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Economic Effects of Climate Change in Developing Countries: Economy-wide and Regional Analysis for Ethiopia

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Abstract

Quantifying the economic effects of climate change is a crucial step for planning adaptation in developing countries. This study assesses the economy-wide and regional effects of climate change induced productivity and labor supply shocks in agriculture in Ethiopia. The study shows, in worst case scenario, the effects on national GDP may add up to -8% with uneven regional effects ranging from -10% in agrarian regions (e.g. Amhara) to +2.5% in urbanized regions (e.g. Addis Ababa). Cost-free exogenous structural change scenarios in labor markets and transaction costs may offset about 20-30% of the ripple effects of climate change. Therefore, the ongoing structural transformation in the country may underpin the resilience of the economy to climate change. Nevertheless, given the role of agriculture in the current economic structure of the country and the potency of biophysical impacts of climate change, adaptation in the sector is indispensable. Otherwise, climate change may hamper economic progress of the country, and make rural livelihood unpredictable.

JEL classification: C68, D58, J21, J43, J62, O55, Q54, Q56, R11, R13

Keywords: Climate change, agriculture, migration, CGE model, Ethiopia

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1. Introduction

Ethiopia is one of the least developed countries (LDCs) where the projected economic costs of climate variability (Arndt et al., 2011; World Bank, 2008) and climate change (FDRE, 2015; Conway and Schipper, 2011; World Bank, 2010) are worrisome. The adaptive capacity of agriculture in Ethiopia, the most climate sensitive economic sector, is very low. The sector is yet subsistence, virtually rain-fed, dominated by cereal crops, and with smallholder farmers producing about 90-95% of the total agricultural output (AgSS, 2014; MoARD, 2010). The existing environmental (e.g. land degradation, soil erosion, and deforestation) and socio-economic (e.g. illiteracy, poor credit and market infrastructure) conditions are roadblocks to agricultural transformation in the country (MoARD, 2010). Even so, agriculture is important economic sector in terms of employment, exports, and national income. It employs between 75-80% of the country's labor force (NPC, 2016; NLFS, 2013; 2005; HICES, 2011) and contributes to 75% of the merchandise export earnings and nearly 40% to the GDP (NBE, 2016). Besides, the overall adaptive capacity of the economy is low. Ethiopia is a low-income country with per capita income of US$690 (NBE, 2016) with no significant score to decrease fiscal deficit for decades (MoFED, 2015). Given these conditions, impacts of climate change are sought to be detrimental to the economic prospects of the country.

This study examines the economy-wide and regional effects of shocks in agriculture due to future climate (of 2050s) compared to the present climate (of 1990s). We consider the primary effects of climate change on grain and livestock productivity, and the likely migration from agricultural occupation. We construct some plausible structural change scenarios to highlight the role of such development to underpin resilience to climate change. We integrate and model these first-order changes into the standard IFPRI-CGE model (Lofgren et al., 2002) calibrated to the 2005/06 Social Accounting Matrix (SAM) of Ethiopia. We use the CGE model to simulate the economy-wide effects, on the macro-economy, sectoral output, and households' welfare, of climate change impacts in agriculture without and with structural change presumed. We, then, project the economy-wide effects on different sectors onto a regional module to glean information about the regional effects.

The CGE simulations show that primary effects of climate change on grain and livestock productivity and agricultural labor migration on the GDP may add up to -8%. The equivalent variation of household welfare effects range from -3% to -11%. Climate change apparently reduces agricultural output and increases agricultural prices. It also alters the international trade mix of the country. The regional economic effects of climate change range from -10% in agrarian regions (e.g. Amhara) to +2.5% in urban regions (e.g. Addis Ababa). Cost-free structural change scenarios in labor markets and transaction costs (or marketing margins) may offset about 20-30% of aggregate GDP and households' welfare losses.

Our study design is the first of its kind applied to a least developed country. We link crop and livestock productivity changes and migration to assess the general equilibrium effects, and then derive regional effects for administrative units (level 1) of the country. The study also contributes to the burgeoning discussion on development (or structural change) as the best measure of adaptation to climate change in LDCs. We believe the research design is elegant yet simple and replicable to other LDCs.

The remainder of the paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the materials and methods of the study. Section 4 and 5 present and analyze the economy-wide and regional effects of climate change, respectively, without and with structural change assumed. Section 6 puts the conclusions along with their policy implications.

2. Literature review

Changes in the mean climatic conditions (such as temperature and precipitation) affect soil moisture, water availability, and the incidence and distribution of plant and animal pests and pathogens. Eventually, these impinge on the growth and development of crops (Hertel and Lobell, 2014; Adams et al., 1998), the quality and quantity of animal feed (Thornton et al., 2009; Adams et al., 1998), and the physiological performance and growth of animals (Nardone et al., 2010; Adams et al., 1998). As a result, for a given set of inputs, climate change is often regarded as an analogous to technical change affecting agricultural production (Antle and Capalbo, 2010; Adams et al., 1998). Not only this, climate change makes future rural livelihood prospects unpredictable and unreliable which in turn may trigger out-migration either to increase earnings or to spread out risks (Brown, 2008; McLeman and Smit, 2006).[1]

The impacts of climate change on agriculture (cf. Müller et al., 2014; Knox et al., 2012; Schlenker and Lobell, 2010; Nelson et al., 2010; Nardone et al., 2010; Seo and Mendelsohn, 2008); on migration (cf. Kubik and Maurel, 2016; Mertz et al., 2011; Naude, 2010); and on the macro economy (cf. Alagidede et al., 2016; Dell et al., 2012; Jones and Olken, 2010) are expected to be immediate, negative, and stronger in the sub-Saharan Africa. This stems from the existing environmental conditions, least diversified and poor rural economies, and low level of agricultural development despite it is the main contributor to exports and the GDP.

[1] It should, however, be noted here that the climate change-migration nexus is very complex since non-climate drivers like population growth, poverty, governance, and physical and cultural distances remain as critical determinants (Brown, 2008; McLeman and Smit, 2006).

Ethiopia is one of the countries where the economic costs of climate change and variability are formidable (Arndt et al., 2011; Conway and Schipper, 2011; World Bank, 2010). The observed trends of the variance and mean climatic conditions since the 1960s (cf. World Bank, 2016; FDRE, 2015) have enormously influenced agricultural production (von Braun, 1991), rural consumption (Dercon, 2004), economic growth (Ali, 2012), food aid and emergency expenses (FDRE, 2015; World Bank, 2010), and temporary and permanent migration (Gray and Mueller, 2012; Ezra, 2001). Further, the mean annual temperature and the number of hot days and nights are sought to increase in Ethiopia despite the projections are sensitive to GHG emission scenarios assumed and climate models used (World Bank, 2016; Conway and Schipper, 2011). The projections also show that rainfall may become erratic but likely decline in Ethiopia's crop growing period (World Bank, 2016; Conway and Schipper, 2011). The combined effects of such projections will be increasing evaporation and plant transpiration rates, decreasing soil moisture, and hence shortening the length of the crop and grass growing period (Hertel and Lobell, 2014). These are apparently deleterious to rain-fed smallholder agriculture like in Ethiopia (Admassu et al., 2013).

Previous studies have shown that climate change in Ethiopia will pose palpable risks to agricultural productivity (Kassie, 2014; Admassu et al., 2013; World Bank, 2010), area suitable for crop cultivation (Admassu et al., 2013; Evangelista et al., 2013), net farm income per hectare (Deressa and Hassan, 2009), agricultural GDP (FDRE, 2015; World Bank, 2010), food aid and drought expenses (FDRE, 2015; World Bank, 2010), and total GDP (Arndt et al., 2011; World Bank, 2010). However, we are not aware of studies other than World Bank (2010) (and other two papers based on it, namely, Robinson et al., 2013 and Robinson et al., 2012) that pursue a structural approach to assess economic costs of climate change in Ethiopia.[2] Therefore, in this study, we attempt to build on and address some of the limitations with the aforementioned study.[3]

We pursue a simple yet leading to the same qualitative conclusion as World Bank (2010). First, World Bank (2010) uses single crop model with four combinations of GCMs and SRES to gauge uncertainty of impacts. However, we use two crop models with a combination of one GCM and RCP.[4] This is because crop models may gauge wider range than GCMs or emission scenarios (Rosenzweig et al., 2014). Second, we benefit from the latest available data, tools, and methods which enabled us to subsume the effects of climate change on all grain commodities.

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[2] Structural approach is a method that blend biophysical models with economic models to assess the economic effects of climate change (Adams et al. 1998).

[3] Of course, we are aware of partial equilibrium studies (and general equilibrium based on them) that draw crop productivity changes with respect to +1°C temperature estimates based on a Ricardian approach (i.e., Deressa and Hassan, 2009) to whose limitations are discussed well in the literature (cf. Adams et al., 1998).

[4] GCM (Global Climate (Circulation) Model), RCP (Representative Concentration Pathway) and SRES (Special Report on Emission Scenarios). Recently, the RCPs have replaced SRES as emission scenarios.

The World Bank (2010, Appendix, p.35) mentions that it apply the CliCrop crop model for seven key Ethiopian crops. However, it is not clear whether they have mapped (and how they mapped) with the crop activities/commodities of the economic accounts. We have offered clear method to map between yields simulated by crop models and crop commodities of economic accounts (see in Section 3.2 below). Third, unlike the hybrid approach in World Bank (2010), we apply a simple specification with regard to climate change effects on livestock productivity. Their hybrid approach is complicated (see World Bank, 2010 for details) and subject to the limitations of the Ricardian approach (see Seo and Mendelson, 2008 for details). Fourth, we use a static instead of dynamic CGE model. The projections about the biophysical effects in specific time are relatively uncertain than the average effects over a period of time. Therefore, the economic effects using dynamic CGE models are much more prone to uncertainties than static CGE models. Dynamic models make it hard to distinguish whether the sign and magnitude of economic consequences of climate change accrue to the climate change projections (and the related uncertainties) or socio-economic projections (and the related uncertainties) (FDRE, 2015; Pielke, 2007). The results may understate or overstate the economic cots of climate change which, either ways, will mislead the timing, the scale, and type of adaptation measures.

