Economy-Wide Estimates of the Implications of INDC[1] Policies for Ethiopia (A Recursive Dynamic CGE[2] Micro-Data Analysis)

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[1] INDC stands for Intended Nationally Determined Contribution.
[2] CGE stands for Computable General Equilibrium

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Chapter 1

Mitigation Polices in Developing Countries: Evidence from the CGE literature

1.1. Introduction

Even though, excluding China, India and Indonesia, developing countries are minor contributors to global GHGs emissions, their participation to mitigation effort is crucial as emission growth in the future will mainly be attributed to them if the current growth paths are maintained (Bluffstone, 2003; Jotzo, 2005). In fact, nowadays, developing countries, even those with negligible share of global emissions, intend to contribute to limiting global warming and appear well aware of the potential environmental benefits and improvements in the quality of development that can be derived from mitigation actions. This fact is clearly reflected in the 21stUNFCCCconference conducted in December 2015 in Paris[3] where 195 countries adopted a global, yet voluntary, climate agreement which sets out a global action plan to combat climate change. One distinctive trait of this landmark agreement is to remove the strict differentiation between developed and developing countries characterizing the past international climate change negotiations. It introduces a "common" framework based on historic, current and future emission responsibilities that commits all countries to engage in mitigations according to "Intended Nationally Determined Contributions" (INDCs[4]). All developing countries including Ethiopia have submitted their INDCs to the UNFCCC secretariat. As of April 4, 2016, a total of 161 INDCs covering 189 parties[5] have been

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[3]The Paris agreement's main aim is to keep a global temperature rise in this century well below 2 degrees Celsius and, if possible, to drive efforts to limit the temperature increase even further to 1.5 degrees Celsius above pre-industrial levels (UNFCCC, 2016).

[4] INDCs are national emission reduction plans meant to achieve the shared goal of limiting climate change set in the Paris agreement. The Paris agreement focuses on the implementation of nationally determined contributions between 2020 and 2030 (Janet & James, 2016).

[5] The INDC of the European Union and its 28 member States is counted as one INDC representing 29 Parties (the European Union and its 28 member States) (UNFCCC, 2016)

submitted to the secretariat (UNFCCC, 2016). The Paris agreement is operational notwithstanding the US position.

The Paris agreement is just the last of many examples of environmental policies that need to be scrutinized to identify costs and benefits, direct and indirect social and economic implications. This is particularly important for developing countries that need to balance the benefits of climate action against potential hurdles to their prospects for growth, development and poverty reduction. It is however relevant also for developed countries, even though there the concerns are more focused on guarding competitiveness and employment.

A variety of analytical approaches have been used for this purpose. Among these, economic model-based assessments play a paramount role (Lu, 2012; Pempetzoglou & Stella, 2008) and, among modelling assessments, Computable General Equilibrium (CGE) models have been widely applied.

Elements of popularity of CGE models are their capacity to analyze the macroeconomic effect of a policy considering the multiplicity of interactions linking markets domestically and internationally, coupled with a tradition of policy support that can be traced back to the '50s (Mitra-Kahn & Benjamin, 2008) that make them "somewhat" familiar to policy making.

This survey reviews the modeling literature applying CGE models to the study of climate change mitigation policies, with a particular focus on the analyses conducted on developing countries.

In what follows, section 1.2 outlines the existing economic models for the analysis of mitigation policies, section 1.3 reviews the cost of mitigation policies in developing and emerging economies, and section 1.4 concludes.

1.2. Economic Models for the Analysis of Mitigation Policies

Mitigation policies, aiming to reduce GHG emissions, impact the activity of key sectors of the economy like energy production, transportation, agriculture and construction. Accordingly, they bring about consequences that affect the macro-economic context and influence GDP, sectorial allocation of production, country competitiveness, welfare and poverty.

To analyze these potential effects, the economic discipline makes ample use of modelling approaches. Albeit highly differentiated, they share the idea to represent, simplifying the structural functioning of the economic system, on the basis of different theoretical constructs in order to determine what might happen in different scenarios or at a future date.

