The Impact of CO_2 Emissions on Agricultural Productivity and Household Welfare in Ethiopia: A Computable General Equilibrium Analysis

Dawit Woubishet Mulatu[1] Zerayehu Sime Eshete[2] Tsegaye Ginbo Gatiso[3]

Abstract
Climate change has become one of the most important development challenges worldwide. It affects various sectors, with agriculture the most vulnerable. In Ethiopia, climate change impacts are exacerbated due to the economy's heavy dependence on agriculture. The Ethiopian government has started to implement its Climate Resilient Green Economy (CRGE) strategy, which is planned to foster development and sustainability while limiting GHG emissions by 2030. However, to the best of our knowledge, research on estimating the economic impacts of CO_2 emissions are limited. Moreover, studies estimating the productivity and welfare effects of Ethiopia's target for reducing emissions in line with the CRGE are lacking. Therefore, this study aims to fill these significant research and knowledge gaps using a recursive dynamic Computable General Equilibrium (CGE) model to investigate CO_2 emissions' impact on agricultural performance and household welfare. We simulate CO_2 emissions- induced variation in agricultural total factor productivity for the period 2010– 2030. The simulation results indicate that CO_2 emissions negatively affect agricultural productivity and household welfare. Compared to the baseline, real agricultural GDP is projected to be 4.5 percent lower in the 2020s under a no-CRGE scenario. Specifically, CO_2 emissions lead to a decrease in the production of traded and non-traded crops, but not livestock. Emissions also worsen the welfare of all segments of households, where the most vulnerable groups are the rural-poor households. Results also suggest that proper implementation of the CRGE strategy can significantly reduce the adverse effects of GHG emissions on agricultural productivity and household welfare.
Keywords: CO_2 emissions, computable general equilibrium (CGE), Climate Resilient Green Economy (CRGE), agriculture, productivity, welfare, Ethiopia

1. Introduction

The burden of climate change is real for poor countries. Studies based on cross-sectional data (e.g., Molua 2002; Muamba and Kraybill 2010; Di Falco et al. 2011) reported a decline in crop yields due to climate change in agriculture-based economies. This implies devastating effects on developing economies that depend heavily on agriculture (Bezabih et al. 2011; Zhai et al. 2009). In Ethiopia, agriculture supports the livelihoods of the majority of people and provides 80% of employment (IMF 2012). It generates about 90% of export revenues, supplies 70% of raw materials for domestic agro-industries and contributes 43% of the GDP (MoARD 2010). Consequently, any negative shock to the agricultural sector can cause devastating impacts on the whole economy. Therefore, this study aims to investigate CO_2 emissions' impact on agricultural performance and household welfare using a recursive dynamic Computable General Equilibrium (CGE) model.

To reduce the risks from climate change, the government of Ethiopia has started the implementation of the Climate Resilient Green Economy (CRGE) strategy for the period 2010-2030. This strategy is planned to foster development and sustainability while limiting GHG emissions to around a base year's 150 Mt CO_2 emissions,[4] which is 250 Mt less in 2030 than the estimated 400 Mt CO_2 emissions under a conventional development path (FDRE 2011).

The CRGE strategy follows a sectoral approach, identifying and prioritizing more than 60 initiatives. It is based on the pillar of increasing agricultural productivity and farmers' welfare while reducing GHG emissions. Therefore, investigating the impact of GHG emissions on agricultural performance and household welfare is crucially important to support decision makers. First, it gives an insight into the significance of pursuing GHG emissions reduction policies, by indicating the direct impacts of GHG emissions on Total Factor Productivity (TFP) in agriculture and on household welfare. Second, it helps measure the economic gains from the implementation of the CRGE strategy.

Despite the importance of the topic, there are limited empirical studies that explicitly examine CO_2 emissions' impact on agricultural productivity and household welfare. Most of the existing studies in Ethiopia

[1] Environment and Climate Research Center (ECRC)/ Ethiopian Development Research Institute (EDRI), Environment for Development (EfD), Addis Ababa, Ethiopia
[2] Addis Ababa University, Department of Economics, AAU, Addis Ababa, Ethiopia
3 Tsegaye Ginbo Gatiso Research Assistant, Ethiopian Development Research Institute (EDRI), Addis Ababa, Ethiopia
[4] In this case, CO2 emission refers to major GHG emissions converted into CO2 equivalent emissions. In our study, we used the projection of CO2 equivalent emissions, in line with the Ethiopia's CRGE strategy.

(e.g., Mideska 2010; Arndt et al. 2011; Robinson et al. 2011; Gebreegziabher et al. 2011; Ferede et al. undated) estimated economic impacts of climate change using Computable General Equilibrium (CGE) analysis. These studies focused on examining the economy-wide impact of climate change, focusing on productivity, food security, income distribution and the role of adaptation. However, to the best of our knowledge, research on estimating the economic impacts of CO_2 emissions is limited. Moreover, studies estimating the productivity and welfare effects of Ethiopia's target for emission reduction in line with the CRGE are lacking. Therefore, this study aims to fill these significant research and knowledge gaps. Estimating the impacts of CO_2 emissions on the overall economy are crucial to understanding the synergies and trade-offs between emission reduction and economic development. Moreover, if it is possible to scientifically validate the actual economic and welfare effects of the carbon emission reduction scheme of the green economy strategy.

The relationship between economic activities and emissions is complex. The level, extent and nature of economic activities affect the amount of GHG emissions, including CO_2 emissions (Pal et al. 2011; Jones and Sands 2013). In turns, the level of CO_2 emissions and its concentration affects the economy directly or indirectly by causing climate change. While some studies (for example, Pal et al. 2011) have investigated the impact of economic activities on emissions, examinations the other way around are lacking. We hypothesize that CO_2 emissions significantly affect the Ethiopian economy through impacts on factor productivity in agriculture for two main reasons. First, the agricultural sector is more vulnerable to environmental impacts. Second, agriculture dominates the economy and supports the livelihood of the majority of the people. Therefore, CO_2 emission impacts can reasonably be transmitted into the economy through their effects on total factor productivity in the agriculture sector, although the effects can be via various channels.

