Trade Thrive in Ethiopia: Navigating Climate Change Impact — A Recursive Dynamic CGE Analysis

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Abstract

This study evaluates the economic implications of the African Continental Free Trade Area (AfCFTA) in Ethiopia's climate-affected economy using a recursive dynamic Computable General Equilibrium (CGE) model. Simulations incorporating climate-induced productivity shocks under RCP 4.5 and RCP 8.5 scenarios reveal that climate change significantly reduces agricultural output and raises food prices, leading to macroeconomic and distributional challenges. Under RCP 8.5, agricultural GDP contracts by 6.2%, food prices increase by up to 25%, and inequality worsens. However, the implementation of AfCFTA—particularly when paired with trade facilitation—partially offsets these losses by enhancing manufacturing and service sector outputs, increasing exports, and improving household welfare. The GDP grows by 0.3%, and rural households in the lowest consumption quantile see welfare gains up to 5.95% under RCP 4.5. Trade liberalization also reallocates labor toward services and manufacturing, especially benefiting unskilled and semi-skilled labor. Despite an 11.5% decline in government tariff revenue, AfCFTA contributes to improved trade performance and resilience. The results underscore the importance of targeted trade policies, climate adaptation strategies, and industrial investments to balance growth, food security, and climate vulnerability. Ethiopia's success un-

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der AfCFTA hinges on aligning trade reforms with climate resilience and inclusive development policies.

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1 Introduction

Economic transformation and poverty eradication via broad-based, accelerated, and sustained growth have been at the forefront of Ethiopian policy priorities over the last few decades. In this regard, Ethiopia recorded impressive economic growth between 2000 and 2019 at 9% annually, which is higher than the average growth rate in sub-Saharan Africa (African Export-Import Bank, 2024). In addition, arguably, such growth emanated from liberalization in the 1990s, enormous investments in public infrastructure, and agriculture-oriented policies (Bachewe & Taffesse, 2018). However, looming challenges such as infrastructure gaps, climate change, and conflicts pose uncertainties and vulnerabilities to the sustainability of growth. Building a resilient economy is more critical than ever, necessitating strengthening LDCs' trade cooperation and revisiting international trade agreements to address global challenges, such as resilient supply chains, energy transition, and secure digital infrastructure (UNCTAD, 2023).

Ethiopia signed the AfCFTA in 2018, which aims to boost intra-African trade significantly, enhance inclusive regional growth, increase income and food security, and reduce external dependency. The AfCFTA liberalization schedules differ among countries according to their level of development. Ethiopia prepared and presented the country tariff offer to the secretariat in November 2023 to be commented on by member countries and concerned bodies of the secretariat and accepted in February 2024 (African Union, 2024). In this liberalization proposal, foodstuffs (over 60 products) and transportation services (50 product categories) represent the bulk of the excluded items at the HS8 product classification level. Ethiopia is a net importer of food products and exports transportation services, which could have significant policy implications. Indeed, earlier estimates by various studies showed that the AfCFTA could increase trade within the African continent by 30% - 80 %, thus significantly improving economic income gains (Abrego, Amado, Gursoy, Nicholls, & Perez-Saiz, 2019; ECA and ATPC & Center, 2024; Simola, Boysen, Ferrari, & Boulanger, 2021; World Bank, 2020). Although these gains are not evenly distributed across sectors and countries, they could raise income for close to 100 million people and lift 30 million out of extreme poverty by 2035, according to the projection of the (World Bank, 2020). This liberalization process will likely shift labor from agriculture to the public, service, and manufacturing sectors.

Ethiopia is expected to be one of the biggest beneficiaries of the AfCFTA, in which gains in agriculture, processed foods, construction, and air transport services would be considerably high, with impacts in manufacturing and some trade services being adverse. Nonetheless, the country faces binding constraints such as high population growth and inadequate infrastructure, especially in drought-prone areas (World Bank, 2021). Thus, the opportunities from the AfCFTA are seriously threatened by climate change, which may reduce the comparative advantage in agriculture, possibly causing spillover effects throughout the economy. Previous studies might underestimate the positive effects of intra-African trade liberalization despite climate change. Climate change results in low crop yields, increasing food prices, and disruption in agricultural productivity owing to increasing temperatures and adverse weather conditions (Godde, Mason-D'Croz, Mayberry, Thornton, & Herrero, 2021; Ndlovu, Prinsloo, & le Roux, 2020; von Braun & Pandya-Lorch, 1991). Several studies (Gebreegziabher, Stage, Mekonnen, & Alemu, 2016; Robinson, Strzepek, & Cervigni, 2013; Solomon, Simane, & Zaitchik, 2021; World Bank, 2008, 2024b) had estimated that climate change could reduce the GDP of Ethiopia by approximately 8% to 10% by the middle of the 21st century. Food security can only improve when trade, nutritional, and social policies are integrated into the climate change framework.

Trade can play a crucial role in adapting to climate change by adjusting the production of vulnerable products (Brenton, Chemutai, & Pangestu, 2022; Calzadilla & Tol, 2011; Huang, von Lampe, & van Tongeren, 2011; Janssens et al., 2020; Leichenko & O'brien, 2002; Reilly & Hohmann, 1993). However, Africa faces significant challenges owing to high tariffs and nontariff trade barriers, complicating international trade and economic growth. In addition, stringent regulation of carbon-intensive products reflects a growing commitment to environmental sustainability (Shapiro, 2021). In Ethiopia, implementing exogenous structural change policies plays a crucial role in mitigating the adverse impacts of climate change. These strategic policies are anticipated to offset approximately 20%–30% of the overall effects associated with climate change in the country (Yalew, Hirte, Lotze-Campen, & Tscharaktschiew, 2017). This proactive approach addresses environmental concerns and promotes economic resilience and sustainability in the region.

Despite numerous studies on the impacts of climate change on the Ethiopian economy, the role of trade agreements in this context has been largely overlooked. This study aimed to fill this gap by analyzing the impacts of the AfCFTA in light of climate change, providing a comprehensive assessment that encompasses sectoral, income level, and rural–urban dimensions. This study contributes to the literature and policy debate on the impacts of trade against climate change on developing countries in the following ways. First, this study projects the annual country-level economic and welfare effects of the product-level agricultural climate shock (rainfall and precipitation). This analysis better accounts for the differential crop sensitivity to climate change over different years (Waldhoff, Wing, Edmonds, Leng, & Zhang, 2020), improving the direct and indirect impact analyses of climate change in a CGE model. Second, the AfCFTA is modeled for Ethiopia using the actual tariff offer. In a full trade liberalization with African countries, the average actual tariff offer allows us to understand better the agreement's potential impacts and future implementation options and challenges. Finally, this study used a trade liberalization vs. climate change simulation to better depict the economic and negotiation power of the country in the AfCFTA. The WTO accession can further imply it. As an agrarian, fast-growing economy and the second-most populous country on the continent, the impacts of climate change are negligible. AfCFTA is one of the many ways to harness this negative shock by enhancing its competitiveness and comparative advantage.

Against this background, this study explores the possible effects of AfCFTA trade liberalization on the climate-affected Ethiopian economy. To achieve this, bilateral tariff liberalization with African countries and TF is simulated, and a single-country recursive dynamic CGE model is employed for the period 2021 to 2035. The climate shock to the agriculture sector is implemented in the baseline. The simulation results indicate that the AfCFTA will significantly impact the Ethiopian economy by overcoming the negative impacts of climate change. At the sectoral and household level, agriculture, food processing, and some manufacturing sectors will benefit the most, while the rural and urban poor will recover from the climate shock significantly. At the macroeconomic level, these trade liberalization efforts foster growth in imports and exports, real income, and GDP. Moreover, AfCFTA has significant effects on welfare, absorption, investment, and private consumption. However, the government's tariff revenue loss is moderate at 11.5% of the total revenue.

This paper is structured into five sections. The second section highlights research gaps in trade liberalization and climate change interactions. Section three discusses details of the recursive dynamic CGE model and simulation scenarios. Our analysis clearly discusses the model's basic assumptions and adjustments. The fourth results section analyzes the main macroeconomic, sectoral, and household impacts of AfCFTA under climate shocks and interprets findings, emphasizing policy trade-offs. Finally, the fifth section summarizes key insights, stressing the need for balanced trade and climate resilience strategies.

2 Trade liberalization and climate change

Trade can be instrumental in resource allocation efficiency, a promoter of development, and a facilitator of the dissemination and transfer of technologies needed to address climate change (Gouel & Laborde, 2018; Hertel, 2018; Truong, 2010; UNCTAD, 2023; WTO, 2023).

2.1 Trade liberalization vs. climate change

Trade can significantly influence climate change via various mechanisms. Trade will be critical for greening, making the world resilient, and inclusively developing in the coming decades, particularly in light of climate change. It offers enormous opportunities for mitigating and adapting to a changing climate. Furthermore, trade facilitates the transition to cleaner production methods by shifting production to countries with a comparative advantage in environmentally friendly technologies (Antweiler, Copeland, & Taylor, 2001; Liu, Tawiah, Zakari, & Alessa, 2023; Yu, Qayyum, & Li, 2024). The comparative export advantage will continue shifting as economies move to low-carbon economies, which will pressure countries to adjust and seize new opportunities.

The developing world, by any count, is a minor contributor to emissions but remains highly vulnerable to the negative impacts of climate change. Therefore, they have much at stake in successfully adapting, especially to climate-sensitive sectors such as agriculture, which remains central to food security, employment, and trade. Shifting investment away from sensitive sectors can help build long-term resilience. How, then, can we achieve such gains? It is imperative to recalibrate trade policies on reviewing and eliminating tariffs biased toward polluting sectors. For instance, facilitate access to environmental goods and services through multilateral negotiations. Another is to do away with NTBs and have better trade facilitation to reduce delays, mainly in the food supply chains, thereby increasing food security. Moreover, tariffs and NTBs should be reduced in the inputs of agricultural use and farmers' access to new technologies.

Trade with Technique effects alter the production technique changes that occur because of trade liberalization and investment agreements, which may result in energy-efficient production, hence reducing GHG emissions per unit of output. The right policy can promote trade and the diffusion of cleaner technologies and best practices. Some EU climate policies, such as incentives to adopt renewable energy sources, have spurred innovation and clean technologies. Furthermore, international negotiations, such as those held at the WTO on the environmental goods and services sector, work toward liberalizing the trade of climate-friendly technologies and thus may further enhance the positive technique effects (WTO, 2022).