The literature proposes many criteria to classify different models based upon their theoretical structure, assumptions and the treatment of different variables. A first important classification distinguishes Bottom-Up vs Top-Down Models. Bottom-up models are more "engineering-like"or "partial equilibrium". This characterization mainly defines energy models representing in detail a huge number of alternative technological options used for harnessing energy resources and convert them into energy services. Examples of bottom-up models include the MARKAL-TIMES family (see e.g. (Dolf & Chen, 2001)), EFOM (Hannele & Sami, 2004)), AIM/end-use (Mikiko, Yuzuru, & Tsuneyuki, 2000).

The Top-Down category groups all those models that share an "economic", "systemic" perspective. That is: they aim to provide a comprehensive picture of the functioning of the economic system based on the behaviour of representative agents "shaped" according to the underpinnings of different economic theories. On their turn, top-down models can be classified into, macro-econometric models, dynamic/ growth models and CGE models.

Macro-econometric models typically consist in huge systems of dynamic equations representing the evolution of demand and supply relations determined and validated by past empirical observations. The fewer theoretical assumptions and the empirical derivation enable macro-econometric models to treat with more flexibility departures from perfect competition, e.g. accounting for market power and bargaining processes. Nonetheless, their requirement of long time series data for estimation makes their application quite difficult especially in the context of developing countries (Barker & Johnstone, 1998). Indeed, in the literature, studies on environmental policies using these models are relatively less frequent (see in this vein (Barker, Foxon, & Scrieciu, 2008; Barker, Junankar, Pollitt, & Summerton, 2007; Bossier, Bracke, & Vanhorebeek, 2002; Ekins & Unnada, 2012; Pollitt & Thoung, 2009)).

The literature using dynamic optimization and computable general equilibrium models is wider. Dynamic growth models are based on the paradigm of neoclassical or modern growth theory. These models, often developed into Integrated Assessment Models with the additions of climate/environmental modules, have been extensively applied to the study of optimal abatement policies, energy and carbon efficiency policies ((Nordhaus & Boyer, 2000) is a prominent example of this stream of literature). Many of them can incorporate strategic behaviours of different countries/regions. They have thus been also used to study the feasibility and sustainability of international environmental agreements (Bosetti, Carraro, De Cian, Massetti, & Tavoni, 2011). They are however very "aggregated": often depict one sector in the economy missing endogenous price adjustments and the intersectoral/international trade dimension.

Computable general equilibrium (CGE) models have many characteristics that make them particularly appropriate to the environmental policy analysis (Bergman, 2005; Böhringer &

Loschel, 2006; Conrad, 2002). Firstly, they provide an explicit representation of domestic and international market interactions that, coupled with endogenous price formation, allows to track direct and indirect impacts of a policy shock on the whole economy including feedback and rebound effects (Sue Wing, 2009). Secondly, they compound macro-economic theory with micro-foundations allowing to analyze a policy at different levels e.g. country and sectoral (Böhringer, Conrad, & Löschel, 2003). Furthermore, and related to this, even though CGE models can be very complex, their solid theoretical background helps the interpretation of results in terms of "fundamental" economic mechanisms (Xie & S., 2000). Finally, GGE models are flexible. In principle they can simulate many different economic shocks as long as they are translated in a supply or demand changes.

Accordingly, it is not surprising that CGE models are widely applied to the investigation of international and national climate change policies, building a more than extended literature (a partial scrutiny includes e.g. (Garbaccio, Ho, & Jorgenson, 1999) and (Liang, Fan, & Wei, 2007) for China, (Wissema & Dellink, 2007) for Ireland, (Pempetzoglou & Stella, 2008) for Greece, (Bucher, 2009) for Switzerland, (Al-Amin, Abdul, & Chamhuri, 2008) for Malaysia, (Ciaschini, Pretaroli, Severini, & Soccia, 2011) for Italy (2011), (Meng, Siriwardana, & McNeill, 2013) for Australia, (Wachirarangsrikul, Sorapipatana, Puttanapong, & Chontanawat, 2013) for Thailand, (Allan, Lecca, McGregor, & Swales, 2014) for Scotland, (Nurdianto & Resosudarmo, 2016) for ASEAN, (Alton, Arndt, Davies, Hartley, & Makrelov, 2014; Van Heerden, Blignaut, Bohlmann, Cartwright, Diederichs, & Mander, 2016) for South Africa).