Specifically, we seek to answer the key research questions: (a) What is the impact of CO_2 emissions on the performance of the agriculture sector? (b) Is there any significant relationship between households' welfare and CO_2 emissions? (c) What is the projected trend of agricultural performance and household welfare if Ethiopia follows a development path with the CRGE strategy versus a conventional economic development path? To answer these questions, we incorporated a CO_2 emission shock into the CGE framework in the context of the Ethiopian economy, through the variation in agricultural total factor productivity induced by the emissions. The variation in productivity is derived using the technical coefficient obtained from Solow's sectoral growth accounting approach (Solow 1957) to link the CO_2 emission and factor productivity at a baseline.

The rest of the paper is organized as follows. Section 2 presents the review of literature. In Section 3, we describe the data and our approach of transmitting CO_2 emission shocks into a CGE model. Section 4 is devoted to discussing key results of the study, and Section 5 highlights concluding remarks.

2. Literature Review

Productivity growth in agriculture is vital for the development of the sector and the whole economy in agriculture-dominated economies. Several studies in developing countries (such as Evenson et al. 1999; Fan et al. 1999; Pasha et al. 2002; Bachewe 2012) have employed growth accounting analysis and reported that growth of TFP in agriculture has been the prime driving force behind overall economic growth. In Ethiopia, the growth in total agricultural production has been largely driven by expansion in grains production, which on average accounted for 84% of the total volume of farming agricultural production and grew at an average annual rate of 9.5% (Bachewe 2012). According to the IMF (2012), Ethiopia's agriculture sector grew by 9%, driven by cereal production, which reached 19.1 million tons in 2011. This growth in agricultural production was caused by favorable weather conditions in main cereal-growing areas, enhanced government support to smallholder farmers, improvement in yields and expansion in the area under cultivation. Increase in productivity, rather than extension of the cultivated area, was primarily responsible for this increased yield (IMF 2012).

Agriculture is a source of GHG as well as a sector that is vulnerable to such emissions (IPCC 2007). According to the World Bank (2013), agriculture generates between one-fourth and one-third of global GHG emissions, from both on-farm activities (about 10-12% of global emissions) and land-use and land-cover (LULC) change to cropland (an additional 12-20%), as LULC changes from forest and pasture to croplands releases soil and biomass carbon. GHG emission from agriculture is dominant in Ethiopia; for 2010, about 50% of Ethiopian GHG emissions are attributable to the agriculture sector, of which livestock accounts for the largest share, followed by crop production (FDRE 2011). Livestock generates GHG emissions mainly in the form of methane emissions arising from digestion processes and nitrous oxide emissions arising from excretions. GHG emissions from livestock in Ethiopia were estimated at 65 Mt CO_2 equivalent in 2010 (FDRE 2011). Crop cultivation contributes to the concentration of GHG emissions mainly due to the use of modern fertilizer and N_2O emissions. GHG emissions in 2010 from fertilizer use and N_2O emissions from crop residues reintroduced into the soil were approximately 10 Mt CO_2 emissions and 3 Mt CO_2 emissions, respectively. These emissions can cause climate change (IPCC 2007), which in turn may affect agricultural productivity.

In addition to reducing agricultural productivity, especially in the tropical regions, climate change directly affects poor people's livelihood and assets, including health, access to water and other natural resources, homes, and infrastructure (World Bank 2010). Increasing climatic variability, manifesting itself as more frequent and erratic weather extremes, or weather shocks, will likely make poor households even more vulnerable. This, in turn, could exacerbate the incidence, severity, and persistence of poverty in developing countries. Because agriculture in Ethiopia is predominantly rain-fed and the economy is dependent on primary commodities, any irregularities in weather and climate conditions may have adverse welfare implications. Moreover, the livelihood of rural people can be more affected due to their heavy dependence on agriculture. Hence, building resilience in the economy and adaptation are vital to reducing risks pertaining to environmental impacts.

Several studies have applied partial as well as general equilibrium approaches to estimate the economic impacts of climate change and variability at both sectoral and economy-wide levels. Using partial equilibrium analysis, Molua (2002), Muamba and Kraybill (2010), Di Falco et al. (2011) and Nkegbe and Kuunibe (2014) investigated the impact of climate change on agriculture and food security. Molua (2002) related farm-level income to precipitation change and estimated the significance of farmers' climate adaptation in Southern Cameroon using a Ricardian approach. Using a similar approach, Muamba and Kraybill (2010) estimated the livelihood impact of rainfall variation in the Mt. Kilimanjaro region of Tanzania. A recent study by Nkegbe and Kuunibe (2014) examined the impact of climate variability on household welfare in Ghana using trend equations and a Ricardian approach. In Ethiopia, Di Falco et al. (2011) used farm productivity and a Ricardian framework to estimate the impact of climate change and the role of adaptation in farm productivity. However, the partial equilibrium analysis fails to incorporate the economy-wide impacts of climate change due to general equilibrium feedback effects and interdependence among various sectors (Carri 2008; Gebreegziabher et al. 2011).

As a result, recently there has been increasing use of CGE models in economy-wide climate change impact analysis. These studies have used varying approaches to introduce climate change shock into CGE models, including various channels with varying timespans. Thurlow et al. (2009) estimated the impacts of climate change on economic growth and poverty in Zambia. Zhai et al. (2009) modeled the potential long-term impacts of global climate change on agricultural production and trade in China using an economy-wide, global CGE model and simulation scenarios of how climate change could affect global agricultural productivity up to 2080. Elshennawy et al. (2013) developed a multi-sectoral inter- temporal general equilibrium model with forward-looking agents, population growth and technical progress to simulate the effects of climate change on aggregate consumption, investment and welfare up to 2050 in Egypt. To examine the interrelationships among the economic activities as well as their impact on the environment in India, Pal et al. (2011) constructed an Environmentally Extended Social Accounting Matrix (ESAM), where environmental impacts are captured through emissions of GHGs and depletion of natural resources. An important implication of the findings of Pal et al. (2011) is that the indirect impact of GHG emissions must be incorporated to understand the economy-wide impacts.

In Ethiopia, there are studies using CGE modeling to estimate climate change impacts. Gebreegziabher et al. (2011) modeled the impacts of climate change on the overall economy using dynamic CGE modeling and simulated the impacts of climate change-induced variations in land productivity for the period 2010-2060. Robinson et al. (2011) also simulated the economic impacts of climate change up to 2050 and linked an Ethiopian multi-sectoral regionalized dynamic CGE model with a system of country-specific crops, hydrology, road and hydropower engineering models. Another study by Ferede et al. (undated) explicitly included different agro-ecological zones in estimating the short-run economic impacts on the Ethiopian economy of climate change, represented by changes in temperature and precipitation, using a CGE model.