The growing prominence of service trade as a source of comparative advantage can help mitigate climate change by reducing reliance on carbon-intensive industries and promoting cleaner economic activities. Unlike traditional manufacturing and resource extraction, many service sectors—such as digital services, finance, education, and professional consulting—have significantly lower carbon footprints (Low & Tijaja, 2015). As economies shift toward services, overall energy consumption and greenhouse gas emissions decline, particularly in high-emission industries like heavy manufacturing and transportation (Copeland & Taylor, 1994). Moreover, advancements in digital trade, including remote work, cloud computing, and e-commerce, reduce the need for physical infrastructure, business travel, and energy-intensive production processes (Organization for Economic Cooperation and Development, 2021). Empirical evidence suggests that economies with a strong service sector tend to have lower per capita emissions, as knowledge-based industries rely more on human capital and technology rather than resource-intensive inputs (Nayyar & Davies, 2023). Additionally, international trade in services facilitates the global diffusion of green expertise, allowing countries to access environmental consulting, climate finance, and technological solutions that support sustainability efforts (Brenton et al., 2022). By shifting comparative advantage toward service-based economies, trade can contribute to a structural transformation that reduces global emissions while fostering economic growth.

The literature on trade and the environment highlights both its potential benefits and drawbacks. While trade can drive environmental and economic benefits by facilitating the diffusion of green technologies, enhancing resource efficiency, and promoting sustainable development, it also poses significant environmental risks. As Brenton et al. (2022) highlight, trade plays a dual role in the climate crisis. While it enables access to low-carbon technologies and supports economic diversification, it simultaneously contributes to greenhouse gas emissions through increased transportation, production expansion, and resource extraction. Developing countries, in particular, face a complex challenge: although they can leverage trade for climate resilience and economic growth, they are also disproportionately vulnerable to environmental degradation and carbon-intensive industrial shifts. This paradox underscores the need for a balanced approach, as the environmental costs of trade - including deforestation, pollution, and carbon leakage - can sometimes outweigh its benefits if not properly managed.

Trade influences environmental outcomes through composition and scale effects. As countries grow wealthier, they tend to shift toward lower-carbon goods and services, such as technology and telecommunications, while outsourcing carbon-intensive production like steel and cement, provided strict environmental regulations are enforced

(Frankel & Rose, 2005). However, in the absence of coordinated international policies, emissions may simply be relocated rather than reduced, undermining trade's potential climate benefits (Garsous, 2019; WTO, 2021). The scale effect of trade expansion, which increases overall economic activity, is particularly concerning for carbon-intensive sectors like industry and transport, leading to higher greenhouse gas emissions (Copeland & Taylor, 1994; Grossman & Krueger, 1991). Critics argue that this accelerates climate change and environmental degradation (IPCC, 2023; WTO, 2018). Despite these challenges, trade has significantly contributed to economic growth and poverty reduction, increasing global incomes by 24% since 1990, with even greater benefits for the poorest populations (World Bank, 2023). However, trade can be part of the solution with the right policies to promote cleaner production and climate-friendly trade. For instance, reducing tariffs and improving infrastructure could significantly lessen the climate-induced rise in global undernourishment (Janssens et al., 2020).

Trade has immediate effects on climate change related to the increased demand for international freight, one of the carbon-intensive sectors, as high dependence on combustible fossil fuels results in an incremental increase in GHG emissions (IPCC, 2023; WTO, 2021). This aspect of trade is constantly negative toward the environment because most emissions are released through the transport sector, which is one of the most dangerous ones to the atmosphere (International Energy Agency (International Energy Agency, 2021). On the contrary, these direct effects should be weighed against trade benefits in the context of improving the economy for growth and development. For instance, these involve efforts at reducing the adverse direct impacts by promoting low-carbon means of transport, such as electrified shipping and aviation and becoming part of within-country-initiated carbon pricing mechanisms applied in the transportation industry of countries exporting to the importing country (Organization for Economic Cooperation and Development, 2021; WTO, 2022). However, this study is constrained by the model structure and data input to account for the adverse environmental impacts of the AfCFTA.

2.2 AfCFTA and climate change: the context of Ethiopia

AfCFTA will be a landmark initiative for a single continental market of goods and services across Africa, with the free movement of businesspersons and investments. Ethiopia is one of the signatory countries, and this subsection briefly explores the AfCFTA case in Ethiopia. Notably, the deal is likely to advance an expansion of trade by eliminating tariffs and other barriers to trade, thus increasing market access for goods and services in Ethiopia. According to the ECA and ATPC and Center (2024), the AfCFTA could increase intra-African trade by over 50% by 2040. This implies an increase in exports, especially in manufacturing and agriculture, for Ethiopia, where both are crucial sectors of the economy.

AfCFTA pushes Ethiopia toward industrialization. It is because of this that its contribution to the deal can come up with value-added industries that will make the country break the cycle of a mono-economy wherein it relies too much on exporting agriculture-based products (African Union Commission/Organization for Economic Cooperation and Development, 2022; Fusacchia, Balié, & Salvatici, 2022; Stuart, 2022). Therefore, it will be able to leverage AfCFTA to FDI in manufacturing and accelerate its industrial development strategy to ensure that it becomes a middle-income country by 2025 (African Development Bank, 2024). It is sagacious to observe that the cost reductions in trade integration into a larger market are pivotal to the aspirations of making Ethiopia a manufacturing hub in Africa.

On the downside, however, some impediments are standing in the way of growth in the industrial sector in Ethiopia, which has primarily been less competitive owing to infrastructural bottlenecks, energy constraints, and logistical challenges (Ciuriak, 2010; FDRE Ministry of Industry, 2021; Gebreeyesus, 2013; Gebrehiwot, Gebreeyesus, & Weldesilassie, 2020; Luther et al., 2009; Oqubay, 2019; UNDP, 2023). The World Bank (2024a) emphasized that unless seriously overhauled, these areas will make it challenging for Ethiopian manufacturers to leave a mark on the more entrenched industries of other African countries. Added to this is the risk of trade diversion and pressure on local industries from competing with imports from more competitive markets in the AfCFTA. In fact, according to several studies (Abrego et al., 2019; ECA, ATPC, the Centre for International Research, & (CIREM(CEPII)), 2021; ECA and ATPC

& Center, 2024; World Bank, 2020), this risk must be cautiously managed.

On the contrary, Ethiopia is among those that are most vulnerable to climate change because agriculture heavily relies on rainfall for most of its GDP contributions and the involvement of most people in the sector (Admassie & Abebaw, 2021; Bouteska & Abedin, 2024; Conway & Schipper, 2011). Moreover, the topography of the nation greatly varies across climatic zones, making it vulnerable to almost all forms of climate-related impacts (Shukla et al., 2021). Climate change is already contributing to the decline in agricultural productivity in Ethiopia. Such a situation has translated into decreased crop yields owing to increasing average temperatures, erratic rainfall patterns, and the increasing frequency of extreme weather events. The International Food Policy Research Institute (Robinson et al., 2013) estimated that potential climate change in Ethiopia may cut as much as 10% of the GDP before 2050, increasing food insecurity and poverty.

AfCFTA and climate change interactions in Ethiopia echo the opportunities and challenges. AfCFTA trade opportunities may provide economic means and technological transfers to help Ethiopia better adapt to and mitigate climate change. For instance, all the revenues gathered from the increase in trade flows can be absorbed with climatically resilient infrastructure, sustainable agricultural practices, and renewable energy development. As envisaged under the AfCFTA, regional cooperation can promote Ethiopia's capacity to develop climate adaptation strategies by sharing technologies and knowledge (African Union, 2024).

On the contrary, climate change may be one of those scenarios in which Ethiopia cannot maximize the benefits of the AfCFTA. For instance, climate-related disruptive events on agricultural production will have negative implications for the export potential of leading commodities such as Coffee, Sesame and oil crops, which are sensitive to the climate. In addition, in the absence of effective adaptation measures, the associated economic gains anticipated from the AfCFTA could be delayed by losses owing to changes in climate, especially those derived from agriculture and other water-related sectors.

Despite numerous studies on the impacts of climate change and available adaptation choices, the role of trade in mitigation has not been given much emphasis. Under the AfCFTA, trade can play a huge role in lessening the burden of climate change. Indeed, AfCFTA is predicted to increase intra-African trade by 30%–80% (Abrego et al., 2019; ECA et al., 2021; Saygili, Peters, & Knebel, 2018; World Bank, 2020) with economic gains of additional income of approximately 7% by 2035 (World Bank, 2020). Labor will be sectorally reallocated from agriculture to manufacturing and services, with different overall effects across countries and sectors.

A number of studies have explored the impacts of climate change on the Ethiopian economy, highlighting significant challenges across sectors. Using the Ricardian approach, Deressa and Hassan (2009) estimated net crop revenue losses of 15.4% by 2050 and over 100% by 2100 under a PCM scenario, indicating severe seasonal and agroecological vulnerabilities. The World Bank (2008) simulated historical climate shocks using a stochastic dynamic CGE model and predicted that the worst-case scenario would result in a 46% reduction in GDP. Similarly, Robinson, Willenbockel, and Strzepek (2012) projected that GDP will be 10% lower by 2050 using a dynamic CGE model without external adaptive funding. In addition, water constraints and flood damage (You & Ringler, 2010) resulted in substantial economic impacts. Moreover, Gebreegziabher et al. (2016) combined the Ricardian approach with CGE simulations and estimated that agricultural productivity will decline by 30% over 50 years. Other regional studies, such as those by Bezabih and Stage (2010) on Tanzania, indicated that although impacts in the early period are relatively moderate, long-term impacts may be devastating and highlight the need for adaptation strategies. These findings highlight the dire need for comprehensive mitigation and adaptation mechanisms in the Ethiopian climate-vulnerable economy.

To fully mitigate the impacts of climate change, complementary policies focusing on climate-smart agriculture, irrigation expansion, and investment in agricultural technology are essential. In modeling adaptations, Yalew et al. (2017) investigated the cost of planned adaptation in Ethiopia, calling for more proactive government policy to enhance agricultural resilience using a CGE model. Solomon et al. (2021) used a recursive dynamic CGE model to investigate the adverse impacts of climate change on various sectors and regions, with the highest sector loss by 2050. Aragie and Gebretsadik (2023) projected the far-reaching impacts and pressures of climate change variations on catchment water flow and energy outputs in agriculture, which have significant effects on the agriculture sector and poor rural households. In a different setup, Aragie (2013) examined the impacts of climate change on the agricultural sector of Ethiopia, employing time-series econometric analysis using data from national and regional sources to establish a relationship between rainfall variability and agricultural output. A simulation to forecast future impacts reveals that owing to declining rainfall, Ethiopia has already lost more than 13% of its agricultural output. Potential future losses could increase to over 6% per year if trends continue. Their study shows that through lowered agricultural productivity, climate change increases poverty and thus requires considerable adaptation measures.

Although interest has been growing in the economic impacts of trade liberalization and climate change, little work has focused on how the combined impact affects the Ethiopian economy. For instance, Kahsay, Kuik, Brouwer, and van der Zaag (2018) examined this relationship within the larger Nile Basin context using a multisector CGE model within the GTAP-W framework. Their findings indicate that trade liberalization promotes economic growth and welfare improvement. However, water conservation is negligible, whereas climate change is a complex problem influencing positive and negative water availability changes. Most of these studies focus on a single resource, such as water, without deeply investigating the broader economy of Ethiopia or the dual challenges/interplays of trade reforms and climate shocks.