1.3. The Use of CGE models to assess the economic cost of mitigation policies in developing and emerging countries

Compared to the extensive application of CGE models to study mitigation policies in developed countries, their application to developing countries is much more limited. Those limited studies have been addressed mostly to emerging countries. Among these, the bulk of works focuses on China and South Africa, with few researches tackling other Asian countries and none African countries.

The pioneer and land mark work in this vein can be considered Shah and Larsen (1992) on Pakistan. The authors noted that a $10 per ton carbon tax burden fell with income, turning out to be regressive. Such regressivity was less pronounced, but still present, if measured against household expenditure. Shah and Larsen (1992) concluded that lower income groups need to be protected with direct subsidies or alternative measures. Tarr & Jensen (2002), reported a somewhat similar result showing that removing subsidies on domestic energy products would have a regressive effect on Iranian households.

(Lu, 2012), applying a static CGE model indicated that the introduction of a carbon tax of 300 RMB¥ per ton of Carbon in China would reduce significantly emission (by 22%) leading to just marginal decrease in major macroeconomic indicators such as consumption, exports, and production. Similar conclusion are reached by earlier works applying recursive dynamic CGE models like the ones by Zhang (1998) on the macroeconomic effects of CO_2 emission limits and that by Liang, Fan & Wei (2007) on Carbon taxation Policy in China.

More recently, Zhou, Shi, Li, & Yuan (2011) using a dynamic CGE model iterate the relatively low cost of emission reduction in China. According to the authors, reducing emissions by 12.26% compared to the baseline in 2020, would result in a decline of GDP by 0.39% and of household income by 1.45% in 2020. The study also points out the importance of tax revenues recycling schemes showing a huge potential to alleviate negative impacts on households. Mu, Wang, and Cai (2017) are the first to address specifically the impacts of

China's 2030 Intended Nationally Determined Contributions (INDC): a reduction in the carbon intensity of GDP by 60% to 65% from the 2005 levels in 2030. The total economic cost required ranges from 0.11% to 0.43% of GDP by 2030. The study further indicates that the implementation of a national carbon market is efficient in reducing the compliance costs of INDC targets, while the deployment of renewable power helps to create employment opportunities and reduce permit prices in the carbon market. Moreover, it was emphasized that the hidden health benefits of China's INDC can offset much of the compliance costs.

Al-Amin, Abdul Hamid, and Chamhuri (2008) analyzed the effects of output-specific carbon tax on the Malaysian economy using a static CGE model. Besides using a static CGE, their treatment of emissions is somewhat simplified, as in their model, emissions depend linearly upon the levels of output rather than being associated to the carbon content of the inputs. This said, they found that the reduction in emissions is proportional to the reduction in output levels (the implemented carbon tax resulted in the same percentage changes in production and emissions, 1.21% each).

Ojha (2009), based on a CGE model for the Indian Economy, has found that a domestic carbon tax policy imposes heavy costs to the economy in terms of lower economic growth and higher poverty. However, the negative impact can be reduced if the emission restriction target is modest and carbon tax revenues are transferred exclusively to the poor.

Corong (2008) assessed the potential impacts of a tax reform in the Philippines that shifts revenue rising from trade tariffs, liberalizing trade, to carbon taxes and emission reduction combining a CGE model with household micro simulation data. According to the results, the carbon tax is able to compensate all tariff revenues lost during the trade liberalisation process, while reducing poverty and increasing welfare of the people at the same time.

Yusuf & Resosudarmo (2015) developed a static CGE assessment, studying the effect on Indonesia of imposing a carbon tax that would induce a 6.6% emission reduction. In this case, the GDP decline would be really minimal (0.04% and 0.03% under no-recycling and recycling of the carbon tax revenues to households respectively). This encouraging result supporting the implementation of abatement policies in a developing country, however, also assumes a modest mitigation goal. Moreover, their distributional analysis with highly disaggregated household groups concluded that the implementation of carbon tax would not be necessarily regressive even if the tax revenue is not recycled. It was in fact progressive in rural areas and neutral in urban areas with an overall progressive distributional effect. Among alternative revenue recycling schemes, lump-sum transfers were found to produce a much more favorable distributional impact in terms of equity objectives.