The results of partial equilibrium studies (Molua 2002; Muamba and Kraybill 2010; Nkegbe and Kuunibe 2014) consistently reported negative impacts of climate change on agriculture through reductions in crop production, farm revenue, and productivity, and, as a result, reduced food security. Similarly, general equilibrium model analyses (Thurlow et al. 2009 for Zambia; Elshennawy et al. 2013 for Egypt; Zhai et al. 2009 for China) have indicated negative impacts of climate change and variability on the performance of the overall economy. These negative impacts of climate change on the economy become less intense as the share of agriculture in GDP declines (Zhai et al. 2009). Adaptation measures, such as coastal protection, irrigation and crop management practices, could reduce the climate-induced loss in GDP (Elshennawy et al. 2013).

Likewise, studies have revealed negative impacts of climate change on agricultural production and the overall economy in Ethiopia. Di Falco et al. (2011) indicated the negative impact of climate change on agriculture, whereas climate adaptation affects farm productivity positively. According to Gebreegziabher et al. (2011), the projected reduction in agricultural productivity may lead to 30% less average income, compared with the possible outcome in the absence of climate change. Robinson et al. (2011) also indicated that, without externally funded climate adaptation investments, Ethiopia's GDP in the 2040s will be up to ten percent lower than under the counterfactual with a baseline of no climate change. Moreover, Ferede et al. (undated) reported negative effects of climate change on economic growth, production activities and household livelihoods, with severe effects on agricultural production in the highland part of the country and on the income of poor households.

From this review of previous studies in Ethiopia and other countries, it is evident that existing studies have focused on estimating impacts of climate change on the economy. However, studies which focus on estimating the economic impacts of CO_2 emissions reduction in line with the CRGE are lacking. Therefore, this study aims to contribute to the existing body of literature.

3. Methodology

3.1 Data

This study uses the economy-wide detailed data set presented in the 2005/6 Ethiopian Social Accounting Matrix (SAM) developed by the Ethiopian Development Research Institute (EDRI) (EDRI 2009). This data set represents the flow of economic resources and transactions among economic agents in 47 activities disaggregated into 14 agricultural, 19 industrial, 1 mining and 13 service sectors. There are also 93 commodities disaggregated into 25 agricultural, 27 industrial, 3 mining and 38 service sectors. Labor input is disaggregated into agricultural labor, administrative workers, professional workers, non-agricultural unskilled workers, and non-agricultural skilled workers. Capital is also disaggregated into land for rural poor, land for rural non-poor, livestock for rural poor, and livestock for rural non-poor and non-agricultural capital. By assumption, both capital and labor are mobile across the three sectors, namely, agriculture, industry and service. The SAM consists of economic institutions, namely, households, private enterprises, the government, and the rest of the world. Households are disaggregated into four groups, namely rural poor, rural non-poor, urban poor, and urban non-poor. The SAM also presents 17 tax accounts as well as aggregated accounts for trade and transport margins (EDRI 2009).

In addition to the data detailed in the 2005/6 SAM, this study also utilizes economy-wide data on variables: CO_2 emissions, agricultural GDP, growth rates in agricultural labor, arable land, and agricultural capital formation. The data on agricultural production per hectare of land and labor employment in each production activity for the SAM year 2005 was collected from the Central Statistics Agency (CSA). The data on total and disaggregated household population (i.e., rural poor, rural non-poor, urban poor and urban non-poor) for 2005/6, CO_2 emissions and arable land come from the World Bank (i.e., World Development Indicators for Ethiopia) and Ministry of Finance and Economic Development (MoFED) of Ethiopia. Using the baseline estimated CO_2 emission level of the year 2010 as indicated in Ethiopia's CRGE strategy, we also projected the CRGE and without-CRGE scenarios yearly CO_2 emission level for the period 2010-2030, assuming a constant growth rate. Then, these long-term time series data are used for simulation exercise to examine the impact of CO_2 emission-induced changes in ATFP on economy-wide performance, using dynamic CGE modeling. The description of the main variables used in this study is presented in Table 1.

Table 1: Description of the variables

Variables	Description	Measurement unit
Agricultural total factor productivity	Total factor productivity in agriculture is the portion of output not explained by the amount of inputs, namely, labor, capital and arable land used in agricultural production	Constant domestic price
CO_2 emissions	Carbon dioxide equivalent GHG emissions from the various economic activities in the country. These include agriculture, forestry, industry, power, transport and buildings and associated businesses.	Metric tons
Household population	Household population refers to the actual number of people, including poor and non-poor in rural and urban areas. The number of households and household size have been taken from Ethiopia's 2005/6 SAM (EDRI 2009)	Number
Agricultural GDP	Gross Domestic Product (GDP) from various production activities in the agriculture sector	Constant domestic price year 2000
Arable land	Area of land suitable for growing crops	Hectare
Agricultural labor	Labor input employed in agricultural activities, such as livestock and crop production	Number

3.2. CGE Modeling and CO_2 Emission Shocks Transmission Approach

The 2005/6 SAM framework (EDRI 2009) includes a set of models representing various supply and demand relationships in the Ethiopian economy. In a CGE model, there are a set of supply- and demand-side equations.

In supply-side models, producers are price takers in output and input markets and maximize profits using constant returns to scale technologies. Demands for the primary factors are derived from Constant Elasticity of Substitution (CES) value-added functions, whereas the demand for intermediate inputs by commodity group is determined by a Leontief fixed-coefficient technology (Robinson et al. 2011). Producers' decisions between production for domestic and international markets are governed by the constant elasticity of transformation functions. Ethiopia faces perfectly elastic world demand curves for its exports at fixed world prices under the small country assumption. Relative prices for import and export commodities are used to determine the profit-maximizing equilibrium ratio of exports to domestic goods in any traded commodity group.

Concerning the demand side, households are also price takers. Households receive factor income from the production sector plus net transfer income; pay direct taxes; and save according to their respective saving propensities. Household consumption expenditure is allocated across commodities according to a linear expenditure system specification as derived from a Stone-Geary utility function (Robinson et al. 2011; Gebreegziabher et al. 2011). The government also receives revenue from direct and indirect taxes and net transfers from the rest of the world, and pays transfers to households. Residual revenue after government consumption expenditure is saved (with budget deficits representing negative savings). All savings from households, government, and the rest of the world are collected in a savings pool from which investment is financed.