Most of the earlier studies focused on the independent impacts of climate change on Ethiopia and less likely focused on how trade liberalization may interact with these climate-induced effects. While ample documentation on what rising temperatures and unpredictable rainfall patterns portend for agriculture exists, analyses regarding how trade policies could further exacerbate or mitigate these challenges remain scarce. Given the agriculture-based economy of Ethiopia, the increasing thrust on regional and global market integration calls for an understanding of the interplay between these drivers and the country's economic resilience.

This study applies a multisectoral CGE model to comprehensively study the nexus between climate change and trade liberalization in an Ethiopian context to address the gaps. It does this by providing insights into how these two forces jointly impinge on key sectors, household welfare, and overall economic performance. Moreover, this study attempted to identify pathways for policy intervention that can offer recommendations toward a balance of trade-driven growth in climate shock. This approach addresses a critical knowledge gap and contributes to developing integrated policies that align economic development with environmental sustainability.

3 Methodology

3.1 The recursive dynamic model and its calibration

This study employs the recursive dynamic CGE model developed by the International Food Policy Research Institute (IFPRI) to analyze the economic dynamics of Ethiopia. The model is structured to operate in discrete time periods, allowing for the gradual simulation of the effects of any shocks and policy changes. Each time period or year reflects the adjustments made by different sectors and households, permitting a detailed examination of their interactions over time. This recursive dynamic framework provides a robust mechanism for projecting future economic scenarios based on prevailing trends, thereby enabling the evaluation of long-term impacts of key agricultural, trade, and climate change policies. By utilizing this comprehensive approach, the study aims to offer insights into the interplay between the economic drivers contributing to the development of effective strategies for sustainable economic growth in Ethiopia.

The recursive dynamic CGE model captures the economy-wide impact of climate-induced agricultural production shocks. The model is annually solved with the initial year of 2018 through 2035. However, the shock began in 2021, the year when AfCFTA liberalization started and was gradually implemented. The base year started in 2021, and it was integrated with the AfCFTA implementation. The model is annually solved by capturing the dynamic path for each year and modifying the capital stock for each period because of depreciation and investment. In addition, the new values for the capital stocks are used in the solution for the subsequent year. New capital is distributed among sectors based on each sector's initial share of aggregate capital income. Furthermore, population size and growth rates of the labor supply are updated from 1 year to the next. The population growth rate updates the total labor supply, i.e., as the population grows, the total labor supply increases at the same rate.

Climate change is the baseline in this analysis. Once the base is calibrated, shocks are introduced. Climate change-induced productivity change is introduced as a crop-level productivity shock, and the macro and sectoral impacts on the Ethiopian economy are assessed. Productivity change is simulated at the baseline, and tariff liberalization is implemented as the AfCFTA proceeds. The national tariff offer is used to determine the liberalization rate and schedule. National trade facilitation proceeds with tariff liberalization as an iceberg trade cost reduction. However, to compare the simulated impact as a difference across the simulations, a separate simulation from the baseline is computed and reported as percentage changes. The AfCFTA impacts are on top of the climate change-affected base economy. Therefore, our results indicate the impacts of climate-induced productivity change and AfCFTA implementation.
Activities and commodities have a one-to-one mapping based on a concordance between the International Standard Industrial Classification of All Economic Activities industries and HS Version 2012 products (Aragie & Thurlow, 2021). For our application of trade liberalization, the rest of the world is divided into ROA and ROW using different national reports and the IMF balance of payment data. For instance, the Comtrade export and import data are used to allocate total exports and imports to the ROA and ROW. The rest of Africa (ROA) and the rest of the world (ROW) transact with the domestic economy via imports, exports, and capital flows. The imperfect substitution between domestic and foreign varieties is modeled within the Armington framework. Many studies have shown that reduced trade costs owing to improved port handling of goods, fast and transparent customs procedures and standard inspections, cheap document requirements, reduced transportation costs, and improved communication/information technologies can have significant economic and welfare effects. Wilson, Mann, and Otsuki (2004) used classified country-level indicators of port efficiency, customs and regulatory environments, and e-business usage. They found that port-efficient management has a higher impact than customs and e-business in the Asia Pacific Economic Cooperation countries. The fact that trade transaction costs can be as much as 15% of the value of shipment suggests that reducing such costs can raise trade volumes and GDP, similar to the effect of reducing tariffs (Organization for Economic Co-operation and Development, 2003). As a transport margin paid by each producing activity, the trade costs are calculated based on the transaction values of

their purchases. These sectoral transport margins are then included in the formation of the domestic sales price. Changes in transport margins directly impact the domestic sales prices, which influence all other prices, owing to their interconnected nature. As sectoral prices fluctuate, resources are reallocated across different production activities. AVEs of the World Bank Doing Business time to trade are used (Wassie, Kornher, & Zaki, 2024). The cost is simulated as a trade margin reduction in an updated product and country-level AVE computation for Ethiopia.

3.2 The analytical model

The equations comprising the dynamic CGE model are a system of simultaneous, nonlinear equations that express the economic system [1] (Diao, Thurlow, Benin, & Fan, 2012; Lofgren, Harris, & Robinson, 2002). The model uses the number of simultaneous equations that represent the economy. The model is based on the International Food Policy Research Institute's standard CGE model with a nested constant elasticity of substitution/transformation (CES/CET) in the production function. The production process begins with the combination of capital, skilled labor, unskilled labor, and land, which are partially interchangeable, to generate value added using a Cobb–Douglas production function. A Leontief-type production function generates the gross domestic product, combining value-added and intermediate inputs. Subsequently, this output is transformed into composite exports and domestic goods using a CET production function. The composite exports are converted into exports to each destination country (region) using another CET function. Similarly, imports from different source countries are combined with domestic goods to create composite imports. Composite imports and domestic goods are then combined to form composite goods using Armington (1969) approach. Throughout these aggregation processes, a CES function is assumed.

Households maximize the utility derived from consumption that is subject to budget constraints. Their income is derived from factor payments, such as wages, rents, transfers, and government subsidies. Savings are endogenously determined as the

[1] The details of the assumptions and structures of the model are presented in the appendix.

difference between disposable income and consumption. Firms maximize profits by employing factors such as production labor and capital to produce goods. Production decisions are represented using nested CES production functions, wherein the intermediate and value-added inputs are combined at the top level and the factors are combined at the lower level. The government imposes taxes equivalent to direct, indirect, import, and export taxes and pays transfers, and supplies public goods. The government's savings are a residual between revenues and expenditures. Each household's demand for good consumption, government purchases, investment, and intermediate use equals supply (domestic production and imports). With respect to factor markets, wages and rents are adjusted to equate the demand and supply of labor and capital. Changes in factor supply are modeled to occur across sectors dynamically. The basic block of equations for the model is presented in the appendix. **Major block of equations**

Income Equations Income can be categorized into two types. The first type comprises payments to factor accounts for the services provided to various activities, which represents the domestic value added. The second type comprises payments made to domestic factors utilized overseas, whose value is fixed in foreign currency terms. Thus, factor incomes (YF) are defined as the total income factors received across all activities:

$$YF_f = \sum_{a \in A} WF_f \cdot \overline{WFDIST}_{fa} \cdot QF_{fa}$$

where:

$$\begin{aligned} YF_f &= \text{income of factor } f. \\ WF_f &= \text{average price of factor } f. \\ \overline{WFDIST}_{fa} &= \text{wage distortion factor for factor } f \text{ in activity } a. \\ QF_{fa} &= \text{quantity demanded of factor } f \text{ from activity } a. \end{aligned}$$

The Income Equations section outlines the factor payments within the economy and how they are distributed among households and other entities, such as tax contributions, savings, remittances, and other international transactions. In this framework, households primarily derive their income from labor, dividends, transfers among household members, government assistance, and remittances:

$\mathrm{YI}_i = \sum_{f \in F} YIF_{if} + \sum_{i' \in INSDNG'} TRII_{ii'} + trnsfr_{i,gov} \cdot \overline{CPI} + trnsfr_{i,row} \cdot EXR$

[Income of institution i] = [factor income] + [transfer from other domestic nongovernment institution] + [transfer from government] + [transfer from ROW]

where:

$$\begin{aligned} YI_i &= \text{income of households.} \\ YIF_{if} &= \text{income to domestic institution } i \text{ from factor } f. \\ TRII_{ii'} &= \text{transfers from the government to households.} \\ trnsfr_{i,gov} &= \text{transfer from the government to households.} \\ trnsfr_{i,row} &= \text{transfer from the rest of the world (ROW) to households.} \\ \overline{CPI} &= \text{consumer price index.} \\ EXR &= \text{exchange rate.} \end{aligned}$$

Household Consumption Expenditure

In addition, the production segment established equilibrium imports within the dynamic model. Given that imports are intermediate inputs, increasing wages results in a significant reliance on imports because companies opt to replace labor with imported goods. The conditions for achieving cost minimization, considering the two pricing factors and subject to the Armington function alongside a set quantity of the composite commodity, produce the subsequent import-to-domestic demand ratio:

$\mathrm{EH}_h = (1 - \sum_{i \in INSDNG} shii_{ih}) \cdot (1 - MPS_h) \cdot (1 - TINS_h) \cdot YI_h, \quad h \in H$

(household income disposable for consumption) = f (household income, net of direct taxes, savings, and transfers to other nongovernment institutions

where:

$$EH_h = \text{household consumption expenditures.}$$
$$shii_{ih} = \text{share of net income of } i' \text{ with } i \quad (i' \in INSDNG'; i \in INSDNG).$$
$$MPS_h = \text{marginal propensity to save for households.}$$
$$TINS_h = \text{direct tax rate for institution } i \quad (i \in INSDNG).$$
$$YI_h = \text{income of institution } i \quad \text{(in the set INSDNG).}$$

Trade Block Equations

Import

In addition, the production segment established equilibrium imports within the dynamic model. Given that imports are intermediate inputs, increasing wages results in a significant reliance on imports because companies opt to replace labor with imported goods. The conditions for achieving cost minimization, considering the two pricing factors and subject to the Armington function alongside a set quantity of the composite commodity, produce the subsequent import-to-domestic demand ratio:

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1-\delta_c^q} \right)^{\frac{1}{1+\rho_c^q}}$$

(Import-to-domestic demand ratio) = f (domestic demand-to-import price ratio)

where PDD$_c andPM_c$

are import and domestic output prices, respectively. The equation defines the optimal mix between imports and domestic output. Thus, its domain is limited to imports with domestic production. The equation ensures that an increase in the domestic demand-to-import price ratio generates an increase in the import-to-domestic demand ratio, resulting in a shift away from the source that becomes more expensive.