Nurdianto and Resosudarmo (2016) analysed the economy-wide impact of carbon tax in South East Asian Nations using a CGE model with disaggregated household groups. They found that the implementation of carbon tax that would reduce emissions by 3-4% would result in a 0.3% increase in real GDP in Malaysia and Indonesia and a 0.2% reduction in Real GDP in the other member countries. However, this happens at a cost in terms of reduction in welfare, and this is so irrespectively of revenue recycling schemes.

Durand-Lasserve, Campagnolo, Chateau, & Dellink (2015), indirectly supported the progressivity of carbon taxation in Indonesia. They used a dynamic CGE model, integrating 10,000 representative household groups to examine the effect of fossil fuel subsidy removal and they found effects to be progressive. The results also showed that the redistribution scheme ultimately matters in determining the overall distributional performance of the policy. Cash transfers are found to make the reform more attractive for poorer households.

Raitzer, Bosello, Tavoni, Orecchia, Marangoni & Nuella (2015) conducted a CGE regional study for 5 developing Asian countries: Indonesia, Malaysia, the Philippines, Thailand and Vietnam testing the economic implication of different GHG concentration stabilization scenarios. Macroeconomic costs of emission reductions are not negligible ranging between the 2.5%–3.5% of regional GDP over the 2010–2050 period in the 500 parts per million (ppm) stabilization scenario. This is the more ambitious scenario considered by the study, but it is anyway less stringent than what would be implied by the Paris agreement. Although the economic costs of such stabilization policies are substantive, benefits and co benefit of climate action are found to far exceed them.

Turning to Africa, South Africa is the only country where the economic costs of climate change mitigation policies have been conducted. This country is also the only African country having adopted a carbon tax. The first study in chronological order is by Van Heerden, et al. (2006) that used a static multi household CGE model of South Africa to explore the potential for a 'double or triple dividend', arising from alternative uses of the revenues raised from a range of energy/environmental taxes. They found the possibility to reap a "triple dividend[6]" when environmental tax revenues were recycled through a reduction in food prices. This result flags, once again, the paramount importance of revenue recycling schemes in determining the overall and distributional effect of the policy.

Second, is the work of Pauw (2007) where an economy-wide modeling was applied to the 2000 Social South African Accounting Matrix to simulate the effects of emission taxes. The results are in line with Van Heerden et al. (2006)indicating on the one hand that emission taxes pose significant costs to the economy, but, on the other hand, that costs could be minimized if the emission tax revenues are recycled in the form of food subsidies.

[6] The three dividends in their study: First one is reduction in emissions, second one is increase in GDP, and third one is decrease in poverty.

Devarajan, Go, Robinson, & Thierfelde (2011) simulated different tax policies to reduce South Africa carbon emissions by 15% percent. They showed that, in a “first-best” economy, a carbon tax outperforms other energy taxes in curbing emissions at the lowest possible cost. This study introduced originally labor market distortions, showing that eventually these are the major determinants of carbon tax costs, even more important than the country’s own carbon emissions.

Alton, Arndt, Davies, Hartley, & Makrelov (2014), employed a recursive dynamic CGE, to assess the cost of achieving the South African 42% emissions reductions target from the business as usual set for 2025. GDP contraction results the 1.2%, however authors found that carbon tax revenues targeted to expand social transfers lead to strongly progressive welfare outcomes.

The fifth and most recent study is the work of Van Heerden, Blignaut, Bohlmann, Cartwright, Diederichs, & Mander (2016). It assesses the possible impacts of the carbon tax proposal announced by South Africa’s National Treasury in May 2013 and set out in the draft carbon tax bill published in Dec 2015. The novelty of the study is to link the CGE model to a detailed electricity-generation model. The results eventually suggest that a carbon tax is an effective tool in reducing South Africa’s emissions with considerable economic cost but the negative economic impact is greatly reduced when the tax revenue is recycled.