The CGE framework is also built on a set of "macro-closure" rules in order to maintain the macroeconomic balance. Investment, government demand, and aggregate consumption are assumed as fixed shares of total domestic absorption. Savings rates are assumed to adjust to finance investment. The time path of the current account is exogenous in foreign currency terms and the real exchange rate adjusts to maintain external balance. Conversely, the fiscal deficit is assumed to be endogenous. Because the government demand is taken as a fixed share of absorption and all tax rates are held constant, government income depends on the level of economic activities. Another assumption in CGE models is full employment and free movement of factors across various sectors. Capital accumulation is modeled with annual resolution. The model adopts the principle that new investment is allocated across sectors in response to rate of return differentials but installed equipment remains immobile. Long-run sectoral factor productivity growth is specified exogenously. In a CGE model, the decisions of consumers, producers, and investors change in response to changes in economic conditions driven by different sets of climate outcomes, as do market outcomes (Ferede et al. undated; Robinson et al. 2011). In our case, GHG emissions are assumed to influence the economic well-being of households through affecting agricultural productivity and then producing general equilibrium feedback effects. Hence, we use the CGE model to analyze the interrelationship between GHG emission and agriculture performance and welfare.

In our study, we examined the CO_2 emissions impact through agricultural total factor productivity. To estimate the total factor productivity in agriculture, we adopt Solow's (1975) growth accounting framework. According to this model, growth in Total Factor Productivity (TFP) is attributed to that part of growth in output which cannot be explained by growth in factor inputs like land, labor and capital. Hence, the growth in TFP is equivalent to the growth in technical change. In addition to demographic change and economic development, technology is an important driving force in greenhouse gas emissions (IPCC undated; Hang and Yuan-sheng 2011). Although CO_2 emission cannot cause progress in technology, its level and intensity can be illustrated by the paths of development in the energy system and resources, including land use patterns which are determined by the level of technology and input utilization (IPCC undated). That is, we use CO_2 emissions as a proxy for the state of technology because the level of byproducts and pollution from production processes and input utilization can be determined by the technology used or adopted. In Solow's approach, total agriculture output (Y_A) is taken as the function of technology (A_t) in a given period/time t and the factors of production such as labor (L), capital (K) and arable land (*l*) used in agricultural production.

$$Y_A = A_t F(L, K, l) \qquad (1)$$

Assuming A_t as Hicks neutral, an improvement in technological progress increases the level of output without affecting the marginal product of inputs, i.e., causes no change to the coefficients of factors in a basic growth accounting equation. This kind of technical progress shifts the production function over time by a uniform upward displacement of the entire function (Chen *et al.*, 2003). Differentiating equation (1) with respect to time gives:

$$g_{GDP_t} = g_{Y_t} = g_{A_t} + \alpha g_{L_t} + \beta g_{K_t} + \gamma g_{l_t} \qquad (2)$$

where g stand for the growth in the allied variables. Our variable of interest is g_{A_t} which represents Solow's residual or the rate of growth of agriculture TFP_A at time t. Coefficients α, β and γ represent respective shares of labor, capital and arable land in total agricultural output. Assuming constant returns to scale (CRS) production technology, the sum of the share of the factors (α, β and γ) equals one. When we rearrange equation (2):

$$g_{A_t} = g_{TFP_{At}} = g_{GDP_{At}} - (\alpha g_{AL} + \beta g_{AK} + \gamma g_l) \qquad (3)$$

From equation (3), we calculate growth in agriculture total factor productivity using yearly data for agriculture GDP, and agricultural labor, capital and arable land growth rate. From the 2005/6 Social Accounting Matrix for Ethiopia, with disaggregated relative factor shares in production, the values of α, β and γ are found to be 0.754, 0.102 and 0.144 respectively (EDRI, 2009). These values are used as coefficients of factors of agricultural production in the calculation of total factor productivity in agriculture.

After estimating total factor productivity in agriculture using sectoral growth accounting, the CO_2 emission impacts entered the CGE model in the form of a shock to agricultural total factor productivity induced by the CO_2 emission. In this study, we used $C0_2$ equivalent GHG emissions, which come from various economic activities in the country, instead of $C0_2$ stock, which is the measure of accumulated $C0_2$ emission from past worldwide economic activities. Although emissions from all economic sectors would have an impact on productivity by causing climate change, we assume that it is difficult to find a direct relationship between CO_2 emission and agricultural productivity; the relationship is complex and not exact. This is because emissions come not only from the agricultural sector but also from other economic activities, including service and industrial sectors. Indeed, emissions from other sectors may not directly explain the output level in agriculture. However, some technological progress can reduce emission and increase productivity through improving energy efficiency. In most cases, the level of technology employed is also different among sectors in the economy. Thus, the relationship between technology and emission is complex (Hang and Yuan-sheng, 2011), implying that the relationship between agricultural productivity and emission is also not exact. In order to derive CO_2 emission-induced agricultural total factor productivity, we calibrate the elasticity coefficient of ATFP with respect to CO_2 using the specification as follows:

$$ATFP = (CO_2 emission)^{\beta} \quad \ldots\ldots (4)$$

Where ATFP is agriculture TFP and β is a coefficient to be used as CO_2 emission induced ATFP in the CGE model. By taking the natural logarithm on both sides of the above equation, we obtain:

$$ln^{ATFP} = ln^{(CO_2 emission)^{\beta}} \quad \ldots\ldots (5)$$

$$ln^{ATFP} = \beta ln^{CO_2\ emision} \quad \ldots\ldots (6)$$

$$\beta = \frac{ln^{ATFP}}{ln^{CO_2\ emision}} \quad \ldots\ldots (7)$$

Finally, the coefficient β is calibrated using the values of ATFP and CO_2 emissions at the baseline. At the 2006 baseline, ATPF is set to be 1 percent (0.01) and the CO_2emissions are 120.89 Mt. By inserting these values into Equation 7, the elasticity coefficient of ATFP with respect to CO_2 emissions is found to be -0.96. We use this elasticity value to derive the CO_2 emissions-induced change in TFP and simulate its impact on agricultural performance and household welfare for the period 2010 - 2030.