Exports

Ethiopia, which has an insignificant global trade impact, acts as a price taker in its export markets. The volume of exports is sensitive to changes in the relative prices of these exports. Consequently, fluctuations in global economic growth can influence export levels by affecting foreign export prices. Other factors that impact export supply are production input prices, wages, and import costs. A decrease in wages and import prices usually increases export supply. The following equation establishes the best balance between exports and domestic sales. When the ratio of export to domestic prices increases, it leads to a higher export-to-domestic supply ratio, shifting toward markets that provide great returns:

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \cdot \frac{1-\delta_c^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t - 1}}$$

(export-to-domestic supply ratio) = f (export-to-domestic price ratio)
where:

$$PE_c and PDS_c$$

are the export and domestic prices, respectively. This equation constitutes the first-order conditions for the maximization of producer revenues given the two prices and is subject to the CET function and a fixed quantity of domestic output. The equation ensures that an increase in the export-to-domestic price ratio results in an increase in the export-to-domestic supply ratio.

This study examines the effects of changing precipitation and temperature on crop productivity. First, we used the estimated shock by Waldhoff et al. (2020) [2], which is particularly effective for evaluating how climate change impacts alternative emission scenarios at the product, year, and country levels. In addition, Waldhoff et al. (2020) used the empirical modeling approach to estimate the impacts of climate change on agricultural yields in different countries and various crops, according to representative concentration pathways (RCP) [3] 4.5 and 8.5—the medium and high greenhouse

[2]The study uses empirical modeling to estimate crop yield responses to climate variables at the country level. Historical yield and weather data are used, incorporating temperature, precipitation, and economic controls in the estimation. Future yield projections are derived by integrating these models with Earth System Model (ESM) simulations under RCP 4.5 (moderate warming) and RCP 8.5 (high warming) scenarios.

[3]RCP4.5 and RCP8.5 refer to Representative Concentration Pathways (RCPs) used in climate model-

gas concentration scenarios. The methodology builds up a set of reduced-form statistical models that estimate crop supplies using historical data for yields and weather patterns (temperature and precipitation). The country-specific crop yield responses of the model are linked to ESM outputs to project future impacts under the RCP 4.5 and 8.5 scenarios. For instance, yield losses for maize are projected to decrease by no more than 30% in RCP 8.5 within certain regions by the end of the 21st century, whereas in RCP 4.5, yield losses may be lower (approximately 10%–20%). Such projections are indispensable for integrating into integrated assessment models to study broader economic and food security impacts.

TFP (alphava in the CGE model) was used for the simulation shock as the efficiency loss of the climate change simulation. TFP is the portion of output that cannot be explained by the number of inputs used in production. Hence, the CES activity production function (alpha) shift parameter is used for the simulations, as shown in the following aggregate value-added production function. The equation states that, for each activity, the quantity of value added is a CES function of the disaggregated factor quantities. The implementation of the productivity shock is in the following equations on alpha for the agriculture sector:

$$QVA_a = \alpha_a^{va} \left(\sum_{f \in F} \delta_{fa}^{va} QF_{fa}^{-\rho_a^{va}} \right)^{\frac{1}{\rho_a^{va}}}$$

(Quantity of aggregate value added) = (CES factor inputs)

ing to project greenhouse gas emissions and their impact on the climate. RCP4.5 represents a moderate scenario in which global efforts stabilize emissions by 2100, resulting in a radiative forcing of 4.5 watts per square meter.
In contrast, RCP8.5 is a high-emission scenario characterized by minimal climate mitigation efforts, leading to a radiative forcing of 8.5 watts per square meter by the end of the century (IPCC, 2014). These scenarios are widely used for economic and environmental assessments to understand potential climate impacts and policy responses.

where:

$$F = \text{set of factors.}$$

$$\alpha_a^{va} = \text{efficiency parameter in the CES value-added function.}$$

$$\delta_{fa}^{va} = \text{CES value-added function share parameter for factor } f \text{ in activity } a.$$

$$QF_{fa} = \text{quantity demanded of factor } f \text{ from activity } a.$$

$$-\rho_a^{va} = \text{CES value-added function exponent.}$$

The CGE model allows us to analyze welfare measures by tracking changes in key indicators such as consumer surplus, real income, equivalent variations (EV), and distributional outcomes across households and factors of production (Gohin, 2005; Robichaud, 2001; Robson, Wijayaratna, & Dixit, 2018). These measures allow us to simulate how policy reforms, in our case, trade liberalization and climate change, affect the overall well-being of a household and the economy. A CGE model assures all markets (labor, goods, capital markets) are balanced and that total savings equal total investment. The model assures consistency between supply and demand throughout the economy (Lofgren et al., 2002). This closure ensures that all income (wages, profits, taxes, etc.) is either spent or saved and that the balance of payments is kept, making the model invaluable for evaluating the full macroeconomic impact of policy changes.

Consumer surplus is the difference between consumers' willingness to pay for a good or service and what they actually pay. For instance, it can be an indicator of the benefits that consumers derive from market transactions. In a CGE model, changes in consumer surplus can be considered as an assessment of changes in prices driven by policy reforms or market shocks that impact the welfare of households. For instance, trade liberalization, which involves tariff cuts, usually implies that price levels decline and the consumers' surplus increases, which can be reflected in their increased welfare.

The real income measure is another relevant welfare indicator. It covers the purchasing power of households over time, reflecting price changes. Under a CGE model, real income would be subject to wage, profit, and price variations across sectors. The model captures the interaction of the factor markets—land, labor, and capital product markets; thus, studying the impacts of policies on the prices and services in a household is possible. For instance, trade liberalization can raise real incomes either through efficiency gains in the production process or because of the drop in the price of imports. EV measures the amount of income that households would need to receive before the policy change to achieve the same level of utility that they experience after the policy change. It reflects the welfare gains or losses associated with a policy reform or economic shock by comparing the utility levels between the initial and new equilibria.

This equilibrium condition uniquely positions the CGE framework to accurately model general equilibrium changes diffusing through an economy well beyond the direct effects of reform/shocks. For instance, the AfCFTA cuts tariffs, which directly affect import prices; however, this may also lead to resource reallocation, shift labor markets, and alter capital flow. These, in turn, have repercussions on production and consumption patterns, which manifest in welfare changes.

The CGE model helps capture distributional impacts by disaggregating households across different income groups of 10 income quantiles, thus allowing a full investigation of how different segments of the population are affected by AfCFTA. This is of great significance in any equity assessment of reforms wherein welfare gains or losses are not evenly distributed among households. For instance, AfCFTA may lower the price level for consumers and benefit them, but may hurt specific industries or labor that lose out owing to increased import competition.

The CGE model integrates a series of welfare measures and holds that all markets are in equilibrium at any instant, owing to policy changes or external shocks. Therefore, this presents a well-rounded framework to analyze the economy-wide welfare impacts of trade, fiscal, and environmental policies. In addition, it allows for the capture of direct and indirect effects, whereas important outcomes may be distributional. Therefore, it has become an essential tool for policymakers looking to understand the wide-ranging and long-term consequences that economic reforms may have for social welfare.

3.3 The model closure

The chosen macroeconomic closure rules provide a coherent framework to analyze the dynamic interactions between climate change, trade liberalization, and economic performance in the context of Ethiopia. Equilibrium within a recursive dynamic CGE model is established through a set of macroeconomic closure rules that outline the functioning of the macroeconomy and factor markets. This model offers three distinct scenarios for factor markets: firstly, it assumes that skilled labor and capital are fully employed and linked to specific activities; secondly, it posits that semi-skilled and unskilled labor remains unemployed and can move freely across sectors. Land is treated as fully employed and also mobile among sectors. The effectiveness of CGE models in analyzing various economic events fundamentally hinges on their specification of mechanisms that achieve equilibrium, particularly concerning three key macroeconomic balances: the fiscal balance, the savings-investment balance, and the external trade balance. In the closure rules for this analysis, government savings are allowed to vary. At the same time, the direct tax rate is held constant, indicating that the government finances its deficits through borrowing, with limitations on increasing taxes to support additional public expenditures. For the savings-investment balance, a savings-driven investment closure is implemented, meaning that investment levels adjust endogenously based on the availability of loanable funds. Regarding the external balance, foreign savings are fixed, and the exchange rate is flexible. This suggests that in situations with limited foreign savings, the real exchange rate adjusts by simultaneously curbing import spending and enhancing export earnings.

3.4 Simulation scenarios

The following scenarios were simulated to evaluate the interplay effects of climate change and AfCFTA trade liberalization in Ethiopia. The experiments demonstrate how the AfCFTA implementation will affect the Ethiopian economy in a time of climate-affected agriculture.

Case 1: baseline climate change impact

- Climate change scenario (RCP 4.5): Introduction of TFP shocks owing to climate change under the RCP 4.5 emission scenario.
- Climate change scenario (RCP 8.5): Introduction of TFP shocks owing to climate change under the RCP 8.5 climate scenario.

Case 2: Impact of climate change with trade liberalization

- Climate change 1 and tariff liberalization scenario (RCP 4.5 tariff): TFP shock from the RCP 4.5 scenario and implementing the AfCFTA liberalization. A gradual full liberalization of tariffs for African countries is only implemented based on the actual yearly promised liberalization. Based on the actual offer of the tariff liberalization, the yearly tariff reduction is computed as an average of the offer.
- Climate change 2 and tariff liberalization scenario (RCP 8.5 tariff): TFP shock from the RCP 8.5 scenario and implementation of AfCFTA liberalization measures.
- Climate change 1 and tariff and trade facilitation (RCP 4.5 tariff and TF): Joint implementation of the TFP shock scenario RCP 4.5, AfCFTA liberalization, and trade facilitation. The implementation of AfCFTA has a trade facilitation section that aims to reduce unnecessary trade hassles and barriers, such as border and customs cooperation. From a structural gravity study Wassie et al. (2024), half of 28.5% (14.25%) and 25.2% (12.6%) AVE of the World Bank time to trade for import and export are used in our simulation, which was implemented as a trade margin reduction in the CGE model.
- Climate change 2 and tariff and trade facilitation (RCP 8.5 tariff and TF): Joint implementation of the TFP shock scenario RCP 8.5, AfCFTA liberalization, and trade facilitation. AfCFTA implementation has a trade facilitation section that aims to reduce unnecessary trade hurdles and barriers, such as border and customs cooperation. From a structural gravity study by Wassie et al. (2024), half of the 28.5% and 25.2% AVE of the World Bank time to trade for import and export are used in our simulation, which was implemented as a trade margin reduction in the CGE model.

3.5 Data input and model calibration

The model is calibrated for the initial year 2018 using the Ethiopian SAM, which accounts for all the economy's income and expenditure flows in that year. The Nexus SAM of 2018 has 42 activities, 45 commodities after further disaggregation, and 5 factors of production (Aragie & Thurlow, 2021). In addition, the SAM has different taxes, saving–investment, enterprise, and rest-of-the-world accounts to show the interaction of different economic agents.

This study uses a dynamic CGE model to capture the economy-wide impacts of climate change on agricultural production. The model is a recursive dynamic model, beginning with the base year of 2021 and annually solved through 2035. The model allows the analysis of the path of transitional dynamics toward a new steady state after an initial impact. This means that the model is solved for an individual year, the capital stock is modified for each period because of depreciation and investment, and the new values for the capital stock are used in the solution for the subsequent year. New capital is distributed among sectors based on each sector's initial share of aggregate capital income. In addition, the labour supply's population size and growth rate are updated from 1 year to the next. The total labor supply is updated by the population growth rate, i.e., as the population grows, the total labor supply increases at the same rate.