Therefore, compared to World Bank (2010) and the other two studies based on it, i.e., Robinson et al. (2013) and Robinson et al. (2012), we use different climate model, emission scenario, crop models, and a static CGE model. This is an advantage to check the robustness of the biophysical and economic impacts of climate change in the country which contributes planning adaptation besides addressing some of the gaps with the previous literature.

Most importantly, however, we bring up three more aspects which are relevant for the scientific as well as policy discourse on the subject in LDCs. First, we consider the case of outmigration from agricultural occupation that may be triggered or exacerbated by climate change. This is a topical question since rural livelihood is inextricably linked to agriculture in many LDCs. Second, we attempt to look at the role of structural change to underpin the resilience of an economy to climate change. This is important addition to the bourgeoning argument that development is the best adaptation to climate change in LDCs. Third, we couple economy-wide and regional analysis which, among others, is important for adaptation policy design and the related decision making process.

3. Materials and Methods

3.1. Climate change impact scenarios

We obtain a set of already processed historical (with current climate) and future (with future climate) crop and grass yield projections from the Agricultural Model Inter-comparison and

Improvement Project (AgMIP).[5] Uncertainty is inherent in climate change impact projections. This may accrue to one or combination of the emission scenarios, climate models, and biophysical impact models used in projections. Previous studies indicate no major differences among RCPs for the 2050s (Moss et al., 2010) and, for a specific crop, crop models imply wider uncertainty than RCPs or GCMs (Rosenzweig et al., 2014). We also check and find corroborating both arguments.

Therefore, we pick the case of two global gridded crop models (GGCMs) in order to gauge uncertainty of biophysical impacts. Since this study is an economy-wide study, we shall focus on the combination of GGCM, GCM, and RCP with which projections are available for relatively large number of crops in our data source. In light of this, we find the projections of LPJmL and EPIC crop models using HadGEM2-ES climate model with RCP8.5 emission scenario to be relatively better combinations. LPJmL is a global ecosystem-based crop model while the EPIC model is a site-based crop model (see Rosenzweig, et al., 2014 and Müller and Robertson, 2014 for more details). The yield projections are with no CO_2 fertilization effects since its actual benefit are small (see Müller and Robertson, 2014 and references within). The biophysical projections are also with 'no-irrigation' assumed as agricultural production in Ethiopia is virtually rain-fed (FAO, 2015; AgSS, 2014) while it is unlikely for the country to have 'full-irrigation' (the other irrigation scenario for AgMIP-GGCM projections) in the next two decades.

In short, this study considers two climate change impact scenarios. Hereafter, for convenience, we simply refer them as LPJmL and EPIC scenarios. However, due to our RCP and GCM choice, one may regard both of our impact scenarios as 'dry' or 'high-end' impact scenarios.

3.2. Climate change and crop productivity

The AgMIP-GGCMs simulate results for globally important crops at a spatial resolution of 0.5x0.5 degree (approx. 50x50 km at the equator) (Rosenzweig et al., 2014; Müller and Robertson, 2014). Therefore, we take four steps to map the yield projections by AgMIP-GGCMs into our CGE model.

First, we use the AgMIP Tool (https://mygeohub.org/resources/agmip) to obtain the mean annual yields for different AgMIP-GGCM crops from 1980 to 2065 for Ethiopia. See Villora et al. (2016) for more about the tool and the aggregation procedures. However, to be consistent with the literature (see for example, Admassu et al., 2013; World Bank, 2010; Nelson et al., 2010),

[5] See more at www.agmip.org or www.isimip.org

we compute the effects of climate change on crop yields as the average yield in 2050s (2035-2065) compared to the average yield in 1990s (1980-2010). The LPJmL model is applied to maize, millet, cassava, groundnut, peas, sunflower, rapeseed, rice, soybean, sugar beet, sugarcane, wheat, and managed grass. And, the EPIC model is applied to barley, maize, millet, dry bean, cassava, cotton, groundnut, sunflower, rapeseed, rice, sorghum, soybean, sugarcane, and wheat. However, some of AgMIP-GGCM crops (e.g. rice and cassava) are economically less important in Ethiopia while some others (e.g. potatoes, sugarcane) are not directly represented in the country's economic accounts. On the other hand, Ethiopia produces many crops some of which (e.g. teff and enset) are local and economically important. For instance, the list of crop activities in the original Ethiopian-SAM include barley, wheat, maize, sorghum, teff, pulses, oilseeds, vegetables and fruits, coffee, enset, cash crops, and crops not elsewhere classified (EDRI, 2009).

Second, therefore, we follow the suggestion by Müller and Robertson (2014) and Hertel and Lobell (2014) to map the AgMIP-GGCM crops with the Ethiopian-SAM crops. Accordingly, we first establish similarity between crops the basis of their photosynthetic pathway and main climatic zone suitable for the crops. Barley, teff, and wheat are 'cold' crops as they grow in areas with mild temperature and reliable rainfall (AgSS, 2014). The AgMIP-GGCM soybean and field pea fall in 'pulses', and the AgMIP-GGCM groundnuts, rapeseed and sunflower fall in 'oilseeds' crop of the Ethiopian-SAM (AgSS, 2014; 2006; EDRI, 2009). Next, we compute the correlation coefficients between the yields of the 'similar' crops using 20 years yield data from CSA (2015). We find high correlation coefficients ($r \geq 0.85$) among barley, teff, and wheat yields; between the average yield of soybean and field pea, and the average yield of pulses; and between the average yield of groundnuts, rapeseed, and sunflower, and the average of yield of oilseeds. The exercises so far gives us yield changes for the seven grain activities/commodities of the original SAM. However, the yield projections and changes may be sensitivity to the crop model artifacts in case the crop model simulates with very low reference productivity (Müller and Robertson, 2014; Nelson et al., 2010).

Third, in order to control sensitivity to such variations (cf. Nelson et al., 2010; Müller and Robertson, 2014), we impose upper (+30%) and lower (-30%) limits to yield changes due to climate change. The procedure give us rounded up average capped grain yield change -10% (LPJmL scenario) and -26% (EPIC scenario). The average as well as specific crop yield changes are in the range of global projections (cf. Müller and Robertson, 2014) and regional projections (cf. Müller et al., 2014; Knox et al., 2012; Nelson et al., 2010).

Fourth, we model these average yield changes as shocks to the efficiency parameter of the grain activity of the calibrated CGE model. Grain crops account for about 84% of total crop area and 66% of all smallholder agricultural land use (AgSS, 2014), and 37% and 18% of agricultural and total GDP at factor cost, respectively (EDRI, 2009).

3.3. Climate change and livestock productivity

The tropical smallholder livestock farming system is sensitive to climate change (Nardone et al., 2010; Seo and Mendelsohn, 2008). Climate change impinge on livestock productivity directly (e.g. growth, physiological performance, and immunity) as well as indirectly (e.g. quality and quantity of forage, water availability, and pests and diseases) (Adams et al., 1998). Nevertheless, unlike for crops, there are no publicly available large-scale physiological models to directly link climate change and livestock productivity (Weindl et al., 2015). However, according to Nardone et al. (2010), the indirect effects are the dominant channels for the case of tropical livestock. Consequently, we here pursue a simplistic approach that link climate change, forage quantity, and livestock productivity.

We can say that about 87% of the total animal feed in Ethiopia (i.e., 59% green fodder and 28% crop residue) is climate sensitive (AgSS, 2014; 2006). We assume that the sum of climate change induced managed grass yield change and grain yield changes, multiplied by their shares in the total animal feed, can represent climate change effects on forage quantity. However, change in forage quantity represents only part of how climate change can impact on livestock productivity. Therefore, we merely assume that forage quantity changes represents only 30 percent of total climate change effects on livestock productivity in Ethiopia. The procedure gives us climate change effects -2% (LPJmL scenario) and -5% (EPIC scenario). We plug them as shocks to efficiency parameter of livestock activity of the calibrated CGE model. In our SAM, livestock output accounts for 30% and 14% of agricultural and total GDP at factor cost, respectively (EDRI, 2009).

We want to underline that our approach is very simplistic. However, the proposed approach makes sense when we consider the importance of the sector, the production structure, the sensitivity of the production system to climate change, and increasing competition for land use in the Sub-Saharan Africa region in general and in Ethiopia in particular.

3.4. Climate change and agricultural labor migration

Climate change may exacerbate rural-to-urban, or at least, agriculture-to-non-agriculture migration in Ethiopia. Nevertheless, it is remains hard to explicitly untangle the exact number of climate change induced migrants (Brown, 2008). This is particularly true for Ethiopia where current regulations make a decision to permanently migrate very hard (Dorosh and Thurlow, 2011). On the other hand, the scant migration statistics in Ethiopia do not provide sectoral migration nor it is easy to do so from the available statistics. As a result, we only attempt to extrapolate climate change induced migration based on the macro and micro evidences of rural-to-urban migration.

Evidences show that rural-urban migration in Ethiopia is increasing over time. For example, between 1999 and 2013, while the total recent migrants increased by 67%, the number of rural-urban recent migrants rose by 130% (NLFS, 2013; 1999).[6] Rural-urban migration is also catching up the rural-rural migration which has been the dominant form of migration for decades. In 2013, the rural-urban migrants accounts for 33% (up from 24% in 2005) of the total recent migrants whereas rural-rural migrants accounts for 35% (down from 46% in 2005) (NLFS, 2013). Evidence from the macro level reports (e.g. NLFS, 2013; 2005; ICPS, 2012) and the micro level studies (e.g. Gebeyehu, 2015; Gray and Mueller, 2012; Miheretu, 2011; Dercon, 2004; Ezra, 2001; Ezra and Kiros, 2001) attribute the increasing rural-urban migration to the fast growing population, environmental degradation, low agricultural productivity, and recurrent droughts and famines in rural areas.