3.3. Specification of Dynamic Baseline Path and Simulation Scenarios

In order to estimate CO_2 emissions' impact on agricultural productivity and households' welfare, we calibrated the model to the 2005/6 SAM of Ethiopia (EDRI 2009). We start by specifying a hypothetical dynamic baseline path to 2030 (S_1) that reflects the trends in economic development, policies, and priorities with no change in CO_2 emissions but includes the observed historical pattern of emissions. The baseline provides a counterfactual trajectory for growth and structural change of the economy in the absence of changes in CO_2 emissions. This serves as a basis for comparison with the various GHG emission scenarios.

In the baseline, underlying rates of labor force growth, trend productivity growth, world prices, foreign aid inflows, tax rates, and government policies toward investment are assumed to be exogenous. In a dynamic path, we specify the growth rate of labor, arable land, capital accumulation and depreciation following NBE (2010) and World Bank (2011). Accordingly, the growth in labor supply is consistent with the projected annual population growth of 2.4%. The average annual growth rate of cultivated land across the modeled period is 3.1%. Capital accumulation is an endogenous outcome of saving and investment and is assumed to increase by 11.5% with a 5% depreciation rate. Following the IMF economic growth projection for Ethiopia, the baseline average annual GDP growth rate over the simulation period (2010 - 2030) is set to be about 6.5% (IMF 2012).

Furthermore, we formulated the GHG emissions scenarios following the Ethiopian CRGE strategy (FDRE 2011). In the business-as-usual (S_2) scenario, GHG emissions increase with the expansion of economic activities. In this scenario, the country is assumed to pursue non-CRGE strategies and the economy grows under a conventional growth path. Under this scenario, GHG would more than double from 150 Mt CO_2 emissions equivalent in 2010 to 400 Mt CO_2 equivalent in 2030 (FDRE 2011). The third scenario (S_3) evaluates the case of a targeted trend of GHG emissions, planned to be achieved through the implementation of the CRGE strategy, through 2030 (i.e., the 250 Mt of CO_2 emissions scenarios in 2030 and the "with- CRGE" intervention scenario).

We simulate the CO_2 emissions impact on agricultural productivity and household welfare with and without CRGE. Although the Ethiopian CRGE strategy has a target of limiting CO_2 emissions to 150 Mt, compared to 400 Mt if the country did not pursue a CRGE strategy, we assume CO_2 emissions to be reduced by

37.5% instead of 64% in 2030. Hence, we become modest about net-zero emission growth and set the level of CO_2 emissions at 250 Mt level in 2030 with CRGE intervention by considering the limited greening technologies, institutions and sequestration capacity of the country. Green economy strategies of other countries also target percentage reductions instead of net-zero emission growth. For instance, Kenya targets a 30% reduction, which is not a net-zero emission level (MENR Kenya 2015). Net-zero emission is also demanding given high growth targets in key economic sectors and lack of strong enforcement of the environmental laws intended to reduce emissions caused by existing and new economic initiatives of developing countries. We further assume a constant and uniform annual growth of CO_2 emissions toward 2030 from 150 Mt in 2010. Accordingly, the CO_2 emission growth rate is found to be 2.7 with the CRGE strategy and 5.25 without CRGE. Using these growth rates, we calculated the long-term yearly level of CO_2 emissions for the period 2010-2030. For the period 2006-2010, the rate of growth of CO_2 emissions is calculated without the CGRE scenario because, during that period, the country had not started implementing the green-economy strategy. Then, the elasticity used in simulation is derived from the forecasted CO_2 emissions, assuming an ATFP growth rate of 1% at the baseline.

4. Results and Discussion

4.1. CO_2 Emission Impacts on Agricultural Productivity

Simulation results indicated that a CO_2 emissions-induced decline in agricultural total factor productivity has an adverse impact on agricultural productivity. As indicated in Table 2, agricultural real GDP decreases from baseline 144.64 to 135.86 billion Birr, which is 6% lower by 2030 under the scenario without CRGE. On the other hand, under the scenario with CRGE, agricultural real GDP decreases by approximately 4.6%, from baseline 144.64 to 137.87 billion Birr by 2030.

Considering particular production activities in the agriculture sector, CO_2 emissions have a negative impact on teff, maize and wheat, which are traded and non- traded agricultural products. Production of teff might decline from 10.53 billion Birr at present to 9.88 by 2030 with CRGE versus 9.69 billion Birr without CRGE. This implies that, if there is no CRGE intervention, CO_2 emissions-induced decline in agricultural factor productivity leads to a 7.9% decrease in teff production. Under the implementation of CRGE, the impact of CO_2 emissions on teff production is reduced to 6.1%. The negative impacts of CO_2 emissions-induced reduction on agricultural factor productivity are more pronounced for maize and wheat production under both scenarios. By 2030, the production of maize and wheat is projected to be about 10.3% and 13.4% lower with and without CRGE than what it would be in the baseline scenario. The results indicated that maize and wheat production will decrease from baseline 16.39 billion to 14.7 and 14.19 billion Birr with and without CRGE. The explanation for the negative impact of CO_2 emissions is that GHG can change the amount and timing of rainfall; this, as well as increasing temperature, can endanger crop production. The reduction in teff, maize and wheat can endanger food security because these are the main consumption commodities in major crop-producing areas of the country.

Table 2: Impact of $C0_2$ Emissions on Agriculture Production by 2030 (in billions)

	Baseline	With CRGE	Without CRGE
Teff	10.53	9.88	9.69
Maize and wheat	16.39	14.70	14.19
Export crops (oilseeds, pulses, coffee & others)	22.78	20.88	20.32
Non-traded agricultural products	47.11	44.21	43.35
Livestock	47.81	48.18	48.29
Agricultural Real GDP	144.64	137.87	135.86
Total Real GDP	553.7	544.26	541.50

Source: Authors' CGE model simulations

Moreover, CO_2 emissions have a negative impact on the production of major agricultural export commodities. The main agricultural export commodities included in our simulation are coffee, oilseeds, pulses and khat. With CRGE, production of primary export commodities declines from baseline 22.78 billion Birr by 8.3% to 20.88 billion Birr by 2030. Without CRGE, the production of export commodities decreases to 20.32 billion Birr by 2030, which is about 10.8% lower as compared to the baseline (Table 2). In addition to traded agricultural commodities, CO_2 emissions- induced reduction in factor productivity affects the production of non-traded agricultural commodities. Due to CO_2 emissions, without CRGE, the production of non-traded commodities is lower by 8% than what it would be in the baseline scenario. With CRGE, the decline in the production of non-traded commodities becomes 6.1%. The result indicates that the production of non-traded commodities decreases from the baseline 47.11 billion Birr to 44.21 and 43.35 billion Birr under CRGE and without CRGE by 2030.

