects of trade liberalization and facilitation in the Nile Basin economies through adjustments in national capital stocks. The study is also limited to the analysis of the impact of short term climate change in the Nile basin. How climate change would modify water resources endowments in the basin in the long-term is a question for further future research.

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