The macro evidences show that the number of rural-urban migrants due to droughts and land scarcity in their areas of origin are increasing over time. For instance, between 1999 and 2013, recent migrants that mentioned shortage of land as their main reason of migration increased by 240% in urban areas and by 50% in rural areas (NLFS, 1999; 2013). The micro evidences are blunt on the correlation between environmental changes and rural-urban migration. For example, the male migration rate for employment increases from 1.4% in no drought periods to 2.6% in severe drought periods (Gray and Mueller, 2012). About 40% of male and 31% of the total sample migrants from rural areas to Woldiya town, northern Ethiopia, relate their emigration to famine, poverty, land shortages, and crop failure (Miheretu, 2011). Similarly, Gebeyehu (2015) finds that population pressure, shortage of land, food insecurity, drought and lack of non-farming opportunities are the major reasons of rural-urban migration in Damot Galie district in southern Ethiopia. In other words, Ethiopian rural households see migration as their risk management and coping strategy during droughts (Gray and Mueller, 2012; Dercon, 2004; Ezra, 2001; Ezra and Kiros, 2001).

On the basis of these macro and the micro evidences, we arbitrarily assume that LPJmL and EPIC climate change scenarios may push out one half and one million labor from agriculture, respectively. The numbers are not far from the scant evidence on environmental change related migrants. For example, the government resettled more than one half million households in response to the infamous 1984/85 drought that stroke northern Ethiopia (Ezra

[6] Recent migrants are people who have changed their place of residence in within the five years prior to the survey (NLFS, 2013; ICPS, 2012).

and Kiros, 2001). Droughts and shortage of land are reasons for about 0.15 million migrants of the total 3.8 million recent migrants (NLFS, 2013). We also know many of such migrants are heading to urban areas. For instance, between 1999 and 2013, recent migrants that mentioned shortage of land as their main reason of emigration increased by 240% in urban areas but by 50% in rural areas (NLFS, 1999; 2013).

We consider and model 'migration' as movement between agricultural and non-agricultural occupations which, in the calibrated CGE context, is equivalent to migration from agricultural to non-agricultural sectors. More specifically, we model it as an exogenous phenomenon that reduces labor in agricultural occupation but increases labor in elementary (jobs that need no specific skills) occupation by the same units of labor. As such, the general equilibrium effects of migration mainly accrue due to changes in wage rates and factor substitution effects. The aforementioned migration figures are equivalent to shocks to agricultural labor supply (LPJmL = -2% and EPIC = -4%) and to unskilled labor supply (LPJmL = +36% and EPIC = +73%).

Our approach requires less information with regard to the specific industries and regions of origin and destination. The migration can be temporary or permanent while the emigrants from agriculture can stay in rural areas and work in cottage manufacturing industries (e.g. weaving, tanning, grain milling, own water supply, and the likes).

3.5. Structural change scenarios

We treat structural change as a cost-free exogenous shock to the calibrated CGE that simultaneously occurs with climate change. The sources of structural change are beyond the scope of this study. However, it may be driven by the rapid economic growth rate of 10% per annum in the last twelve years (NBE, 2016), the government's commitment to expand micro and small enterprises (NPC, 2016), and the rapid urbanization rate (ICPS, 2012). It may also accrue to the bulk of public investment in human capital, transport and communications, energy, institutions, and markets (NBE, 2016; NPC, 2016; ERA, 2010). On the basis of the observed and planned developments in the country, we construct some reasonable structural change scenarios which we discuss below. Our interest here is only to see whether such changes in the economy would help to dampen the adverse economic consequences of climate change.

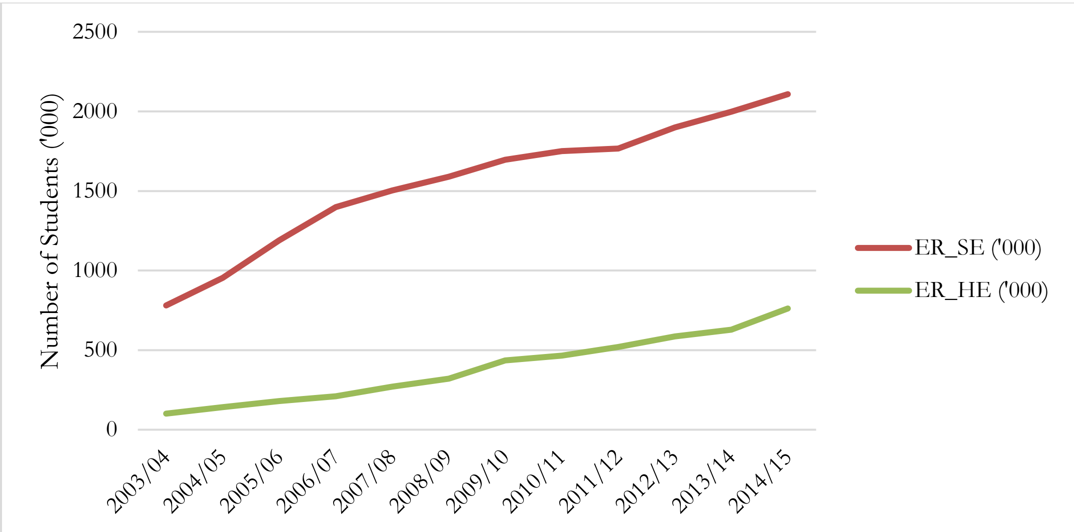
3.5.1. Improving labor skills

Labor markets are among the markets in an economy where structural change manifests itself. Structural change will deploy labor (of course many of the productive factors) from primary (e.g.

agriculture) to secondary (e.g. manufacturing), and then to tertiary (e.g. wholesale and retail trade) sectors. It is also represented by accumulation of labor skills and increase in labor productivity.

The ratio of education (especially that of higher education) to the total government expenditure in Ethiopia has increased in the past two decades (MoE, 2016; MoFED, 2015) along which literacy rate, enrollment rates, and number of graduates are increasing steadily (MoE, 2016). The adult literacy rate (>15 years old), and the youth literacy rate (15-24 years old) increased from 36% to 49%, and from 50% to 69%, respectively, between 2004 and 2015 (WDI, 2016). The net enrolment rate in primary education (Grade 1-8) tremendously increased from 22% in 1995/96 to 94% in 2014/15 (MoE, 2016). Similarly, in the period of 2004/05-2014/15, the number of undergraduates and postgraduates grew at average annual growth rate of 30% and 32%, respectively (MoE, 2016). These observed trends in the education sector will modify the structural features of the present labor markets. Among others, it narrows down the skill differences among different labor segments giving the possibility to migrant from agricultural occupation to other labor occupations that may even require specific skills which include skilled workers (FLAB4), professional and technical associates (FLAB2), and administrative workers (FLAB1).[7]

Figure 1. Trends in number of enrolled students in secondary and higher education



Source: Authors' illustration based on data from MoE (2016)

We construct a set of experiments (Scenario A) that represent changes in labor skills narrowing down the skill differences required for different labor segments (occupations). Under

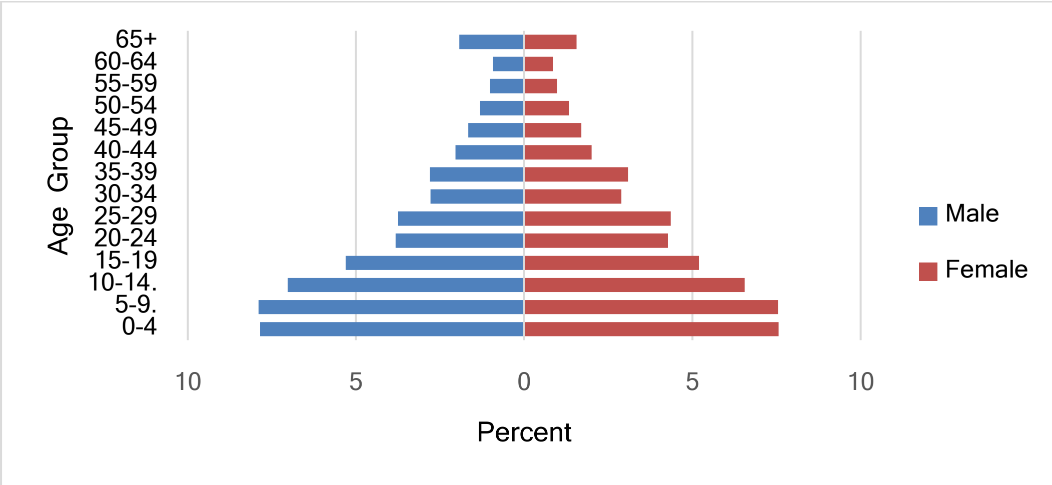
[7] The name of the labor segments are kept as given in the original SAM (EDRI, 2009) to ease correspondence. The 'skilled' labor segment includes workers that have some skills obtained through formal education and training, experience or informal training (EDRI, 2009)

these scenarios, for a portion of agricultural workers, working in agriculture would be a matter of preference not of skill. When the agriculture sector is hit by external shocks such as climate change, this portion of agricultural labor would easily 'migrate' to other labor segments. Climate change induced migration decreases agricultural labor supply (FLAB0, currently 25.4 million workers) and increases the labor supply in other segments by the same units of workers. Since farmers usually do not possess skills other than farming, what would normally happen is migration to elementary occupation (i.e., FLAB3, currently 1.4 million workers). This is what we did in Section 3.4. This will serve as a benchmark occupational migration scenario. For the same portion of the agricultural labor (FLAB0, currently 25.4 million workers), we construct three additional occupational migration scenarios which will definitely depend on the strength of the public investment in human capital.

First, with small investment in basic literacy and skill trainings, migration into 'skilled' labor category (FLAB4, currently 4.8 million workers) may be possible. Second, with considerable investment in education and training, migration to professional and technical associates occupation (FLAB2, currently 0.5 million workers) may be possible. Third, with huge investment in human capital, especially in the long-run, migration to administrative occupation (FLAB1, currently 0.1 million workers) may be possible. One can think of these investment in education and training target the current working children (10-15 years old) that account for about 16% (the bulk of which is in agriculture) of the country's total labor force (NLFS, 2013; 2005). Such migration between occupations maintains the total labor supply in the economy fixed at observed level. Absence from the labor market at the time of education and training, the period of time required to finish and attain the set of skills to fit to a specific labor segment, and similar issues are beyond the scope and objectives of this study.