Unlike the effect on crop production, the effect of CO_2 emissions on livestock is positive. Livestock production increases in both with and without CRGE. In specific terms, livestock production increases from baseline 47.81 to 48.18 and 48.29 billion Birr by 2030 with and without CRGE, respectively. This result is partly consistent with the findings of Gebreegziabher et al. (2011), who found a positive effect of climate change on livestock production until 2030, although their results turn negative beyond 2040 and 2030 (approximately) for the case of moisture-sufficient cereals- based and drought-prone highlands, respectively. The important implication of our finding is that livestock production as an alternative source of income can reduce risks pertaining to GHG emissions and climate change. At the economy-wide level, the results indicate a negative impact of CO_2 emissions on real GDP. By 2030, real GDP is projected to be 2.2% lower than it would be under the baseline scenario. Putting this in numbers, real GDP declines to 541.5 billion Birr from the baseline projection of 553.7 billion Birr without CRGE. 3 This negative impact on real GDP is consistent with the findings of existing climate change studies, for example, a case study by Elshennawy et al. (2013) in Egypt and the research of Robinson et al. (2011) in Ethiopia. They reported that, in the absence of externally funded policy-driven adaptation investments, real GDP will decline by 10% in both countries compared to what it would be under a baseline scenario without climate change,

Table 3: Average deviation of real GDP from the baseline scenario by decades

(Percentage)

	2011 – 2020		**2021 - 2030**	
	With CRGE	*Without CRGE*	*With CRGE*	*Without CRGE*
Real GDP	-0.5	-0.7	-1.3	-1.8
Agricultural Real GDP	-1.2	-1.5	-3.5	-4.5

Source: Authors' computation based on CGE model simulation results

The impact of CO_2 emissions on both real total GDP and agricultural GDP is negative. Table 3 shows the decade average percentage deviations of real GDP from the baseline path by decade from 2010 to 2030. The adverse impacts are more noticeable in the case of agriculture GDP both with and without CRGE, and the severity of losses increase over time. In the period 2021-2030, real agricultural GDP is projected to be 3.5% and 4.5% smaller than the baseline with and without CRGE. The results indicate that the implementation of CRGE significantly reduces the adverse impact of CO_2 emissions on agriculture and the whole economy (Table 3).

4.2. CO_2 Emission Impacts on Institutional and Factor Income

Both with and without CRGE, CO_2 emissions are found to have a negative influence on the annual growth rate of income earned by institutions, represented by households and the government (Table 4). As compared to the baseline scenario, the annual income growth rate of institutions – namely public enterprises, rural poor, rural non-poor, urban poor and urban non-poor households – declined due to CO_2 emissions-induced reduction in agricultural factor productivity. The reduction in the growth rate of income is larger without CRGE than with CRGE in the case of public enterprises and rural non-poor households. On the other hand, for rural poor, urban poor and urban non-poor households, the declines in their annual income growth rates are similar with or without CRGE.

Table 4: Growth rate of institutional income under various $C0_2$ emissions scenario (%)

Institutions *	Initial Value	Baseline	With CRGE	Without CRGE
Enterprises	0.13	2.68	2.65	2.63
Rural poor HHDs.	2.48	11.34	11.23	11.19
Rural non-poor HHDs.	7.31	33.74	33.39	33.29
Urban poor HHDs.	0.49	1.95	1.93	1.92
Urban non-poor HHDs.	3.00	11.34	11.24	11.20

*Note: HHDs. stands for households

Source: Authors' CGE model simulations

Simulation results also revealed that CO_2 emissions have a negative impact on the income of factors of production, except in the case of livestock. As compared to a baseline scenario of no increase in CO_2 emissions, growth rates for income from labor, land and capital decreased due to the emissions-induced reduction in total factor productivity in agriculture. The negative impact of CO_2 emission is larger in the case of labor and capital than for land. However, the growth rate of livestock income slightly increases. This is in line with the increase in livestock production as a result of CO_2 emissions that is described in the preceding section.

Table 5: Percentage growth rate of factor income under various CO_2 emissions scenarios

Factors	Initial Value	Baseline	With CRGE	Without CRGE
Labor	6	30.3	30	29.9
Land	0.8	3.9	3.84	3.82
Livestock.	0.5	1.712	1.715	1.716
Capital	0.48	23.6	23.3	23.2

Source: Authors' CGE model simulations

Moreover, there is a significant difference in the emissions-induced decrease in institutional and factor income growth rates with and without CRGE. As indicated in Tables 4 and 5, the CRGE strategy might help reduce the adverse impact of CO_2 emissions on institutional and factor incomes even if our assumption about the level of CO_2 emissions in 2030 is higher than the level targeted in the Ethiopian CRGE strategy. The implication of this result is that implementation of CRGE initiatives can help reduce the vulnerability of the income of households, public enterprises and factors of production. This may contribute to the realization of the country's goals of reducing poverty and attaining middle-income status.

4.3. CO_2 Emission Impacts on Household Welfare

The simulated values of welfare status measured by Equivalent Variation (EV) for different segments of households are presented in Table 6. The net effects of an emissions-induced reduction in agricultural total factor productivity worsen the welfare of each segment of households. However, the magnitude of loss in welfare differs among the different households. The welfare loss is larger in the case of rural poor households as compared to the other segments of households. This result indicates that rural poor households might be the most vulnerable to GHG emissions and climate change impacts.

The plausible reason behind the substantial welfare loss borne by rural poor households is that the majority of these households depend entirely on agriculture. Agricultural practices in Ethiopia are highly dependent on rain-fed cultivation and alternative farming practices are limited. Moreover, rural poor households have few diversified sources of income, unlike urban households, who have relatively diverse income sources. This makes the livelihood of rural poor households the most vulnerable to GHG emissions and associated climate change and variability.