4 Simulation results

The economy-wide and sectoral effects of climate change-induced shocks to agricultural productivity in Ethiopia highlight the significant economic implications for the agricultural and nonagricultural sectors. The high dependence of Ethiopia on agriculture amplifies the adverse effects of climate change on the broader economy, showing vulnerabilities beyond the agricultural sector. This section explores how the implementation of AfCFTA interacts with these challenges. Our results indicate interactions between the tariff and trade facilitation reforms of AfCFTA and the agricultural productivity shocks induced by climate change under the RCP 4.5 and RCP 8.5 scenarios. The key findings have implications for the impacts of trade policy on trade performance, price adjustment, sectoral resource allocation, and income distribution in the context of a climate-affected Ethiopian economy.

4.1 Economic impacts of AfCFTA with climate change

This section discusses whether the implementation of the AfCFTA can mitigate the negative impacts of climate change in Ethiopia. Two scenarios are used—tariff reductions only and tariff reductions plus trade facilitation—to assess the impacts on GDP, trade, employment, and household welfare. The findings suggest that implementing the AfCFTA can stimulate trade, industrialization, and development through enhanced market access and regional integration. However, the magnitudes of these gains are mitigated by the severity of climate change, especially under RCP 8.5, which results in substantial losses in agricultural productivity.

4.2 Sectoral output impacts: Agriculture vs. Industry and Services

Several factors explain the impacts of changes in output [4]. When import prices decrease in the standard Armington framework, a higher expenditure on imports compared to domestic production is observed across different sectors. Without exports, production overall decreases. However, exports increased owing to real exchange rate depreciation, reduced production cost from low-priced imported intermediate goods, assumed enhancements in trade facilitation for Ethiopian exporters, and improved market access in Africa and globally.

The Ethiopian economic structure, which is heavily reliant on agriculture, makes it particularly vulnerable to the impacts of climate change. However, the AfCFTA enables regional market access, encouraging export diversification and industrial development, particularly in the manufacturing and services sectors. Although agriculture remains a critical component of the economy, it is experiencing negative effects due

[4] These results are tariff liberalization and TF on a climate change base economy. Sectors are aggregated according to the products concordance in the modelling and for a simple presentation purpose.

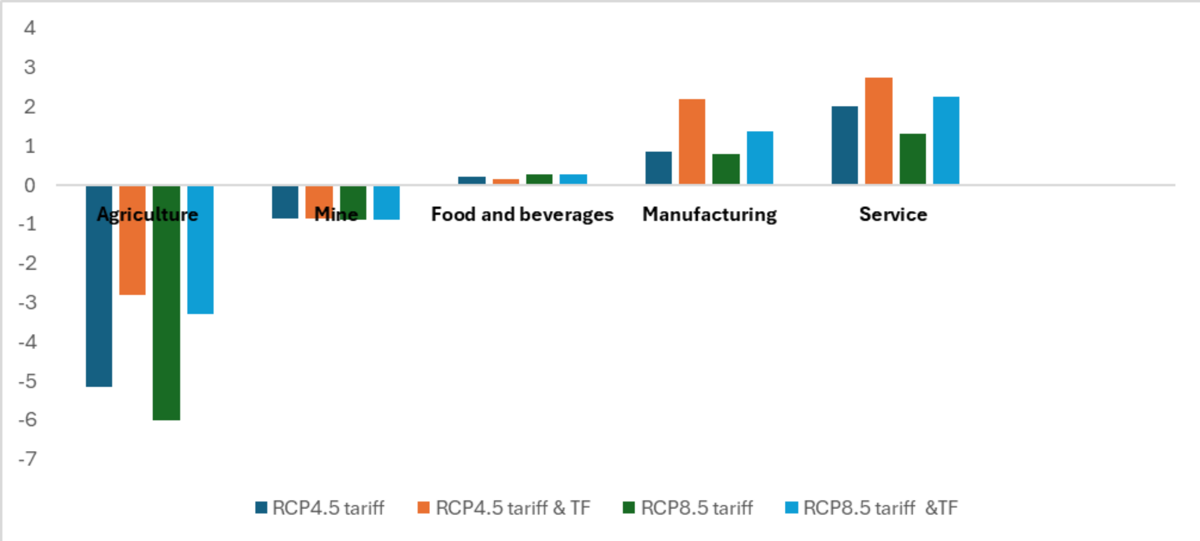

Figure 1: Annual Average Output Impact of AfCFTA Tariff and TF With Climate Change

to climate change, including declines in the output and exports of key agricultural products such as maize, poultry, vegetables, and coffee.

However, the manufacturing and services sectors benefit from increased demand in African markets driven by tariff reductions and TF, as shown in Figure 5.1. Textiles, processed foods, and manufactured products are among the sectors poised for significant growth. This shift helps mitigate losses in agricultural exports, contributing to a gradual improvement in Ethiopia's trade balance over time.

Figure 5.1 presents the sectoral results from implementing the two policy instruments (tariffs and trade facilitation) under two climate scenarios (RCP 4.5 and RCP 8.5). According to the estimates, agriculture suffers the highest loss in all scenarios, with the loss being substantial in the RCP 4.5 and 8.5 scenarios of tariff liberalization. This highlights the vulnerability of Ethiopian agriculture, a major contributor to the country's GDP and employment, to climate change and trade policy. Given the sector's reliance on rain-fed farming and limited adaptive capacity, these results underscore the risks to food security and rural livelihoods. Similarly, while the mining sector is a minor component of Ethiopia's economy, it also has consistent but minor negative impacts, reflecting potential challenges to global competitiveness and resource demand. By contrast, the food and beverage sector has relatively minor impacts, which may indicate resilience, likely owing to its linkage with domestic demand.

On the contrary, the manufacturing sector appears to be largely unaffected, reflecting the country's low level of industrialization and limited exposure to international trade dynamics. Moreover, the service sector shows a positive impact across all scenarios, with more substantial gains under the RCP 4.5 scenarios. This suggests that the service sector, which is becoming increasingly important in the Ethiopian economy, could experience a relative gain from trade facilitation reforms and growing urban demand. Similarly, other service sectors have revealed marginally positive outcomes, supporting the relative robustness of nonclimate-sensitive activities. For Ethiopia, these results underscore the urgent need to address the vulnerabilities of the agriculture sector through targeted investments in climate adaptation measures.

Trade facilitation measures, although beneficial for services, must be designed to enable primary sectors, such as agriculture, to integrate more effectively into value chains and reduce export revenue losses. The muted response from manufacturing highlights the importance of accelerating industrialization and value while diversifying the economy and reducing the dependency on agriculture. Furthermore, the resilience of the service sector suggests an opportunity to leverage urbanization and technological advancements to drive growth.

4.3 Macroeconomic effects

One of the key findings is the differentiated impacts on trade performance under the two climate scenarios of RCP 4.5 and RCP 8.5. Although the implementation of AfCFTA generally boosts Ethiopia's trade volume, the gains are constrained by the severity of agricultural productivity shocks. Under RCP 4.5, with moderate climate shocks, Ethiopia enjoys a modest increase in agricultural exports owing to improved market access and lower trade costs facilitated by the AfCFTA. However, the productivity loss in agriculture under RCP 8.5 significantly diminishes agricultural exports, preventing Ethiopia from fully exploiting its trade benefits. This result suggests that climate change could substantially reduce the trade benefits of regional agreements for economies that rely on the exports of climate-sensitive products, such as agriculture. These results further indicate that Ethiopia's trade balance is shifting toward greater reliance on manufacturing and processed food imports. This highlights the need for supportive policy measures to promote agricultural export diversification and value addition.

As discussed in Chapter 4, climate change has a negative impact on the economy. Figure 5.2 presents the impact of implementing AfCFTA on tariffs and TF according to the RCP 4.5 and RCP 8.5 climate scenarios for key macroeconomic variables in Ethiopia using a CGE model simulation. The results indicate a significant increase in exports and imports under all scenarios, with the combined tariff and trade facilitation scenario under RCP 4.5 exhibiting the highest increase, thereby underscoring the crucial role of improved trade facilitation in enhancing Ethiopia's trade performance despite climate-induced agricultural productivity shocks. In addition, private consumption and fixed investment increased; however, the impacts are more substantial under the RCP 4.5 scenarios than in the RCP 8.5 scenarios, reflecting a better recovery of domestic demand and milder economic shocks under a less severe climate scenario. Aggregate absorption, representing total economic spending, GDP at market prices, and factor cost, shows marginal but positive growth across all scenarios, with more substantial increases if trade facilitation measures are included. These findings suggest that the implementation of AfCFTA, particularly through trade facilitation measures, mitigates the adverse economic effects of climate shocks and promotes economic integration and growth in Ethiopia. However, the magnitude of these gains depends on the level of climate change impacts, as shown by the differences between the RCP 4.5 and RCP 8.5 scenarios. The annual growth rate of detailed sectoral exports exhibits a varied trend over the simulation period. As an economy reliant on rain-fed agriculture, Ethiopia's future sectoral export growth rate is expected to be volatile due to climate change shocks and turbulent trade dynamics. Despite the anticipated boost in intra-African trade with the implementation of the AfCFTA (Appendix to Chapter 5), our simulation results suggest that Ethiopia's export growth rate is limited. Specifically, agricultural products (maize, poultry, and vegetables), coffee, fish, meat, and cattle, as well as food, indicate negative export growth rates. This could be attributed to the increasing impact of climate change on the country's exports. Deressa and Hassan (2009) and Solomon et al. (2021) have suggested that the regressive impact of climate change will intensify in the future.