Alternatively, we consider as if a structural change that helps to harness the net labor supply due to demographic structure of the country. As shown in Figure 2 below, about 45% and 3.5% of the total population in Ethiopia, respectively, is aged below 15 and above 65 years (NLFS, 2013).

Figure 2. Population pyramid of Ethiopia



Source: Authors' illustration based on data from NLFS (2013)

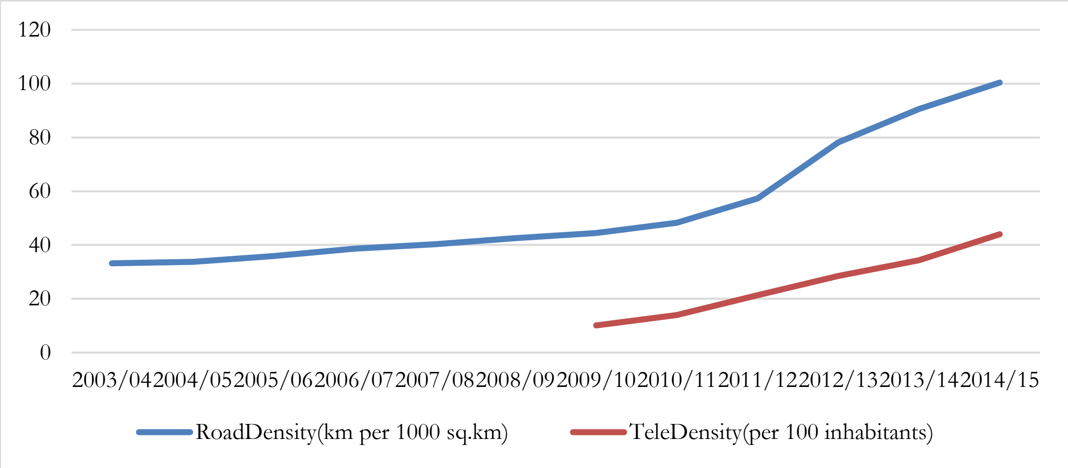
Structural change in the country may help to harness this opportunity positive net labor force supply every year shown in the population pyramid (see Figure 2). Therefore, we design a structural change Scenario B, which stems from the investments in education and human capital and enables the economy to allocate, say, an extra one half million workforce in to either of the five labor segments indifferently. To control the economy-wide effects that accrue to the total labor supply increase, the benchmark among Scenario B's experiments would be allocating the extra labor to agriculture.

3.5.2. Squeezing marketing margins

Poor transport and marketing infrastructure are among the main reasons of market inefficiency and high marketing margins in LDCs. Ethiopia is a typical example. Transportation is still a barrier and main contributor to higher transaction cost and market inefficiencies, especially, in agricultural product markets. About 83% of the gross grain marketing margins accrue to physical marketing costs related to transport, handling, and other marketing activities (Gabre-Madhin, 2001). Transport costs account for 6-21% of market prices per quintal of maize, sorghum, and millet in rural villages surrounding Atsdemariam town in the North West Ethiopia (Stifel et al., 2016).

Therefore, transport and communication is one of the sectors Ethiopia has remarkably invested in the past two decades. Road density per 1000 km^2 increased from 30km in 2001/02 to 100km in 2014/15 while roads connecting rural villages and communities grew by 162% per annum on average between 2007/08 and 2014/15 (NBE, 2016).

Figure 3. Trends in transport and communications



Source: Authors' illustration based on data from NBE (2016)

As a result, the average distance to reach to a nearby all-weather road is declining, for instance, from 21km in 1997 to 11km in 2010 (ERA, 2010). The government is striving to double the road density by 2019/20 and halve the distance to reach to all-weather roads while new railway network constructions are underway (see NPC, 2016 for more). Similarly, the telecom density, mobile plus fixed telephone subscribers per 100 inhabitants, increased from 10 in 2009/10 to 44 in 2014/15 (NBE, 2016). These developments in transport and communications are already contributing to domestic market integration while lowering trade margins (NPC, 2016) and narrowing the regional price disparities (NBE, 2016). Thus, we construct Scenario C such that the observed and projected development of transport and communication networks in the country will reduce transaction (marketing) costs in the economy, arbitrarily, by 10% in all market-commodities. Other things remaining constant, reducing transaction costs increases producers' income for a given demand price or reduces consumer price for a given producer price. For a given set of world export and import prices, lower transaction costs increases the domestic receipt from exports but decreases the domestic expenditure on imports.

Table 1 below summarizes the CGE experiments. The economy-wide and regional effects of the simulations presented are discussed in the subsequent two sections. The economy-wide effects are simulated by the CGE model while the regional effects are obtained by projecting economy-wide effects on sectoral output in to a regional module depicting economic structure of regions. The description of the CGE model, its database (i.e., SAM), and calibration along with construction of the regional module and regional projections are presented in detail in Appendix 2.

Table 1. Summary of CGE simulations

Simulation	Description
Climate change without structural change	
LPJmL-P	Productivity effects on grain and livestock activities, simulated by LPJmL model
EPIC-P	Productivity effects on grain and livestock activities, simulated by EPIC model
LPJmL-M3	Migration from agriculture to elementary occupation, related to LPJmL model
EPIC-M3	Migration from agriculture to elementary occupation, related to EPIC model
LPJmL-PM3	Productivity plus migration effects, LPJmL scenario
EPIC-PM3	Productivity plus migration effects, EPIC scenario
Climate change with structural change	
EPIC-PM4	EPIC-P & migration from agriculture to skilled occupation
EPIC-PM2	EPIC-P & migration from agriculture to professional occupation
EPIC-PM1	EPIC-P & migration from agriculture to administrative occupation
EPIC-PL0	EPIC-P & extra labor force allocated to agriculture occupation
EPIC-PL3	EPIC-P & extra labor force allocated to elementary occupation
EPIC-PL4	EPIC-P & extra labor force allocated to skilled occupation
EPIC-PL2	EPIC-P & extra labor force allocated to professional occupation
EPIC-PL1	EPIC-P & extra labor force allocated to administrative occupation
EPIC-PTC	EPIC-P & reductions in transaction costs
EPIC-PM3TC	EPIC-PM3 & reductions in transaction costs

4. Economic effects of climate change without structural change

Economic effects of climate change without structural change refers to the economy-wide and regional effects of shocks to grain productivity (section 3.2), livestock productivity (section 3.3) and agricultural labor supply (section 3.4). The economy-wide and regional analysis show that these primary effects in agriculture have profound economic consequences.

The households' real consumption declines in a range of 0.3% to 9% corroborating Arndt et al. (2011) and Dercon (2004) that have similarly shown the sensitivity of Ethiopian households' consumption to climate change and variability. Exports decline by 2.8% to 7.8% impeding the country's trade balance. The total GDP declines by 2.6% to 8%, and is larger than the total absorption decline (2% to 6.5%). This indicates that imports may have a potential to dampen the macroeconomic effects of climate change affirming the previous studies' claim (see for example, Robinson et al., 2012 and World Bank, 2010). The macroeconomic effects of the presumed migration scenarios are negligible which also substantiates Dorosh and Thurlow (2011) that argue that rural-urban migration in Ethiopia positively affects the macro-economy. As one would expect, climate change hits hard agricultural activities. The effects could reach -26%, under EPIC-PM3 scenario, for grain output. The shocks to grain and livestock activities ripple through the rest of agricultural activities which include enset crops, cash crops, and fishing and forestry (see Table 2). This is explained by the increasing competition for cropland and agricultural labor. The agricultural labor supply shocks (i.e., only migration scenarios) cause proportional fall in agricultural output. This contrasts with previous micro studies which find no or little effect of migrating out from agriculture on agricultural productivity (de Brauw, 2014) and agricultural output (Wondimagegnehu, 2015).

Table 2. Sectoral output effects of climate change (without structural change)

Activity	Simulations (% change)					
	LPJmL-P	**EPIC-P**	**LPJmL-M3**	**EPIC-M3**	**LPJmL-PM3**	**EPIC-PM3**
Grain crops	-9.3	-24	-1.7	-3.4	-10.8	-25.6
Cash crops	-3.8	-13.1	-1.5	-3.1	-5.5	-15.7
Enset crop	-3.4	-10.4	-0.8	-1.7	-4.2	-11.6
Livestock	-4	-11.4	-1.3	-2.7	-5.3	-13.6
Fishing & forestry	-2.5	-8.1	-1.1	-2.2	-3.6	-10
Mining & quarrying	0.8	2.2	1.6	3	2.4	5.1
Construction	0	-0.1	0	0	0	0
Manufacturing	2.5	7	3.5	6.7	6	13.2
Wholesale & retail trade	-1.6	-5	0	0	-1.6	-4.8
Hotels & restaurants	-0.8	-3.2	0.5	0.8	-0.4	-2.6
Transport & comm.	1.2	4	0.7	1.4	2	5.6
Financial intermediaries	0.2	0.5	0.8	1.4	0.9	1.9
Real estate & renting	0	0	0.1	0.2	0.1	0.2
Public admin. (general)	0	0	0	0	0	0
Public admin.(agriculture)	0	0	0	0	0	0
Social services	0.1	0.1	0.3	0.6	0.4	0.7
Other services	1.1	3.3	5.1	9.8	6.2	13.5
Total GDP at factor cost	-2.7	-7.6	-0.2	-0.5	-2.9	-7.6

Source: CGE simulations

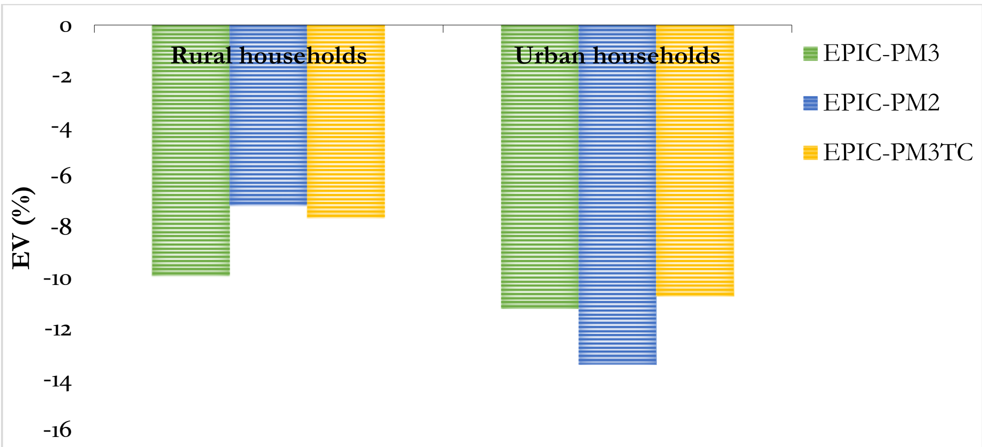
In Table 2, with increasing productivity shocks, we see repercussions to some non-agricultural activities (e.g. hotels and restaurants, and construction) that use agricultural commodities as intermediate inputs. Likewise, since agricultural commodities contribute to the total traded output of the economy, we see wholesale and retail trade output declining.