1.4. Conclusion

The literature surveyed in general demonstrates that carbon taxes in developing countries are economically costly, though somehow moderated when the carbon tax revenues are recycled. Moreover, the distributional impact of mitigation policies in developing countries, though some studies have indicated it to be progressive, is quite mixed and less conclusive than for developed countries. The findings also appear to favour using the carbon tax revenue to subsidise households in order to minimise the economic and distributional costs of the policy. Therefore, more studies are needed with reference to developing countries to come arrive at more definite conclusion about the progressivity of carbon tax in developing countries. More importantly, due to the peculiar characteristics of the Ethiopian economy, the results in other developing countries may not hold for Ethiopia. On top of that, none of the studies in the literature considered an emission reduction target that is as ambitious[7] as Ethiopia. For a country that affirmed and communicated its emission reduction plan to the international community, a quantitative assessment of the potential economy-wide effects of such plan is unambiguously required. Hence, studies specific to Ethiopia are crucially important. Moreover, this study contributes to the literature by employing a dynamic CGE model given that most of the studies in developing countries employed a static one.

[7]Ethiopia's set an ambitious emission reduction target equal to 64% of the business as usual projection in 2030.

Chapter 2
Economic and Environmental Effects of INDC Policies for Ethiopia (A Recursive Dynamic CGE Analysis)

Abstract

Mitigation of climate change has become unavoidable discussion item in policy making agendas in both developed and developing counties. Having understood the important role played by developing nations in fighting against climate change, Ethiopia submitted its Intended Nationally Determined Contributions (INDC) to the UNFCCC secretariat with an emission reduction goal of 64% in 2030 compared to the BAU scenario.

The main objective of this study is to analyse the economic and environmental effects of the implementation of Ethiopia's INDC policy in the form of carbon tax. In doing so, a recursive dynamic computable general equilibrium (CGE) model is employed and is calibrated on the updated 2009/10 SAM of Ethiopia with the corresponding emission data of the same year.

Four simulation scenarios have been introduced. In the first simulation, carbon tax revenue has been allocated entirely for government consumption, whereas in the second simulation, the carbon tax revenue has been equally divided between government consumption and households in form of lump sum transfer. In the third and fourth simulations, productivity gains from government expenditure allocated to health and education sectors are combined with the respective first two simulations. The results of simulation experiments on selected macroeconomic variables indicate that, in real terms, GDP, national absorption and household consumption are found to be adversely affected relative to the baseline scenario, the impact being considerably high in the first simulation. The simulations with productivity gains, in relative sense, have improved the negative effects of the carbon tax abatement policy on the economic variables. The implication of this is that policies that increase productivity of government expenditure have better spillover effects on GDP than those of household consumption.

Finally, to achieve the emission reduction target set out in the INDC policy of Ethiopia with reasonable cost to the economy, the country has to invest in clean technologies that are meant to improve emission efficiency as most of the emissions emanate from activities in the agricultural sector, and for this end, huge international support is required.

Keywords: Emission, INCD, carbon tax, Simulation, baseline, climate change, economy, environment, CGE Model, Ethiopia

2.1. Introduction and Background

Nowadays, the concept of economic growth is increasingly linked to the idea of sustainability where the environmental dimension plays a major role. One of the major challenges that unsustainable use of the environment poses to social and economic growth is climate change. It is caused by the accumulation of greenhouse gases (GHGs) in the atmosphere stemming from the use of fossil fuels, that alters atmosphere's chemical composition, increase temperature (global warming), induce variations in the atmospheric, ocean and earth cycles with adverse and sometimes potentially catastrophic consequences for human social-economic systems and development opportunities. Among these are: loss of wild life, drought, floods, changes in mortality and morbidity associated to many diseases, degradation of natural resources and loss of agricultural productivity (IPCC, 2014). Eventually, not only global economy is concerned, but also potentially future fate of life's survival on earth. This poses an urgent need to mitigate its causes and adapt to its adverse effects.

Climate change is a global externality. Irrespectively of who contributes and the degree of her/his contribution, all experience its adverse effects. Accordingly, an effective climate change policy aiming to GHG emission reduction requires both a concerted international response and national efforts (FDRE, 2011).