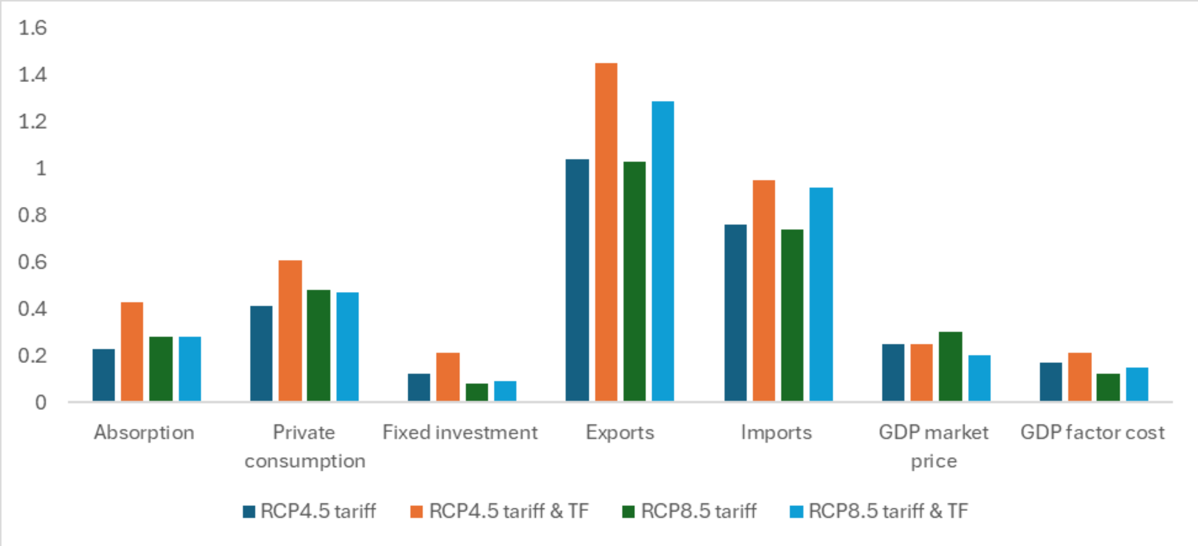

Figure 2: Percentage of Annual Change in Major Economic Variables at the National Level Owing to AfCFTA with Climate Change

In fact, the value of manufacturing output is higher under the AfCFTA in 2035 than under the baseline scenario, and the output of several manufacturing sectors expands at a slower rate than that of other sectors. Similarly, for agriculture, the volume of output for most activities under the combined tariff and TF scenarios by 2035 is higher than under the baseline and lower in the climate change path, whereas for services, the volume is higher under the baseline and AfCFTA, indicating the less vulnerable status of the services sector relative to the agriculture sector.

4.4 Household consumption effects

The household consumption expenditure simulation of the AfCFTA implementation scenarios with tariff and TF measures, across RCP4.5 and RCP8.5 climate scenarios, reveals notable insights into consumption patterns across rural and urban quantiles. The results demonstrate a general increase in household consumption across all quantiles when trade facilitation measures are included, with more pronounced gains under the RCP4.5 scenario. These findings align with previous studies that have highlighted the positive impacts of regional trade agreements and improved TF on household welfare in sub-Saharan Africa.

In rural areas, households in the lowest consumption quantile (quantile 1) exhibit the highest expenditure growth, reaching a 5.95% increase under the RCP4.5 tariff and trade facilitation scenario. This suggests that trade facilitation measures help reduce market inefficiencies and improve access to affordable goods, which benefits poorer rural households disproportionately. Consumption gains gradually decline across higher rural quantiles, with rural quantile 5 seeing only a modest 1.30% increase under the same scenario. This pattern reflects the tendency for lower-income households to experience greater relative improvements in welfare from trade liberalization. Urban households also exhibit positive expenditure changes, though the impact is slightly less pronounced compared to rural households. Urban quantile 1 shows a significant increase of 4.94% under RCP4.5 with trade facilitation, underscoring the importance of AfCFTA in enhancing market access and reducing the cost of living for urban low-income families. Higher urban quantiles experience diminishing consumption gains, with urban quantile 5 registering only a 1.12% increase under RCP4.5 with trade facilitation. Interestingly, the consumption expenditure response is less favorable under the RCP8.5 scenario, particularly without trade facilitation measures, where urban quantile 5 records a negligible 0.30% increase. Our simulation results are consistent with prior studies that emphasize the role of trade agreements in boosting household welfare, particularly in rural regions where market fragmentation and high transportation costs often limit access to affordable goods. The findings also highlight the vulnerability of household consumption patterns to climate risks, as evidenced by the lower growth in expenditure under different scenarios. Trade facilitation measures appear critical for mitigating these climate-related impacts by improving supply chain efficiency and reducing trade costs. Overall, Ethiopia's implementation of AfCFTA, particularly with trade facilitation measures, holds the potential to significantly enhance household consumption and welfare, especially for low-income households.

However, this net effect is highly dependent on sectoral linkages, government policies, and household heterogeneity in terms of income sources and consumption patterns. Prior studies projected consumption gains for Ethiopia to be positive. However, although the World Bank (2020) found a higher rate than the African average, Abrego et al. (2019) found a rate lower than the African average for Ethiopia.

Table 1: Annual average percentage change on household consumption due to afcfta with climate change.

ccccc

	RCP4.5 tariff	RCP4.5 &TF	Tariff	RCP8.5 tariff	RCP8.5 tariff & TF
Rural quantile 1	3.90	5.95		1.91	3.90
Rural quantile 2	2.36	4.36		1.55	2.57
Rural quantile 3	2.39	3.41		1.67	2.67
Rural quantile 4	2.12	2.14		1.33	2.33
Rural quantile 5	0.79	1.30		0.53	0.94
Urban quantile 1	2.39	4.94		1.52	2.85
Urban quantile 2	2.32	3.41		1.15	2.43
Urban quantile 3	1.19	2.26		1.32	1.29
Urban quantile 4	1.10	1.46		1.02	1.20
Urban quantile 5	0.80	1.12		0.30	0.91

4.5 Factor allocation

Our results indicate that unskilled labor benefits significantly from the implementation of AfCFTA, particularly under the RCP4.5 moderate scenario with trade facilitation. The service sector is expected to show the highest allocation of unskilled labor, increasing by over 9% by 2035 under RCP8.5 conditions (Figure 5.3). Agriculture also experiences robust growth, with unskilled labor increasing by approximately 8% under RCP4.5 with trade facilitation. Although the manufacturing sector benefits, the gains are smaller compared to services and agriculture. These trends suggest that the service and agricultural sectors in Ethiopia will become key absorbers of unskilled labor as trade and logistics improve.

For semi-skilled labor, the manufacturing and service sectors are expected to see strong growth across all scenarios. Under RCP8.5 with trade facilitation, the service sector is expected to experience a nearly 7% increase in semi-skilled labor allocation, while manufacturing follows closely with a 6% rise. The agriculture sector shows more modest gains, which are more pronounced under RCP4.5 scenarios. This growth in demand for semi-skilled labor highlights the importance of Ethiopia's manufacturing and service sectors as engines of employment under improved trade conditions. The allocation of skilled labor presents a mixed picture. Under RCP4.5 scenarios, skilled labor allocation remains relatively stable in manufacturing and agriculture but shows negative changes in the service sector, with declines of up to 3% under RCP4.5 with

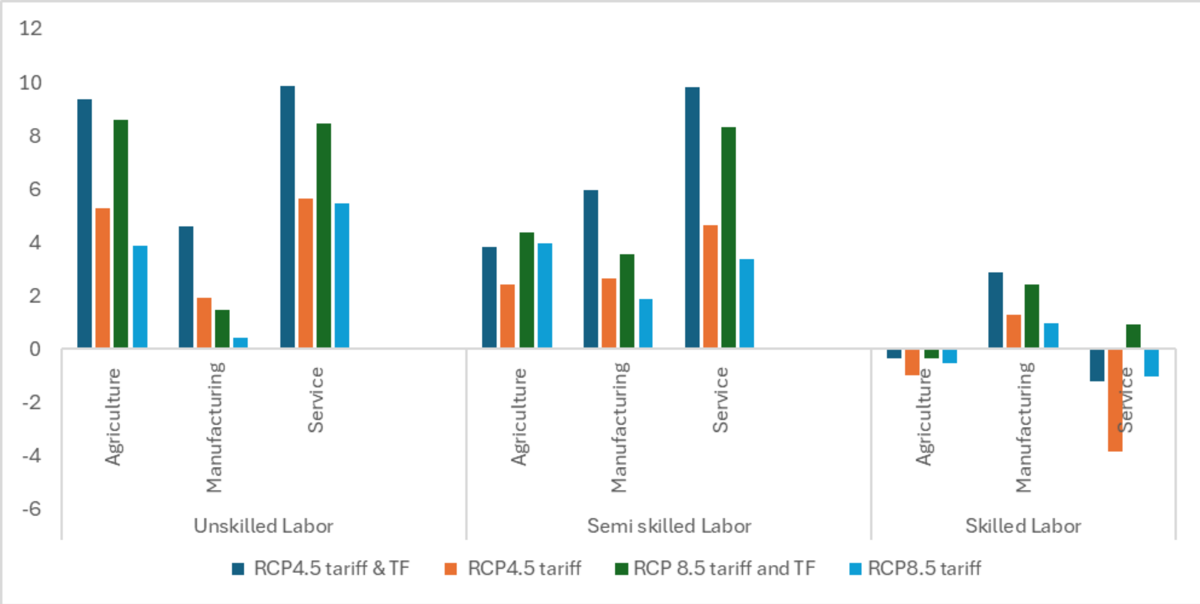

Figure 3: Factor Employment Impacts AfCFTA with Climate Change

trade facilitation. Conversely, RCP8.5 scenarios with trade facilitation show marginal positive increases in skilled labor allocation for manufacturing and agriculture, while the service sector continues to exhibit minor negative shifts. The decline in the service sector's skilled labor allocation may reflect a shift toward less labor-intensive or more automated services. The findings suggest that Ethiopia's implementation of AfCFTA with trade facilitation under varying climate scenarios will have differentiated impacts on labor allocation across skill levels and sectors. The service sector emerges as a dominant absorber of both unskilled and semi-skilled labor, driven by trade expansion and improved logistics. Agriculture continues to play a crucial role in employing unskilled labor, particularly under scenarios with moderate climate impacts. The manufacturing sector shows consistent demand for semi-skilled and skilled labor, reinforcing Ethiopia's ambition to industrialize and participate more actively in regional value chains.

4.6 Price effects

The price simulation results provide significant insights into the potential impacts of AfCFTA implementation under climate change scenarios (RCP4.5 and RCP8.5) on Ethiopia's economy. Sectoral price changes indicate varying outcomes depending on whether trade liberalization is limited to tariff reduction or accompanied by trade facilitation measures. Our findings are particularly important for Ethiopia, where the economy is highly dependent on agriculture and is increasingly focused on growth in the manufacturing and service sectors.