Declining agricultural output pushes up domestic agricultural prices which eventually alters the ratio of domestic prices to export (and import) prices. As a result, agricultural exports decline while agricultural imports increase which, in order to maintain the trade balance, will require to increase exports (and decrease imports) of non-agricultural commodities. The latter requires to increase non-agricultural output which is reflected on manufacturing (2.5 to 13%), transport and communications (1 to 6%), 'other' services (1 to 13%), and minerals and quarrying (1 to 5%) activities. The output from these activities increases, partly to fill the export gap (e.g. manufacturing, transport and communications, and 'other' services), and partly to fill the gap in domestic demand created as a result of declining import variety (e.g. manufacturing, and mining). Activities which employ the bulk of unskilled labor (e.g. manufacturing, 'other' services) will expand further under migration scenarios. Adding migration scenarios offset some of the indirect effects due to productivity shocks in those activities (e.g. wholesale and retail trade, and hotels and restaurants) with non-negligible share of unskilled labor.

In general, Table 2 depicts, the negative effects of climate change are largely contained in agriculture. However, revealing the contribution of agriculture, the impacts on agricultural output vividly influence the macroeconomic effects (e.g. GDP at factor cost, GDP at market prices, and exports). Nevertheless, the ripple effects on the rest of economic sectors are not as large as expected. This attributes to the low factor reallocation effects, the weak inter-industry linkage, and the low households' demand elasticities. Factor reallocation effects are apparently weak as the majority of agricultural factors of production (cropland, livestock units, and agricultural labor) are used only in agriculture. The interlinkage between agriculture and nonagricultural activities is weak as the majority of agricultural output is consumed at home by rural households while the two main intermediate inputs in agriculture are self-produced (i.e., seeds) and entirely imported (i.e., fertilizer). Nor shall we expect strong effects through relative commodity prices change. The income elasticities are low as Ethiopia is low-income country while the LES demand system implies low own-price and cross-price elasticities and assumes commodities are gross complements to each other (de Boer and Missaglia, 2006).

Climate change effects on commodity supply and prices as well as factor wages and demand, eventually, influence rural and urban households' welfare. Climate change increases factor competition among agricultural activities. This drives up wage (and income) of agricultural labor and land which would contribute to total rural household income. However, increasing agricultural prices dominate to result in negative rural households' welfare effects. Urban households' wellbeing is affected from both declining factor incomes (of especially non-agricultural labor) and increasing agricultural (food) prices. Therefore, in Figure 4, we see that the welfare effects to urban households (-0.3% to -11%) are slightly worse than to rural households (-0.3% to -10%). Besides, adding the migration scenarios on top of productivity shocks worsen the welfare loss of both household groups, especially, that of urban households.

Figure 4. Households' welfare effects of climate change (without and with structural change)

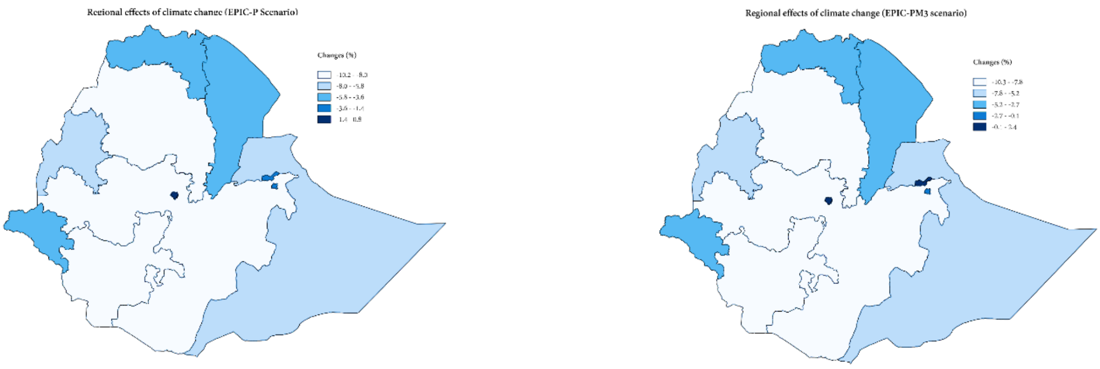


Source: CGE simulations

It is important to note here that households' welfare effects are also influenced by the income, own-price and cross-price elasticities of demand which all can be said low. We have also set Frisch parameters which impose minimum (mandatory) consumption for both household groups. All of these make the households' consumption spending is less responsive to income and commodity prices changes. Therefore, implicitly, households will forgo their savings and transfers to other institutions to smoothen their consumption during harsh times. This corroborates with the findings of micro studies (e.g. Dercon, 2004; von Braun, 1991) according to which asset selling is the common method of consumption smoothing during the periods of droughts.

The regional effects of climate change range from -4.1% to +1.1% (in LPJmL scenario), and from -10.3% to +2.4% (in EPIC scenario). The effects are adverse and strong in the three largest agrarian regions of the country, i.e., Oromia, Amhara, and Southern NNP states. Under each of the experiments, the effects to these regions are larger than the Ethiopia-wide effects as well as the effects in every other region. In contrast, climate change effects are relatively low in urbanized regions like Addis Ababa, Dire Dawa, and Harari. The changes in Addis Ababa city are favorable under all impact scenarios. This is expected as the contribution of agriculture to Addis Ababa's GDP is negligible (see Table 2A).

Figure 5. Regional effects of climate change (without structural change)



(a) | (b)

Source: Regional Projections

Figure 5 shows that climate change induced occupational migration may offset the productivity shock effects in regions with significant shares of non-agricultural industries (i.e., Addis Ababa, Dire Dawa, and Harari) and to some extent Tigray and Afar. Conversely, the presumed occupational migration scenarios may worsen the effects in Southern NNP, Amhara, Oromia, and Somali regions. By implication, since there is no constraint over inter-regional migration, the agricultural labor migrants from agrarian regions may end up in the manufacturing and services sectors of the urbanized regions. The national migration statistics affirms our argument. The net migration rate per 1000 people was positive and high in Addis Ababa (430) and Dire Dawa (289) but negative in Amhara (-64) and Southern NNP (-27) (ICPS, 2012). Nevertheless, it is important to remind the reader that the direct and indirect costs of immigration to receiving regions are not accounted here. If such costs are high, which probably may be, climate change induced migration will have negative consequences for both regions of origin (i.e., agrarian regions) and regions of destination (i.e., urbanized regions).

The regional projections also show that the regional effects of climate change depend on the regional economic structure per se and relative to the national economic structure. For instance, Tigray is an agrarian region. However, the role of grain activity in Tigray is relatively smaller than in Ethiopia. It follows that the effects of climate change on Tigray-wide GDP are relatively smaller than the effects on Ethiopia-wide GDP.

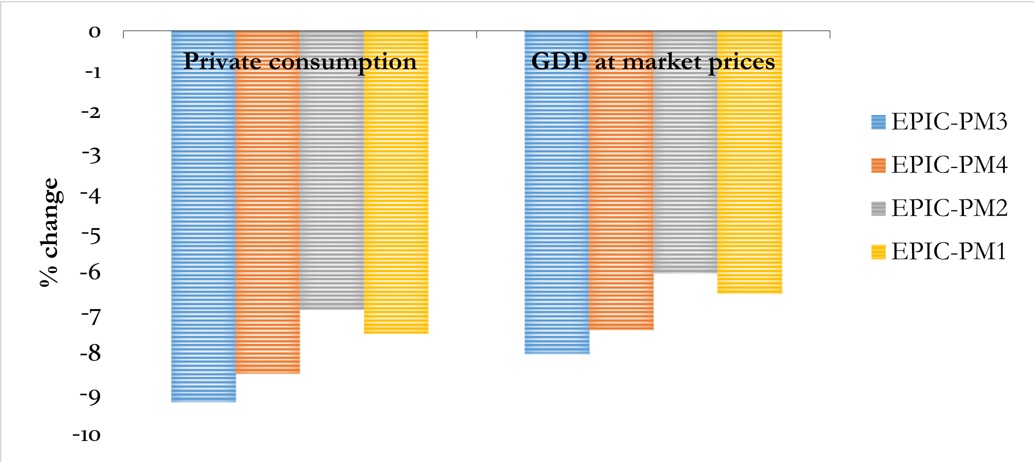
Therefore, regional economic diversification may help to trap and benefit from climate change induced migration in the same region. This explains the case of Tigray, Afar, and Harari regions where there are some sectors, other than grain and livestock, with important contribution to their regional GDP. Therefore, occupational migration tends to dampen the regional effects of productivity shocks in such states (see Figure 5a & 5b).

5. Economic effects of climate change with structural change

We go further to investigate the role of cost-free exogenous structural change scenarios (see section 3.4) to offset the adverse effects of climate change presented in the preceding section. We focus and present the economy-wide and regional effects under the EPIC impact scenario.