Table 6: CO_2 Emission Induced Change in Household Welfare Status

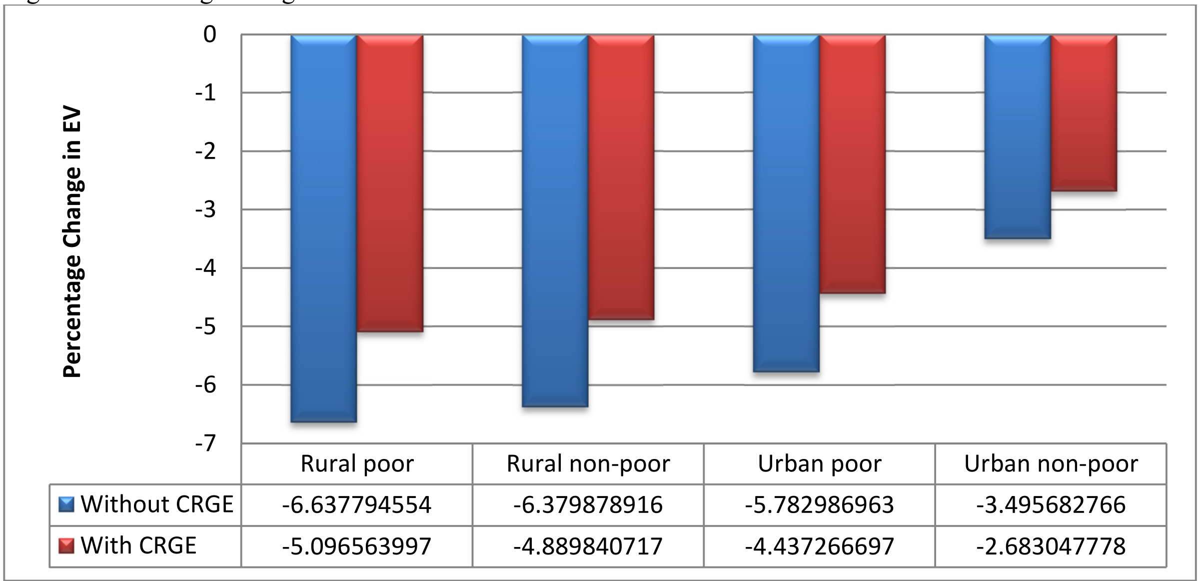
Households	EV in Baseline	EV with CRGE	EV without CRGE
Rural poor	0.0470	0.0446	0.0439
Rural non-poor	*0.1569*	0.1493	0.1469
Urban poor	0.0086	0.0082	0.0081
Urban non-poor	0.0550	0.0536	0.0531

Source: Authors' CGE model simulations

Next to rural poor households, the welfare of rural non-poor households is also severely affected by CO_2 emissions, followed by urban-poor and non-poor households. Urban non-poor households are least affected, partly because of their lower dependence on the climate-vulnerable farming sector. Besides, urban non-poor households have numerous sources of income which reduce their vulnerability. Figure 1 shows the percentage decline in household welfare measured by changes in EV. CO_2 emission-induced variation in total factor productivity in agriculture leads to a reduction in households' welfare under all scenarios. Without CRGE, the welfare of rural-poor and non-poor households declines by 6.6% and 6.3% respectively. Under the same scenario, the reduction in welfare in the case of urban households is relatively lower as compared to their rural counterparts, reaching 5.7% and 3.5% for poor and non-poor households. As can be seen from Figure 1, reduction in welfare becomes moderate for all segments of households under the CRGE scenario.

The notable implication of our findings is that the CRGE strategy can effectively reduce impacts of GHG emissions. Under all simulation scenarios, CRGE lessens the negative impacts of CO_2 emissions on agricultural productivity, institutional and factor income, and household welfare. This shows that the CRGE initiatives can not only help reduce GHG emissions while achieving the ambitious goal of middle-income status by 2025 but can also moderate the associated environmental impacts of CO_2 emissions.

Figure 1: Percentage change in welfare effects with and without CRGE



Source: Authors' computation based on CGE model simulation results

5. Conclusion

Currently, Ethiopia has started the implementation of a CRGE strategy, aiming to become a low-carbon, middle-income country by 2025. This study aims to investigate CO_2 emission impacts on agricultural productivity and household welfare. We simulate CO_2 emissions-induced agricultural total factor productivity using dynamic CGE model. Alternative simulation scenarios were set in line with the emission targets of the Ethiopian CRGE strategy. Simulation results reveal that CO_2 emissions have a negative impact on agricultural performance. As compared to the baseline, real agricultural GDP is projected to be 3.5% and 4.5% lower in the 2020s with and without CRGE strategy scenarios, respectively. The impact of CO_2 emissions-induced reduction in agricultural factor productivity leads to a decrease in production of agricultural traded and non-traded crops, except livestock production. The production of teff, maize and wheat, export commodities such as coffee, oilseeds and pulses, and non-traded crops, declines due to the impact of CO_2 emissions both with CRGE and without CRGE during the simulation period of 2010-2030, but the impacts are worse without CRGE.

In addition, the net effect of CO_2 emissions on household welfare has been found to be negative. The welfare of all segments of households worsens due to the emissions-induced reduction in total factor productivity in agriculture. The percentage loss in welfare is more manifest in rural areas, where rural poor households are the most vulnerable. High vulnerability of the welfare of rural poor households can be explained by their heavy dependence on rain-fed agriculture for livelihood and their limited income diversification. Results indicate that proper implementation of the CRGE strategy can significantly lessen the devastating effects of GHG emissions on agriculture and particularly on household welfare, thereby promoting sustainable economic development. Therefore, in Ethiopia, more actions should be taken in agricultural and other economic sectors for the implementation of the CRGE strategy because they are timely and vital to the goal of achieving low-carbon, middle-income status.

Our results must be interpreted with caution because we analyze CO_2 emissions' impact only through agricultural total factor productivity. In order to measure the direct and indirect economic impacts, consideration of environmental accounts such as natural resource depletion, pollution and greenhouse gas effects is essential. In this regard, future efforts are needed to extend the Ethiopian 2005/6 SAM by including environmental accounts. An Environmentally Extended Social Accounting Matrix (ESAM) can provide more insightful evidence on the economy- wide impacts of GHG, including CO_2 emissions, and can help evaluate the real-time impact of effective implementation of the CRGE strategy. As we simply discuss the relationship between ATFP and CO_2 without considering other factors which can affect ATFP, further study should also focus on using regression approaches that take into account all variables explaining ATFP.

References

Arndt, C., S. Robinson, and D. Willenbockel (2011). Ethiopia's Growth Prospects in a Changing Climate: A Stochastic General Equilibrium Approach. *Global Environmental Change* 21: 701-710.