The agricultural sector, which forms the backbone of Ethiopia's economy, exhibits notable price declines under a moderate climate shock scenario (RCP4.5) with tariff-only and trade facilitation measures, suggesting potential supply challenges or increased foreign competition under improved trade conditions. Conversely, under a severe climate shock, such as RCP8.5, agricultural prices rise, possibly due to constrained supply driven by harsher climate impacts. These results highlight the need for climate-resilient agricultural practices and adaptations. On the other hand, the mining sector demonstrates relatively modest price changes across all scenarios, reflecting its resilience and potential to benefit from AfCFTA's tariff liberalization. However, without proper climate adaptation measures, mining operations may face long-term environmental risks, particularly under the more severe RCP8.5 scenario. Meanwhile, the food and beverage sector exhibits modest positive price changes, particularly under RCP8.5 with trade facilitation, indicating enhanced demand and opportunities for trade expansion. Ethiopia's agro-processing industry could benefit from improved logistics and trade efficiencies, provided climate risks to raw material supply are addressed. The service sector exhibits a strong and positive response across all scenarios, particularly with trade facilitation measures under RCP8.5, underscoring the potential for Ethiopia's digital economy and logistics services to thrive under liberalized trade conditions and enhanced infrastructure. Furthermore, the price increases in the manufacturing sector are notable when trade facilitation measures are implemented, particularly under the RCP8.5 scenario. This underscores the importance of complementary actions in logistics and regional value chain integration to enhance Ethiopia's competitiveness as a manufacturing hub. In brief, the findings highlight several key economic

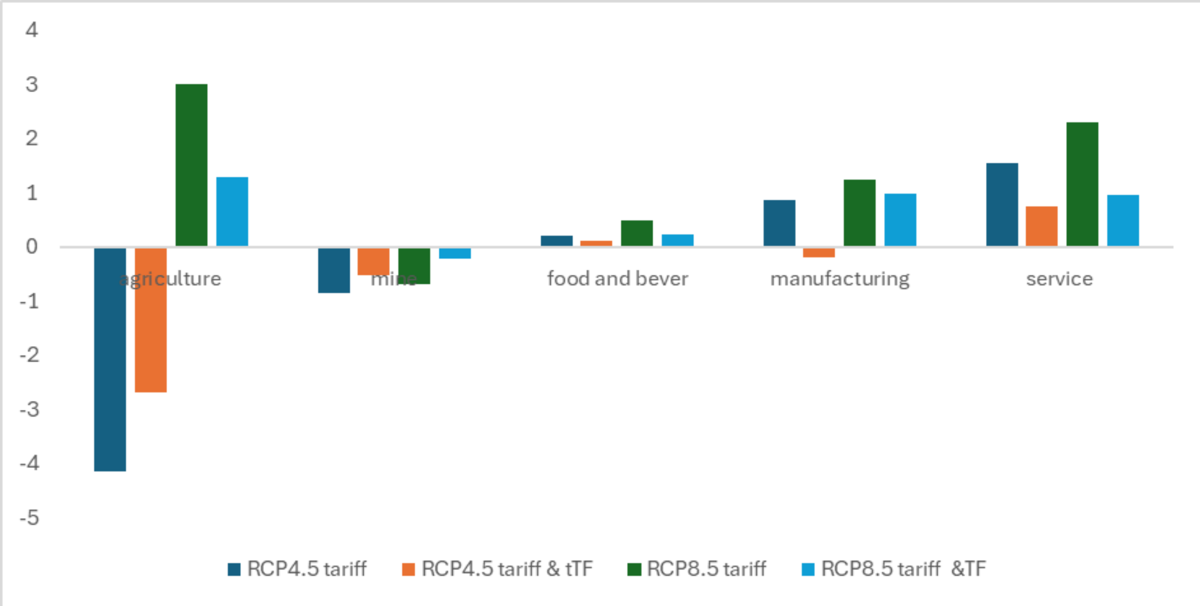

Figure 4: Price effects of the AfCFTA with climate change

implications for Ethiopia. Climate resilience must be a top priority, particularly for the agricultural sector, where adverse impacts and price volatility are most apparent, and its implications for food security are of great importance. Investments in trade facilitation infrastructure and customs efficiency are crucial to maximizing the benefits of the AfCFTA across all sectors. Tailored support policies should be developed to bolster vulnerable sectors, such as agriculture, while fostering growth in manufacturing and services.

5 Discussion of results

The successful implementation of the AfCFTA is expected to have positive economic and welfare effects on Africa as a whole, as well as for Ethiopia in particular (Simola et al. (2021); Fofack, Dzene, and Hussein (2021); World Bank (2020); Abrego et al. (2019); ECA and ATPC and Center (2024)). If successfully implemented, Ethiopia's real income gains from tariff and nontariff measures, including TF, will exceed the African average (World Bank (2020)). Thus, the AfCFTA will have a counterbalancing effect on the negative impacts of climate change. Our simulation results indicate mixed net macroeconomic and sectoral impacts on tariff-only liberalization and a net positive impact on TF implementation under climate change scenarios. The indirect effects of climate change on the macroeconomy, non-agricultural economic activities, and household consumption become relatively minor in the scenario of RCP 4.5 emissions.

The AfCFTA, by eliminating tariffs and reducing non-tariff barriers (NTBs), will enable Ethiopia to access large regional markets. This creates opportunities for export diversification and industrial development (World Bank (2020)). Although agriculture remains critical, the industrial and service sectors benefit from increased demand from other African countries, driving GDP growth and compensating for the negative impacts on agriculture resulting from climate change. With reduced tariffs and TF, Ethiopia will experience a significant increase in exports to African markets. Manufactured goods, textiles, and food processing benefit most from the tariff reductions. This helps to mitigate the decline in traditional agricultural exports caused by climate change, improving the trade balance over time. Moreover, AfCFTA creates new employment opportunities, particularly in industries and services, partially offsetting agricultural job losses. Expanding regional trade promotes job creation in transportation and various industries, thereby improving household welfare in both urban and rural areas. Although climate change severely reduces incomes in poor rural and urban areas, the increased economic activity spurred by the AfCFTA helps raise incomes in non-agricultural sectors, thereby dampening the negative impacts.

Diversification of activities in implementing the AfCFTA stimulates growth in sectors less vulnerable to climate risks, such as manufacturing and services. However, the agricultural sector, which employs a large portion of the Ethiopian population, mainly rural households, remains vulnerable to the negative effects of climate change. While diversification into industry is essential for long-term resilience, short-term impacts on food security and rural livelihoods may persist without targeted climate adaptation measures. The effectiveness of the AfCFTA in overcoming climate-induced economic shocks also depends on the overall resilience of other African countries to climate change. If neighboring countries face similar climate challenges, regional markets may not be as robust in absorbing Ethiopian exports. This underscores the need for broader climate adaptation strategies across the continent to ensure that the trade gains of AfCFTA are not undermined by climate change, which requires a significant and continent-wide modeling that addresses the climate adaptation options. This is beyond the scope of this dissertation, and future studies should address this limitation.

For AfCFTA to fully mitigate the impacts of climate change, complementary policies focusing on climate-smart agriculture, irrigation expansion, and investment in agricultural technology are essential. Yalew et al. (2017) simulated various alternative adaptation options and assessed the effectiveness of the government in this context. However, modeling such alternative adaptation mechanisms is beyond the scope of this study. These measures will make the country less vulnerable to climate risks and enable it to fully capitalize on the new market opportunities presented by the AfCFTA, thereby achieving more balanced and inclusive economic growth. Although specific mechanisms of adaptation have not been modeled in this study, broader debates about funding climate adaptation, such as those highlighted during recent COP29 negotiations, underscore the growing impetus for urgency in climate adaptation financing, particularly in developing nations like Ethiopia, which face disproportionate climate risks despite making minimal contributions to global emissions. For instance, Yalew et al. (2017) discussed the potential of alternative adaptation options, such as state-led adaptation programs, to be generally more effective.

Integration into CGE modeling entails significant scenario development and data inputs that extend beyond the scope of this study. However, recognizing the role of climate policy in trade-related analyses is important. Climate adaptation funding, through programs such as the Green Climate Fund or regional initiatives, can directly support the implementation of complementary policies that will allow Ethiopia to thrive under the AfCFTA. The AfCFTA is likely to increase regional output by enhancing competition and prompting countries to specialize in sectors where they have a comparative advantage. However, as Winters, McCulloch, and McKay (2004) noted, trade liberalization is also a process of creating winners and losers.

Less competitive sectors are likely to experience declines in production, whereas more advantageous sectors grow. In Ethiopia, agriculture and manufacturing are expected to experience modest declines in output relative to the baseline by 2035, ranging from -5% to 1.3% and -0.18% to 1.38%, respectively. Similarly, mining output may decline by

0.8%, whereas services, processed foods, and beverages may increase slightly (World Bank, 2020). The AfCFTA will view East African economies as regional aggregates, specializing in agricultural and service products. Nevertheless, these must be combined with climate adaptation mechanisms to avoid setbacks caused by specific climate shocks that may occur within the agricultural sector. Without this intervention, the advantages accruable from trade liberalization will be outweighed by the negative effects of climate change on output and availability. Targeted adaptation investments may yield enormous opportunities for Ethiopia and other East African economies via sustainable land management, crop diversification, and water resource management (World Bank, 2024b).

Furthermore, this gap could be bridged through international climate finance and mechanisms for technology transfer, which could be elaborated upon within the context of COP29. In fact, the integration of climate policy considerations into trade frameworks will continue to be at the heart of how AfCFTA catalyzes sustainable and inclusive growth across the region.

6 Implications for food security and poverty

Trade plays a crucial role in mitigating the adverse effects of climate change on poverty and food security in general and in Ethiopia in particular. While climate variability disrupts agricultural production, trade serves as a stabilizing mechanism by facilitating access to food supplies, diversifying income sources, and enhancing economic resilience. Given Ethiopia's heavy reliance on rain-fed agriculture, climate-induced yield declines pose a direct threat to rural livelihoods and national food security. However, strategic trade policies and market integration can alleviate these pressures by ensuring food availability, stabilizing prices, and generating alternative employment opportunities.

The findings of this study suggest that expanding export markets and enhancing trade logistics through the AfCFTA can help mitigate climate-induced agricultural losses. By leveraging the AfCFTA, Ethiopia can offset domestic production shortfalls through imports while sustaining foreign exchange earnings through diversified exports. This approach reduces the vulnerability of both producers and consumers to climate shocks, preventing sharp fluctuations in food supply and prices. Furthermore, trade-driven investments in agricultural technology, infrastructure, and value chain development can enhance productivity and strengthen food security by reducing post-harvest losses and improving distribution efficiency. The AfCFTA further amplifies Ethiopia's ability to use trade as a climate adaptation tool. The agreement is expected to boost income by up to 9% for Ethiopia and lift as many as 30 million people out of extreme poverty in Africa by 2035 (World Bank, 2020). Given Ethiopia's agrarian economy, reductions in non-tariff barriers and increased intra-African agricultural trade under the AfCFTA could significantly enhance food security (ECA et al., 2021). The agreement is projected to drive a 20% to 30% increase in intra-African trade in agricultural and food products, ensuring greater availability of staple goods even in times of climate-induced production shortfalls.

At the household level, increased trade openness provides access to a wider variety of food products, mitigating the nutritional risks associated with climate-induced crop failures. Additionally, trade-related employment opportunities in non-agricultural sectors help reduce rural poverty by offering alternative income streams to those affected by climate stressors. This study's findings underscore that well-structured trade policies can serve as an adaptation tool, ensuring that climate change does not exacerbate existing socio-economic inequalities.

Despite these advantages, challenges remain in ensuring equitable benefits from trade. Smallholder farmers, who are most vulnerable to climate change, often face barriers in accessing export markets and adapting to shifting trade dynamics. Strengthening institutional support, enhancing trade infrastructure, and promoting inclusive policies are essential to ensure that the benefits of trade-driven climate adaptation are accessible to all segments of the population. By aligning trade strategies with climate resilience efforts, Ethiopia can enhance food security and reduce poverty, transforming climate challenges into economic opportunities.