The indirect effects of climate change on the macro-economy, non-agricultural economic activities, and households' real consumption gets relatively smaller with Scenario A experiments. The redeployment of agricultural labor (i.e., 4% of total agricultural labor) to the skilled (EPIC-PM4), professional and technical associates (EPIC-PM2), or administrative occupations (EPIC-PM1) results in about 20-30% smaller effects compared to the benchmark migration scenario (EPIC-PM3). The offsets are strong with immigration into professional and technical associates (see Figure 6). The offsets to the aggregate households' welfare are also similar to that of the offsets to the GDP. Nevertheless, any form of occupational migration relatively increases (decreases) the real wage rate and factor income of agricultural labor (non-agricultural labor). Therefore, in Scenario A simulations, the rural households' welfare effects are relatively dampened while that of the urban households' welfare effects worsen (see Figure 4).

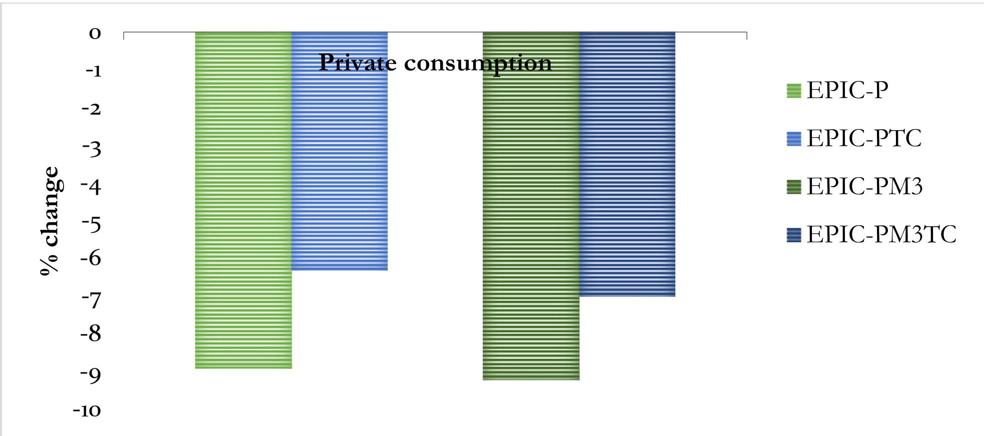
Figure 6. Macroeconomic effects of climate change (Scenario A)



Source: CGE simulations

Similarly, Scenario *B* simulations show that the economy would be better climate-resilient if the next generation of labor force is directed towards professional and technical associates. For instance, the adverse effects on GDP in the case of allocating the extra labor force to professional occupation (-5.7%) is lower than allocating the same units of labor to agricultural occupation (-6.7%) or elementary occupation (-7%) (see also Table 1A). The total households' welfare effects in the case of allocating to professional and technical associates are lower than allocating to the agricultural occupation by 1.5 percentage points. However, allocating the extra labor force into occupation other than agriculture may worsen the urban households' welfare (see Table 1A for more).

Figure 7. The effects of climate change on households' consumption (Scenario C)



Source: CGE simulations

Reducing transaction costs could offset the effects on households' consumption by around two percentage points (see Figure 4). The offsets are clearer on rural households (see

Figure 4). This may attribute to relatively increased net agricultural revenue, for instance, due to increased domestic receipts from exports as transaction costs decline.

The regional projections also show that migration and allocation to professional labor bear better outcomes (see Table 1A). Regional GDP of urbanized states expands, particularly, with labor-oriented structural change scenarios. For instance, regional effects to Addis Ababa increase by one to five percentage points compared to without structural change scenarios. This is expected as Addis Ababa and other urban states of the country mainly depend on manufacturing and services that employ skilled labor. For the agrarian regions (e.g. Southern NNP, Amhara, and Oromia), migration into other skill categories will slightly dampen (or leave unchanged) the productivity shock effects. Allocation of the extra labor force to non-agricultural occupations also increases the gains to the urban regions' GDP in particular. However, reductions in transaction costs affects the wholesale and retail trade output which include the trade margins realized on all marketed-commodities. As a result, the effects to Harari and Dire Dawa regions get worse despite shrinking transaction costs is important to the macro economy (see Table 1A).

One may raise two more questions with regard to climate change effects with structural change (see Table 1A for more). First, all structural change scenarios hardly modify the effects on grain and livestock output, and the indirect effects on other agricultural activities' output. This is expected since structural change would do nothing for preventing (or even modifying) the direct biophysical impacts of climate change. In other words, structural change absorb the primary effects in agriculture but offset the ripple effects to the rest of the economy. Second, the offsets with the structural change scenarios are not big as such although the transition (transformation) costs leading to such scenarios are not accounted here. This, however, is not a surprise since we did not modify the macroeconomic relevance of agricultural sector. The policy implication is that non-agricultural sectors' expansion, parallel to upgrading labor skills and reducing transaction costs, would further offset the adverse effects. Yet, since we do not consider the transition (transformation) costs, the dampening effects shall be taken as the upper boundary that shall be expected from the structural changes we assumed.

In summary, the results indicate that improving labor skills, and market connectivity and efficiency contribute to climate-resilient economic development in Ethiopia. Therefore, the country can expect co-benefits from its current growth and structural transformation plans (see for example, NPC, 2016).

6. Conclusions and policy implications

We assess the economic effects of climate change without and with structural change presumed. The economy-wide analysis without assuming a structural change shows that climate change reduces agricultural output, increases agricultural prices, alters the trade mix, and profoundly affects households' welfare. The macroeconomic effects on aggregate GDP and households' welfare resemble that of the effects on agricultural GDP and rural households' welfare, respectively. The macroeconomic effects of the presumed migration scenarios are negligible despite their effect on agricultural output remains important. In general, the indirect effects of climate change on non-agricultural sectors are not as big as expected. This attributes to the structural features of the economy that include weak inter-industry linkages, the use of the bulk of agricultural output for own (rural) household consumption, low income and price elasticities, and virtually void of factor competition between the agriculture and the non-agricultural sectors. Even though we use different materials and methods, our findings and general conclusions substantiate the findings of previous studies on similar topics for Ethiopia (see for example, Robinson et al., 2012; Arndt et al., 2011; World Bank, 2010; Dorosh and Thurlow, 2011; Dercon, 2004). The regional analysis shows that the regional effects of climate change primarily depend on the share of agriculture in the regions' GDP, and therefore, are uneven among regional states. The effects are negative and strong in some agrarian regions (e.g. Amhara, Oromia, and Southern NNP) but positive in Addis Ababa and less adverse in other urbanized regions (e.g. Dire Dawa and Harari). The regional analysis also shows that diversifying regional economies may help to harness opportunities that may arise with migration from agriculture. Otherwise, migration from agriculture may widen regional disparity and impair the economic prospects of sending agrarian regions (due to loss in productive labor) as well as receiving urban regions (due to pressure on real wage rates and on infrastructure).

The economy-wide analysis of climate change with cost-free exogenous structural change scenarios indicates that structural change would contribute to climate-resilient economic development in Ethiopia. This substantiates the view that structural change underpins the resilience of least developed countries to a multitude of shocks including climate change. However, the regional analysis show that the type of structural change may matter for the regional effects. The offsetting effects of labor related structural change scenarios lean towards urban regions in contrast to that of transaction cost related scenarios which lean towards agrarian regions. The former would expand urban output but impinge on the urban households: The latter would have clear effect to households' welfare, especially, to rural households.

In general, the economic effects of climate change in Ethiopia call for public action for adaptation in agriculture. Given the importance of the sector in the present economic structure, and potency and the likelihood of the biophysical impacts, postponing adaptation in agriculture in the country may hamper the economic development (Millner and Dietz, 2015), and may narrow the spectrum of adaptation in later stages (Müller et al., 2014). However, on the other hand, our findings show that structural change may contribute to climate-resilient development in the country. This affirms the arguments raised elsewhere in the literature (e.g. Henderson et al., 2017; Millner and Dietz, 2015; Mendelsohn, 2012; Fankhauser and Schmidt-Traub, 2011). Therefore, the current economic growth and transformation plans of Ethiopia (see for example, NPC, 2016 and MoFED, 2010) may also contribute to the resilience of the economy to climate change. The policy challenge may be how to allocate the country's scarce public resources between the short-term (i.e., public adaptation in agriculture) and long-term (i.e., structural transformation) goals of the country, and to promote private investment compatible with climate resiliency. Investigation of a bundle of such measures is a major topic for future research.

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Appendix 1: Results

Table 1A. Economy-wide and regional effects of climate change: without and with structural change