Bachewe, F.N. (2012). Growth in Total Factor Productivity in the Ethiopian Agriculture Sector: Growth

Accounting and Econometric Assessments of Sources of Growth. Ethiopia Strategy Support Program II (ESSP II) Working Paper No. 37, Addis Ababa, Ethiopia.

Bezabih, M., M. Chambwera, and J. Stage (2011). Climate Change and Total Factor Productivity in the Tanzanian Economy. *Climate Policy* (forthcoming).

Carri, C.B. (2008). CGE Approaches to Policy Analysis in Developing Countries: Issues and Perspectives. SPERA Working Paper No. 2/2008.

Chen, P., Yu, M., Chang, C. and Hsu, S. (2003). Total Factor Productivity Growth in China's Agricultural Sector. *China Economic Review*. 19 (4): 580–593.

Di Falco S., Yesuf M., Kohlin G. and Ringler C. (2011). Estimating the Impact of Climate Change on Agriculture in Low-Income Countries: Household Level Evidence from the Nile Basin, Ethiopia. *Environmental Resource Economics* 52:457–478.

EDRI (Ethiopian Development Research Institute) (2009). Ethiopia: Input Output Table & Social Accounting Matrix. December, Addis Ababa, Ethiopia.

Elshennawy, A., S. Robinson, and D. Willenbockel (2013). Climate Change and Economic Growth: An Inter-temporal General Equilibrium Analysis for Egypt. Netherlands Enterprise Agency, Institute of Development Studies, FEMISE Research FEM 34-23.

Evenson, R.E., Pray, C. and Rosegrant, M.W. (1999). Agricultural Research and Productivity Growth in India. Research Report 109. International Food Policy Research Institute (IFPRI), Washington, D.C.

Fan, S., Hazell, P.B. and Thorat, S. (1999). Linkages between Government Spending, Growth, and Poverty in Rural India. Research Report 110. International Food Policy Research Institute, Washington, D.C.

Ferede, T., A. Belayneh, and M. Hanjra (forthcoming) *Agro-ecology Matters: Impacts of Climate Change on Agriculture and its Implications for Food Security in Ethiopia*. USA: Nova Science Publishers, Inc.

FDRE (Federal Democratic Republic of Ethiopia) (2011). Ethiopia's Climate- Resilient Green Economy: Green Economy Strategy. Addis Ababa, Ethiopia.

Gebreegziabher, Z., J. Stage, A. Mekonnen, and A. Alemu (2011). Climate Change and the Ethiopian Economy: A Computable General Equilibrium Analysis. Environment for Development Discussion Paper Series, EfD DP 11-09.

Hang, G., and J. Yuan-sheng (2011). The Relationship between CO_2 Emissions, Economic Scale, Technology, Income and Population in China. *Procedia Environmental Sciences* 11(C): 1183-1188.

IMF (International Monetary Fund) (2012). Ethiopian Economic Outlook. http://www.africaneconomicoutlook.org/EthiopiaFullPDFCountryNote.

IPCC (Intergovernmental Panel on Climate Change) (2007). Fourth Assessment Report (AR4). Climate Change 2007: Synthesis Report. Available at: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessme nt_report_synthesi s_report.htm.

IPCC (International Panel for Climate Change) (undated). Emissions Scenarios: Summary for Policymakers. A Special Report of IPCC Working Group III. Published for the Intergovernmental Panel on Climate Change.

Jones, A., and D. Sands (2013). Impact of Agricultural Productivity Gains on Greenhouse Gas Emissions: Global Analysis. *American Journal of Agricultural Economics* 95(5): 1309-1316.

MoARD Ministry of Agriculture and Rural Development (2010). Performance of Ethiopian Agriculture Sector. Addis Ababa, Ethiopia.

MENR (Ministry of Environment and Natural Resource of Kenya) (2015). Kenya's Intended Nationally Determined Contribution (INDC). Submitted to UNFCCC on 23 July, 2015.

Mideksa, T. (2010). Economic and Distributional Impacts of Climate Change: The
Case of Ethiopia. *Global Environmental Change* 20: 278-286.

Molua, E. (2002). Climate Variability, Vulnerability and Effectiveness of Farm-Level Adaptation Options: The Challenges and Implications for Food Security in Southwestern Cameroon. *Environment and Development Economics* 7: 529-545.

Muamba, F., and D. Kraybill (2010). Weather Vulnerability, Climate Change, and Food Security in Mt. Kilimanjaro. Poster prepared for presentation at the Agricultural & Applied Economics Association 2010 AAEA, CAES, & WAEA Joint Annual Meeting. Denver, Colorado, 25-27 July, 2010.

NBE (National Bank of Ethiopia) (2010). Annual Report on Ethiopian Economy 2009/10. Addis Ababa, Ethiopia.

Nkegbe, K., and N. Kuunibe (2014). Climate Variability and Household Welfare in Northern Ghana. WIDER Working Paper 2014/027.

Pal, B., S. Pohit, and J. Roy (2011). Impact of Economic Growth on Climate Change: An Environmentally Extended Social Accounting Matrix (ESAM) based Approach for India. MPRA Paper36540. Available at: http://mpra.ub.uni- muenchen.de/36540/

Pasha, H., A. Pasha, and K. Hyder (2002). The Slowing Down of the Growth of Total Factor Productivity in

Pakistan. Social Policy and Development Centre, Karachi.
Robinson, S., K. Strzepek, and D. Willenbockel (2011). A Dynamic General Equilibrium Analysis of Adaptation to Climate Change in Ethiopia. UNU- WIDER Working Paper No. 2011/89.
Solow, R. (1957). Technical Change and the Aggregate Production Function. *The Review of Economics and Statistics* 39 (3): 312-320.
Thurlow, J., Zhu, T. and Diao, X. (2009). The Impact of Climate Variability and Change on Economic Growth and Poverty in Zambia. International Food Policy Research Institute (IFPRI), Development Strategy and Governance Division, and Environment and Production Technology Division. IFPRI Discussion Paper 00890. Washington DC.
World Bank (2010). *Economics of Adaptation to Climate Change: Synthesis Report*.
Washington, DC: World Bank.
World Bank (2013). World Development Indicators Online. Washington, DC.
Available at: http://go.worldbank.org/U0FSM7AQ40
Zhai, F., T. Lin, and E. Byambadorj (2009). A General Equilibrium Analysis of the Impact of Climate Change on Agriculture in the People's Republic of China. Asian Development Review 26(1): 206-225.