Global efforts to reduce the adverse effect of climate change led to the development of a long lasting international negotiation process starting with the 1992 United Nations Framework Convention on Climate Change (UNFCCC). The first (and at the moment unique) global binding emission reduction commitment produced, is the 1997 Kyoto Protocol. It classifies countries by their level of industrialization and commits the so called "ANNEX I" countries, basically developed and transitional economies to reduce their emissions by an average of 5% below 1990 levels over the period 2008 to 2012 (the first commitment period). Non ANNEX

I countries, coinciding with the developing world, were not imposed binding emission reduction limits under the principle of "common but differentiated responsibilities". Nonetheless, this does not mean that developing countries have not a crucial role to play in emission reduction. Leaving aside the many and large co-benefits from mitigation primarily in the form of better health (Stern, 2008), developing countries represent (a) a large share of GHG abatement potential that (b) could be accessible at a relatively low cost. This is because the marginal abatement cost is relatively lower in developing countries than in developed countries where the technology is, on average more efficient and less energy/carbon intensive, makes further reductions more difficult (Landis & Bernauer, 2012; Lopez, 1999). Accordingly, developing countries' involvement in the abatement effort responds both to efficiency and to effectiveness principles. In fact, a considerable number of developing countries, including Ethiopia, are participating to the international climate negotiation process to shape mitigation and adaptation efforts also in the post-Kyoto period. The major and more recent outcome of this process is the submission of Intended Nationally Determined Contributions (INDCs) at the 2015 Paris climate conference, the 21st international negotiation round on climate policies.

The key outcome of the conference was an "inspirational" agreement to limit global warming to well below 2 degree Celsius compared to pre-industrial levels. To this end, member states submit their respective and voluntary INDCs to the convention setting the first steps to that achievement. The Paris conference also iterates that the costs of mitigation falls primarily on developed countries who have contributed the most to the problem and set the importance of international support from developed to more vulnerable and with limited capacity developing countries both in the areas of mitigation and adaptation (FDRE, 2011) UNFCCC, 2015).

A perfect example of this high vulnerability/limited capacity combination is Ethiopia: the country is heavily dependent upon climate sensitive sectors, like livestock and rain-fed agriculture, large share of the country are prone to desertification and drought, and it has limited economic and institutional resources for adaptation with having one of the lowest per capita incomes in the world.

As a responsible member of the world community, Ethiopia is aware of the important role that developing countries can play in fighting climate change, and has consequently taken on a constructive role in international climate negotiations. Ethiopia's ambition to become a "green economy front-runner" is an expression of its potential for and belief in a sustainable model of growth. To this end, the Government of the Federal Democratic Republic of Ethiopia, has initiated in 2011 the Climate-Resilient Green Economy (CRGE) initiative aimed at reducing future emissions to protect the country from the adverse effects of climate change and to build a green economy that will help realize its ambition of reaching middle income status before 2025 (FDRE, 2011). In practice the CRGE aims at keeping 2030 emissions to their levels in 2010. The target is very ambitious as according to projections under Ethiopian business as usual scenario, greenhouse gas emissions are expected to increase strongly, from 150 Mt CO2e in 2010 to 400 Mt CO2e in 2030.

In its Paris INDCs, the country restated that it intends to reduce 2030 emissions by 255 $mtCO_2e$ from the BAU scenario which represents a 64% reduction. Against this background, there is an urgent need for a quantitative assessment that takes into account direct and indirect effects of the various CRGE-related interventions in the country (FDRE, 2015; UN, 2015) .

One "typical" leverage to reduce emissions, advocated by the economic discipline, is the use of carbon taxes (Angelopoulos, Economides, & Philippopoulos, 2010; Crane & Bartis, 2007; Full, 2012). Economists and international organizations have been suggesting market based instruments in general and carbon tax in particular to reduce emissions due to their higher efficiency than command-and-control measures. Carbon taxes are price based policy instruments intended to increase the price of carbon intensive goods and services thereby decreasing the quantity demanded and/or produced.