		Scenario O						Scenario A			Scenario B					Scenario C	
Notation	Description	LPJmL-P	EPIC-P	LPJmL-M3	EPIC-M3	LPJmL-PM3	EPIC-PM3	EPIC-PM4	EPIC-PM2	EPIC-PM1	EPIC-PL0	EPIC-PL3	EPIC-PL4	EPIC-PL2	EPIC-PL1	EPIC-PTC	EPIC-PM3TC
Macroeconomic Effects																	
ABSORP	Absorption	-2.1	-6.3	-0.2	-0.4	-2.3	-6.5	-6	-4.9	-5.3	-5.5	-5.7	-5.5	-4.6	-4.9	-4.5	-5
PRVCON	Private consumption	-3	-8.9	-0.3	-0.6	-3.3	-9.2	-8.5	-6.9	-7.5	-7.8	-8	-7.7	-6.6	-7	-6.3	-7
EXPORTS	Exports	-2.8	-7.8	-0.2	-0.5	-2.9	-7.3	-4.7	-2.5	-3	-6.7	-6.7	-5.4	-3.8	-4.1	-2.6	-2.6
IMPORTS	Imports	-1	-2.8	-0.1	-0.2	-1	-2.6	-1.7	-0.9	-1.1	-2.4	-2.4	-1.9	-1.3	-1.5	-0.9	-0.9
GDPMP	GDP at market prices	-2.6	-7.7	-0.2	-0.5	-2.9	-8	-7.4	-6	-6.5	-6.7	-7	-6.7	-5.7	-6.1	-5.5	-6.1
GSAV	Government saving	5.8	16	7.2	13.4	12.6	26.1	33	105.3	84.8	14.1	20	23.4	82.3	62.9	21.1	31.3
EXR	Real exchange rate	-0.8	-3.6	0.1	0.2	-0.8	-4.3	-4.2	-4.1	-4.1	-2.9	-3.3	-3.2	-2.9	-3	-3	-4.1
Sectoral Output Effects																	
AGRAIN	Grain crops	-9.3	-24	-1.7	-3.4	-10.8	-25.6	-25.6	-25.6	-25.6	-21.9	-23.1	-23.1	-23.1	-23.1	-23.2	-25.7
ACCROP	Cash crops	-3.8	-13.1	-1.5	-3.1	-5.5	-15.7	-15.3	-15.9	-15.8	-10.9	-12.6	-12.3	-12.7	-12.6	-10.3	-14
AENSET	Enset crop	-3.4	-10.4	-0.8	-1.7	-4.2	-11.6	-11.5	-11	-11.1	-9	-9.8	-9.8	-9.3	-9.4	-9.4	-11.2
ALIVST	Livestock	-4	-11.4	-1.3	-2.7	-5.3	-13.6	-13.6	-13.6	-13.6	-9.8	-11	-11.1	-11.1	-11.1	-11.2	-13.7
AFISFOR	Fish & forestry	-2.5	-8.1	-1.1	-2.2	-3.6	-10	-9.7	-9.3	-9.3	-6.4	-7.5	-7.4	-7	-7.1	-6.9	-9.3
AMINQ	Mining & quarrying	0.8	2.2	1.6	3	2.4	5.1	6.1	6.8	6.3	1.9	3.5	3.9	4.9	4.5	4	7.2
ACONS	Construction	0	-0.1	0	0	0	0	0	0.1	0.1	-0.1	0	0	0	0	-0.2	-0.1
AMAN	Manufacturing	2.5	7	3.5	6.7	6	13.2	16.6	18.1	16.8	6	9.6	11	13.4	12.3	12	18.9
ATSER	Wholesale & retail	-1.6	-5	0	0	-1.6	-4.8	-3.4	-3	-3.2	-4.3	-4.2	-3.6	-3.1	-3.2	-10.5	-10.5
AHSER	Hotels & restaurants	-0.8	-3.2	0.5	0.8	-0.4	-2.6	0.3	0.6	1.1	-2.6	-2.3	-0.9	-0.1	0.1	0.6	0.8
ATRNCOM	Transport & comm.	1.2	4	0.7	1.4	2	5.6	8.7	12	11.9	3.4	4.3	5.7	8	7.8	4.6	6.4
AFSER	Financial intermediaries	0.2	0.5	0.8	1.4	0.9	1.9	3.2	9.7	12.3	0.5	1.2	1.8	6	7.3	1.1	2.6
ARSER	Real estate & renting	0	0	0.1	0.2	0.1	0.2	0.2	0.5	0.7	0	0.1	0.1	0.3	0.4	0.1	0.3
APADMN	Public admin. (general)	0	0	0	0	0	0	0	0.2	0.2	0	0	0	0.1	0.1	0	0
APAGRI	Public admin.(agriculture)	0	0	0	0	0	0	0.1	0.3	0.3	0	0	0	0.2	0.2	0	0.1
ASSER	Social services	0.1	0.1	0.3	0.6	0.4	0.7	1	12	3.6	0.1	0.4	0.5	7.4	2.2	0.6	1.2
AOSER	Other services	1.1	3.3	5.1	9.8	6.2	13.5	11.1	37.6	28.6	2.8	8.1	6.7	21.8	16.6	6.3	17
GDPFC	Total GDP at factor cost	-2.7	-7.6	-0.2	-0.5	-2.9	-7.6	-7	-5.3	-6	-6.7	-6.8	-6.5	-5.4	-5.8	-7.1	-7.5

Households' Welfare Effects																	
RURH	Rural households	-3.1	-9.4	-0.3	-0.7	-3.5	-9.9	-9.1	-7.1	-7.7	-8.2	-8.6	-8.2	-6.6	-7.1	-6.6	-7.6
URBH	Urban households	-3.1	-10.1	-0.3	-0.8	-3.6	-11.2	-11.1	-13.4	-12.7	-8.6	-9.3	-9.3	-10.9	-10.4	-9	-10.7
TOTAL	Total households	-3.1	-9.6	-0.3	-0.7	-3.5	-10.2	-9.6	-8.6	-8.9	-8.3	-8.8	-8.5	-7.7	-7.9	-7.2	-8.4
Regional Effects																	
ETH	Ethiopia	-2.7	-7.6	-0.2	-0.5	-2.9	-7.6	-7	-5.3	-6	-6.7	-6.8	-6.5	-5.4	-5.8	-7.1	-7.5
TIG	Tigray	-2.1	-5.7	0.1	0.1	-2	-5.1	-4.6	-2.7	-3.5	-5.1	-4.9	-4.7	-3.4	-3.9	-5.3	-4.9
AFR	Afar	-1.4	-3.9	0.3	0.5	-1.1	-3.2	-2.3	0	-0.7	-3.4	-3.1	-2.7	-1.1	-1.6	-3.4	-2.8
AMH	Amhara	-3.8	-10.2	-0.4	-0.8	-4.1	-10.3	-9.7	-8.3	-8.9	-9.1	-9.3	-9.1	-8.1	-8.5	-9.4	-9.9
ORO	Oromia	-3.2	-9.1	-0.4	-0.8	-3.6	-9.4	-8.8	-7.4	-8	-8	-8.3	-8.1	-7	-7.4	-8.6	-9.3
SOM	Somali	-2.2	-6.6	-0.4	-0.8	-2.6	-7	-6.4	-5.1	-5.5	-5.6	-5.9	-5.7	-4.7	-5	-6.4	-7.2
BNG	Benshangul-Gumuz	-2.6	-6.8	0	0	-2.5	-6.4	-5.7	-4.2	-5	-6.2	-6	-5.7	-4.6	-5.1	-6.2	-5.9
SNNP	Southern NNP	-3.2	-9.3	-0.6	-1.3	-3.8	-10.1	-9.6	-8.6	-9	-8.1	-8.6	-8.4	-7.7	-7.9	-8.7	-10
GAM	Gambela	-1.7	-4.9	0.1	0.1	-1.6	-4.5	-3.6	-1.4	-2.3	-4.3	-4.1	-3.8	-2.2	-2.8	-4.7	-4.5
HAR	Harari	-1	-3	0.3	0.4	-0.8	-2.4	-1.5	1.5	0.2	-2.6	-2.3	-1.9	0.1	-0.8	-3.7	-3.2
ADD	Addis Ababa	0.2	0.8	0.8	1.6	1.1	2.4	3.3	7.2	6.1	0.6	1.5	1.9	4.4	3.7	0.9	2.6
DD	Dire Dawa	-0.5	-1.4	0.6	1	0.1	-0.1	1	4.3	3.3	-1.2	-0.6	-0.1	2.1	1.5	-2.1	-0.9

Source: CGE simulations and Regional projections

Notes: The CGE results of different simulations are robust to ±25% of the elasticities of production (i.e., factor substitution), international trade (i.e., import substitution and export transformation), and household's demand (i.e., income and Frisch parameter) used in calibration.

Appendix 2: The CGE model calibration and Regional projections

1. The CGE model calibration

We apply the static IFPRI-CGE model (Lofgren et al., 2002).[8] The model assumes perfect competition in commodity and factor markets, a small-open economy with respect to international trade, imperfect transformation between domestic sales and exports, and imperfect substitution between domestic output and imports. Producers, households, enterprises, government, and rest of the world (ROW) represent decision making nodes in the CGE model. The CGE model database is the 2005/06 SAM of Ethiopia (EDRI, 2009) which we modify into 54 total accounts that consists of 17 activity, 18 commodity, 8 factor, 2 household, 3 tax, and 6 other accounts (enterprise, government, ROW, savings-investment, changes in stock inventory, and transport and trade margin).

The calibration of the model involves a specification of production technology nest, a range of elasticities, a factor market closure, and a combination of macro closures that are common to the empirical CGE modeling tradition for developing countries. Producers' decision is guided by profit maximization goal subject to the output and input prices, and the production technology. Each producers face a two-stage production technology nest. Leontief function combines the aggregate value-added and the aggregate intermediate input at the top of the production technology nest. The aggregate value-added nest is a composite of primary factors of production aggregated using a CES function. The aggregate intermediate input is a composite of different intermediate commodities combined using a Leontief function. Every producer is allowed to produce one or more commodities that can be consumed at home or sold at markets. The producers' decision to sale market commodities in domestic or foreign markets is guided by profit maximization goal constrained by a CET function. Households receive income from factors of production they own directly and indirectly (e.g. capital through enterprises), remittances from abroad, and transfers from the government. Households pay direct taxes, remit to abroad, transfer to the other household group, save, and spend on consumption. Their consumption decision is specified by LES demand system. Households are allowed to consume both home (valued at producer prices) and market (valued at market prices) commodities. The households' consumption bundle include both domestic and foreign varieties of goods aggregated using a CES (or Armington) function.

The value of the elasticities, which can be said low in general, are borrowed from the related the literature. The value of elasticities of factor substitution increase from agricultural

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[8] The mathematical details of the model (along with its GAMS code) is available at (https://www.ifpri.org/publication/standard-computable-general-equilibrium-cge-model-gams-0).

activities to service activities and income elasticities of demand increases from agricultural commodities to services commodities. The elasticities of export transformation and import substitution increases with the tradability of the commodity. We set the absolute value of the Frisch parameter of 2 for rural households and 1.5 for urban households.