7 Conclusion

Ethiopia signed the AfCFTA in 2018 and has since been actively participating in negotiations and implementing measures to ensure the beneficial implementation of the agreement. This study aimed to examine the economic impacts of AfCFTA in a climate change-induced shock economy. The AfCFTA tariff liberalization is implemented as full liberalization for African countries, whereas TF is implemented as an iceberg trade cost reduction based on the estimated AVEs of time to trade. Results highlight the multifaceted impacts of AfCFTA liberalization and climate change on its economy. The gradual elimination of tariffs and TF under the AfCFTA would significantly enhance Ethiopian trade, particularly in mining, manufacturing, processed food, textiles, transportation, and financial sectors. On the macroeconomic level, these trade liberalization efforts foster growth in imports and exports, real income, and GDP. GDP is expected to grow at 0.3% and 0.21% in the tariff and TF implementation periods. Rural households in the lowest income quantile (Q1) experience an average consumption increase of 5.95% under the RCP 4.5 scenario with trade facilitation. Urban households in quantile 1 similarly benefit, with a 4.94% increase in consumption. These results indicate that the gains from trade liberalization are pro-poor, helping to reduce vulnerability and improve resilience among the most affected populations. Furthermore, sectoral employment is more focused on unskilled labor in the manufacturing and service sectors. However, the government's tariff revenue loss is moderate, at 11.5 percent of the total revenue.

From a policy perspective, Ethiopia's strategy should focus on leveraging the trade benefits of the AfCFTA to sustain economic growth and enhance resilience against the impacts of climate change. This balanced approach is crucial for achieving long-term economic stability and enhancing the welfare of its growing population. Specifically, the Ethiopian government should strengthen the reduction of tariff and non-tariff barriers to ensure the efficient implementation of AfCFTA, which can amplify the positive effects of the agreement, particularly in enhancing exports and economic integration while offsetting negative climate impacts. It should also accelerate industrialization by fostering value addition in agro-processing and encouraging investment in sectors like textiles, manufacturing, and services. This includes leveraging AfCFTA for regional market access and attracting foreign direct investment (FDI) into priority industries.

Beyond economic growth, the successful implementation of AfCFTA has direct implications for poverty reduction and food security, particularly in light of Ethiopia's vulnerability to climate change. By facilitating regional food trade, reducing trade costs, and improving agricultural supply chains, AfCFTA can help stabilize food markets and ensure greater availability of essential commodities. This is particularly important in rural areas where climate-induced shocks disproportionately impact smallholder farmers and low-income households. The shift of labor from agriculture to manufacturing and services also presents an opportunity to diversify rural incomes, reducing dependency on climate-sensitive agriculture and enhancing economic resilience. Moreover, food security improvements will depend on Ethiopia's ability to align trade policy with climate adaptation strategies, investing in climate-smart agriculture, irrigation, and sustainable farming practices. If properly integrated, trade liberalization under the AfCFTA could enhance Ethiopia's capacity to withstand climate shocks, improve food affordability, and contribute to reducing poverty and malnutrition.

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8 Appendix

1. Theoretical framework of the CGE model

In the following technical description of the dynamic CGE model, the description of the flow of the economic activities in economy is presented with the kind of technology applied in each of the activities. For instance, the top household utility function is presented in Cobb-Douglas function whereas, the Armington function is used in the composite domestic and imported goods aggregation. By the same way, the production function at the top is a Leontief function of intermediate goods and value added.

2. Basic functions of the standard CGE model

1. Price Block

The price block of equations consists of the import price in local currency paid by the domestic users, excluding the sales tax, the export price in local currency received by the domestic producers when they export, and the same as the import price equation but excluding the tax and the cost of trade inputs, domestic price of domestically sold, activity price. The system of equations is differentiated by the assumed quality differences among commodities of different origins and destinations (exports, imports, and domestic outputs used domestically). *1. Domestic Sales Price Equation* PDS_c *:*

$$PDS_c = (1 + tqc) \cdot PX_c \tag{1}$$

where: PDS_c : Supply price of commodity c produced and sold domestically

tqc : Sales tax rate on commodity c

PX_c : Producer price of commodity c

2. Composite Commodity Price PQ_c *:*

$$PQ_c = \left[\alpha_c \cdot (PM_c)^{-\rho_c} + (1 - \alpha_c) \cdot (PD_c)^{-\rho_c}\right]^{-\frac{1}{\rho_c}} \tag{2}$$

PQ_c : Composite commodity price

PM_c : Import price of commodity c

PD_c: Domestic price of commodity c

α_c : Shift parameter for Armington function

ρ_c : Armington function exponent

2. Activity Production Function QA_a

Th four main blocks in the production and trade block are the domestic production and input use; the allocation of domestic output to home consumption, the domestic market, and exports; the aggregation of supply to the domestic market; and the definition of the demand for trade inputs that is generated by the distribution process. Production is based on a perfectly competitive market. Production is carried out by activities that are assumed to maximize profits subject to their technology, taking prices as given. Therefore, the production technology at the top of the nest is either a CES or a Leontief function of the quantities of value-added and aggregate intermediate input use.

$$QA_a = \left[\alpha_{va,a} \cdot (QVA_a)^{\rho_{va,a}} + \sum_{c \in C} \delta_{ac} \cdot (QINT_{c,a})^{\rho_{va,a}}\right]^{\frac{1}{\rho_{va,a}}} \tag{3}$$

QA_a : Level of activity a

QVA_a: Quantity of aggregate value-added

$QINT_{c,a}$: Quantity of intermediate input ccc used in activity a

$\alpha_{va,a}$: Shift parameter for CES production function

δ_{ac} : Share parameter for intermediate input c

$\rho_{va,a}$: CES production function exponent

3. Export Supply Function QE_c

$$QE_c = \alpha_t \cdot \left(\frac{PE_c}{PX_c} \right)^{\rho_t} \tag{4}$$

QE_c : Quantity of exports of commodity c

PE_c : Export price of commodity c

α_t : Shift parameter for CET function

ρ_t : CET function exponent

PX_c : average output price

4. Institution Block

The institution block of equations consists of the domestic nongovernment and governmental institutions and the external or the rest of the world. Factor income, household consumption expenditures on home commodities and marketed commodities, intra-institutional transfers, investments, government income and expenditure. In general, these institutional blocks are households, enterprises, government, and the rest of the world. 1. **Household Consumption Demand** $QH_{c,h}$:

$$QH_{c,h} = \beta_{h,c} \cdot (Y_h - T_h) + \gamma_{h,c} \tag{5}$$

$QH_{c,h}$: Quantity of commodity ccc consumed by household h

$\beta_{h,c}$: Marginal share of consumption spending on commodity c

Y_h : Income of household h

T_h: Taxes paid by household h

$\gamma_{h,c}$: Subsistence consumption of commodity c

2. Government Revenue YG :

$$YG = \sum_{i \in INS} TINS_i \tag{6}$$

YG : Total government revenue

$TINS_i$: Direct taxes collected from institution I including transfers

5. System Constraint Block

1. **Market Equilibrium for Commodity** $COMEQUIL_c$:

$$QD_c + QX_c = QQ_c \tag{7}$$

$COMEQUIL_c$: Composite commodity market equilibrium for commodity c

QD_c : Quantity demanded of commodity c

QX_c : Quantity of domestic output of commodity c

QQ_c : Total quantity supplied to the domestic market 2. **Savings-Investment Balance** $SAVINVBAL$:

$$\sum_{i \in INS} S_i = \sum_{i \in c} QINV_c \tag{8}$$

$SAVINVBAL$: Savings-Investment balance

S_i : Savings by institution i

$QINV_c$: Quantity of investment demand for commodity c

3. Parameter and Variable Descriptions

- $\alpha_a(A)$: Shift parameter for top-level CES function for activity A
- $\alpha_{ac}(C)$: Shift parameter for domestic commodity aggregation function for commodity C
- $\delta_a(A)$: Share parameter for top-level CES function for activity A

- $\rho_{ac}(C)$: Exponent for domestic commodity aggregation function for commodity C
- PQ_c: Composite commodity price
- QVA_a: Quantity of aggregate value-added
- WF_f: Average price of factor f
- PX_c: Producer price of commodity c

4. Simulation scenarios of productivity shocks

Table 2: Annual crop productivity shocks under RCP4.5

RCP4	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Maize	-0.18	-0.05	0.00	-0.02	-0.23	0.23	0.04	0.11	0.18	0.10	0.23	0.16	0.12	0.11	-0.20
Rice	-0.09	-0.04	0.04	0.01	-0.10	0.16	-0.05	0.08	0.13	0.12	0.10	0.05	0.07	0.05	-0.17
Pulse	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Oilseeds	-0.05	-0.02	0.02	0.00	-0.05	0.08	-0.02	0.04	0.06	0.06	0.05	0.02	0.04	0.03	-0.08
Fruits	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16
Root	0.07	-0.11	-0.24	0.02	0.04	0.01	-0.15	0.09	-0.04	0.04	-0.02	-0.06	-0.02	0.00	-0.07
Other cereals	-0.13	0.03	0.01	-0.11	-0.33	0.22	0.03	0.11	0.25	0.00	0.20	0.18	0.11	0.15	-0.14
Coffee	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Other crop	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Cotton	-0.29	0.14	0.08	0.77	1.79	-0.07	-0.47	0.54	0.14	0.01	0.01	-0.95	-0.72	0.38	-0.30
Sugar	0.02	-0.06	-0.23	-0.09	0.03	0.17	-0.14	-0.02	-0.03	-0.05	-0.10	-0.10	-0.03	-0.23	-0.20

Source: Based on (Waldhoff et al., 2020) projections

Table 3: Annual crop productivity shocks under RCP8.5

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Maize	0.04	-0.20	0.17	0.19	-0.01	0.01	0.14	0.01	0.21	0.22	0.02	-0.02	0.14	0.11	-0.13
Rice	-0.03	-0.21	-0.01	0.06	-0.05	-0.04	0.06	-0.05	0.10	0.11	0.02	-0.06	0.01	0.09	-0.15
Pulse	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19	-2.19
Oilseed	-0.02	-0.11	0.00	0.03	-0.03	-0.02	0.03	-0.03	0.05	0.05	0.01	-0.03	0.01	0.04	-0.08
Fruit	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56	-2.56
Root	0.07	0.10	0.15	0.01	0.04	-0.07	0.09	0.12	-0.12	-0.01	0.06	0.03	0.14	0.02	-0.02
Other cereals	0.17	-0.05	0.11	0.14	0.13	0.08	0.09	0.13	0.23	0.21	0.02	0.03	0.25	0.15	-0.08
Coffee	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61
Other crop	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97
Cotton	-0.57	-0.54	-0.14	-0.46	-0.89	-0.39	-0.19	0.59	-0.78	0.05	0.70	0.44	-0.27	-0.52	-0.50
Sugar	0.10	-0.15	-0.06	-0.10	-0.09	-0.14	0.01	-0.09	-0.08	-0.16	-0.03	-0.06	-0.04	-0.03	-0.16

Source: Based on (Waldhoff et al., 2020) projections