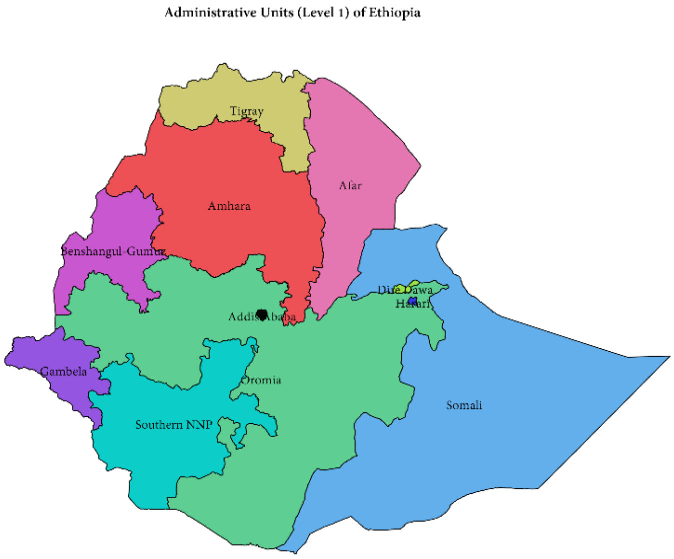
All factors are assumed to be fully employed. For mobile factors, an economy-wide wage rate is flexible to assure that the sum of factor demands is equal to the fixed (observed) quantity of factor supply. For activity specific factors, activity specific wage (product of economy-wide wage rate and activity specific wage distortion) equilibrate aggregate labor demand with aggregate labor supply. All categories of labor and land are assumed to be mobile across activities whereas livestock and capital are activity-specific. We obtain the observed employment of each labor category by activity from NLFS (2005). We use the AgSS (2006) to allocate the total agricultural labor employment (from NLFS, 2005) among the five agricultural activities of the modified SAM, and to compute the tropical livestock unit (TLU, a factor used only in the livestock activity). For factor capital, we set the average wage rate equal to unity. Thus, the observed employment of capital per activity is represented by the payment from the activity to factor capital in the SAM. The combination of the macroeconomic closures is the 'Johansen' type (Lofgren et al., 2002). For the external sector balance, the real exchange rate is flexible while the foreign saving is fixed. The government's saving adjusts to maintain the balance between the government's revenue and recurrent expenditure. All tax rates and real government consumption of goods and services are fixed. The saving-investment (S-I) balance closure is investment-driven. The consumer price index (CPI) is the numeraire of the model. The CGE model determines prices relative to this reference price. Accordingly, all simulated changes shall be interpreted relative to the CPI.

2. Regional projections

There are eleven administrative units of level one – nine regional states and two federal city administrations (see Figure 1A). The administrative units vary in terms of their socio-economic development, economic structure, and share in different national indicators. This implies that the economy-wide effects, simulated by the CGE model, will be shared among the regions unequally.

However, in general, the households' consumption pattern (HICES, 2011) and the retail prices for the majority of commodities, especially of food items (NBE, 2016; CSA, 2011; HICES, 2011) in different regions exhibit similar pattern and hovers around the national average. The tax rates across regions are more or less the same (MoFED, 2009). With the exception of Addis Ababa, the federal block-grant comprises about 80-95% of regional governments' recurrent budget (MoFED, 2009). One can also assume that each of the production activities of the CGE model exhibit similar production technology irrespective of their regional location. Therefore, it can be fairly argued that the economy-wide representative agents (markets) represent the regional representative agents (markets).

Figure 1A. Administrative Units of Ethiopia



Given these conditions, the policy relevance of regional projections and analysis based on the CGE results will be paramount. Top-down, bottom-up, and hybrid approaches are used in the literature to complement an economy-wide analysis with a regional analysis.[9] What we pursue here is a top-down approach comparable to the ORANI Regional Equations System (ORES) for Australia (see Dixon et al., 1982 for the details). However, we do not have data and a priori knowledge of technological and institutional reasons that underpin the ORES-Australia. Therefore, unlike the ORES-Australia which explicitly classifies regional industries (activities) as 'national' or 'local', we consider all economic activities in all regions to be 'national' activities (see Higgs et al., 1988 and Dixon et al., 1982 for more).[10] Accordingly, irrespective of the sales pattern of its output (i.e., where its output is consumed), a regional industry maintains its share in the aggregate (economy-wide or Ethiopia-wide) output of the same industry. The simplest method is to assume that activities in each regions produce a constant portion of the corresponding economy-wide sectoral output (Naqvi and Peter, 1996). In other words, the regional shares are exogenous and fixed. As such, the effects of a specific CGE simulation on output of an activity in

[9] See Naqvi and Peter (1996) and Higgs et al. (1988) for more on the relative merits and demerits of the three approaches.
[10] 'National' activities produce commodities tradable among regions of the country. The demand for commodities of 'national' activities comes from the whole country regardless of the regional location of the activities. 'Local' activities, on the other hand, produce commodities which are non-tradable across regions. What is produced is consumed only within the region where it is produced (Naqvi and Peter, 1996; Higgs et al., 1988; Dixon et al., 1982).

a region (q_a^r) is equal to the economy-wide effect of the same simulation on the activity's output (q_a^e) (Higgs et al., 1988; Dixon et al., 1982). For example, a 5% decrease in the economy's aggregate sectoral output of manufacturing leads to a 5% decrease in the output of manufacturing in each of the regions (Dixon et al., 1982).

$$q_a^r = q_a^e$$

The Ethiopia-wide sectoral output effects (q_a^e) are simulated by the CGE model. Then, for each of the eleven regions, the regional projections involve taking the Ethiopia-wide effects in all of the economic sectors as 'inputs' to compute the regional effects (q_A^r) of a specific CGE experiment:

$$\sum w_a^r . q_a^e = q_A^r$$

Where w_a^r represents the share of industry *a* in region *r*'s region-wide GDP at factor cost. The sum of w_a^r is equal to unity. It captures the importance of a specific industry in region *r*.

However, except for Addis Ababa for selected years, there is no data for regional industries' output and region-wide GDP. Therefore, we are compelled to take a remedial measure to compute sectoral and region-wide GDP at factor cost directly from the SAM. First, we apply a simple rule to disaggregate the Ethiopia-wide sectoral output to obtain regional sectoral output. We find the employment statistics relatively comprehensive and easy to modify and map with the SAM. We take a regional share in Ethiopia-wide sectoral employment as proxy to a regional share in Ethiopia-wide sectoral output.[11] Second, based on these shares, we obtain regional output for each sectors. That means, we obtain the output value of each of the 17 activities in every region. Third, summing the regional sectoral outputs yields us the region-wide GDP for each regions. Then, fourth, for each regions, we compute the share of each industries (w_a^r) in the region-wide GDP (see Table).

[11] Our main source of employment data in each regions per industry is NLFS (2005). We make adjustments. We use the population and housing census (PHC, 2007) to control for sampling bias in regional labor force reported in NLFS (2005). We use AgSS (2006) to adjust employment among agricultural activities. We use the government expenditure on agriculture and rural development in each regions (MoFED, 2015) to compute regional shares of public administration (agriculture) activity. To check the robustness the regional module, we apply the same procedures using employment data from HICES (2005) instead of NLFS (2005). The regional economic structure remains more or less similar except for Tigray region. Since the employment in manufacturing as per HICES (2005) is lower than reported in NLFS (2005), the regional module based on the former increases the role of agriculture in Tigray region. Despite this, there are no noticeable differences in the rest of regions. Therefore, we stick on the former as it is used for creating the original SAM (EDRI, 2009).

The economy-wide effect (q_a^e) (see Table 2A) captures the sign and strength of a specific CGE experiment on industry *a*'s output. Therefore, other things remaining constant, the regional effects depends on the nature of the CGE experiment as well as the economic structure of the regions. The approach that we pursue here is remedial to both data availability and consistency problems. It does not require to modify the CGE model as long as the SAM is modified to accommodate this. However, it requires a strong assumption to hold, i.e., the labor intensity (and production technology in general) of an industry is the same regardless of the administrative region it is located.

Table 2A. Economic structure of regions

			Regions										
Notation	Description	ETH	TIG	AFR	AMH	ORM	SOM	BNG	SNNP	GAM	HAR	ADD	DD
GDPFC	GDP at factor cost (billion USD)	14.05	0.76	0.34	2.44	4.71	1.06	0.14	2.79	0.09	0.06	1.57	0.11
Share	% Ethiopia	100	5.4	2.5	17.3	33.6	7.5	1.0	19.9	0.7	0.4	11.2	0.8
AGRAIN	Grain crops	18	21	7	34	21	8	26	13	11	5	0	3
ACCROP	Cash crops	10	2	7	7	12	7	5	19	15	9	0	3
AENSET	Enset crop	1	0	0	0	0	0	0	5	1	0	0	0
ALIVST	Livestock	14	5	15	12	20	13	3	20	2	1	0	2
AFISFOR	Fishing & forestry	5	0	3	2	2	25	0	8	0	0	0	0
AMINQ	Mining & quarrying	1	2	0	0	0	1	9	0	2	1	0	1
ACONS	Construction	4	14	4	5	3	2	15	1	6	5	8	8
AMAN	Manufacturing	7	7	12	9	7	3	9	5	7	4	7	4
ATSER	Wholesale & retail trade	11	9	12	7	12	14	9	12	18	27	12	27
AHSER	Hotels & restaurants	2	2	2	2	3	1	3	2	1	1	2	1
ATRNCOM	Transport & comm.	5	3	8	3	3	6	1	2	8	10	19	22
AFSER	Financial intermediaries	2	1	5	1	1	2	1	1	3	3	6	4
ARSER	Real estate & renting	8	7	6	7	5	9	2	4	6	4	25	10
APADMN	Public admin. (general)	4	13	9	2	2	4	7	2	9	14	7	4
APAGRI	Public admin.(agriculture)	1	4	2	1	1	1	2	1	2	1	0	1
ASSER	Social services	4	5	5	4	4	3	6	3	7	13	7	5
AOSER	Other services	3	4	3	2	3	2	2	1	3	4	7	6
TOTAL	Total GDP at factor cost	100	100	100	100	100	100	100	100	100	100	100	100

Source: Authors' computation based on EDRI (2009), NLFS (2005), PHC (2007), AgSS (2006), and MoFED (2015)

Notes: ETH (Ethiopia), TIG (Tigray regional state), AFR (Afar regional state), AMH (Amhara regional state), ORM (Oromia regional state), SOM (Somali regional state), BNG (Benshangul-Gumuz regional state), SNNP (Southern nations, nationalities, and peoples regional state), GAM (Gambella regional state), HAR (Harari regional state), ADD (Addis Ababa city administration), and DD (Dire Dawa city council).