Advantages of carbon taxes are, in principle, manifold: Efficiency stems from the fact that they fix the same marginal cost for carbon emissions for all and allow quantities emitted from the different sources to adjust accordingly. As a consequence, the distribution of abatement effort is "automatically" regulated by the "market" imposing higher abatement to those more able to do so. They require a lower degree of public sector intervention. Once the tax is fixed, the quantities self-adjust with lower administrative costs compared to tradable permits. When we say this, it should be noted that this theory of efficiency may not be fully reflected when it comes to implementation especially in developing countries. Moreover Like other taxes, they generate revenues that could find different and useful usages, but differently from other taxes they correct a market failure (excessive externalities from emission) thus imposing a desired distortion to the price system, rather than an unwanted one as the case of distortionary taxation on non-externality-generating activities e.g. labour (Dower & Zimmerman, 1992; Goulder & Schein, 2013; Nordhaus W. D., 2006; Stern, 2008).

Finally, carbon taxes tend to minimize the regulatory mistakes in the presence of uncertainty. Nonetheless, levying carbon taxes is a thorny issue. The primary reason refraining countries from adopting such policies is the uncertainty associated with effects on economic growth, international competitiveness, welfare and equity. In Particular, developing nations such as Ethiopia fear undesirable consequences on economic growth and poverty reduction which are its top priorities.

Empirical literature, concentrating mostly on developed countries, suggests that imposition of a carbon tax would decrease carbon emissions significantly and might not dramatically reduce economic growth (Allan, Lecca, McGregor, & Swales, 2014; Meng, Siriwardana, & McNeill, 2013; Susanne & Henrik, 2015). Limited number of studies is found in developing countries in general and sub-Saharan Africa in Particular. From those scant studies, Al-Amin, Abdul, & Chamhuri (2008), with the objective of examining the economic impact and effectiveness of carbon tax, simulated an output specific carbon tax on the Malaysian economy using a static Computable General Equilibrium model. They found that the simulated carbon tax reduced emissions and output by the same percentage changes (both by 1.21%). However, apart from using static CGE, this study is rather simplistic in the representation of emission processes assuming emissions are linearly related to the levels of output, neglecting the role of inputs characteristics. A computable general equilibrium (CGE) simulation study by (Alton, Arndt, Davies, Hartley, & Makrelov, 2014) on the South African economy analyzed the implementation of a CO_2 tax consistent with the national emission reduction target of 34% by 2020 and 42% by 2025 relative to the ‘‘business-as-usual’’. The results indicated moderate adverse impact on GDP (-1.23%) and national absorption (-1.20%) in 2025. However, this study is not comprehensive in the sense that emissions other than CO_2 were excluded from the analysis.

The present study will contribute to the literature of the economy-wide effects of carbon tax in developing countries in general and Sub-Saharan Africa in particular. It is the first of this kind focusing on Ethiopian economy and will provide useful information to support the implementation of the country’s Climate Resilient Green Economy (CRGE) strategy as well as the Intended Nationally Determined Contributions especially for the second Growth and transformation Plan (GTP-II) of Ethiopia (2015 to 2020) where the government is planning to mainstream CRGE and INDCs with much more emphasis (FDRE, 2011; FDRE, 2015).

In particular, by developing and applying an Ethiopian-tailored, dynamic computable general equilibrium model, this study aims to examine the effect of emission tax on

- Key macroeconomic variables
- Sectoral allocation of production
- Household income
- Emission Levels

2.2. Model Description and Extensions

The study tailors the recursive-dynamic International Food Policy Research Institute (IFPRI) CGE model (Lofgren, Harris, & Robinson, 2002) to the socio-economic and emission characteristics of Ethiopia. IFPRI designed the model to contribute to and facilitate the use of CGE models for policy analysis in developing countries. Even though the CGE model seems standard, it includes some of the basic features designed to reflect the characteristics of a developing country such as household consumption of non-marketed (or home.) commodities, explicit treatment of transaction costs, and a separation between production activities and commodities that allows any activity to produce multiple commodities and any commodity to be produced by multiple activities (Lofgren, Harris, & Robinson, 2002). Its specification follows the neoclassical-structuralist modeling tradition presented in Dervis et al. (1982).

The CGE approach is chosen because of its ability to integrate into a systemic perspective economic theory with real world data (Conrad, 2002). In particular CGE models provide a multi sector representation of the economic systems taking into account market transmission mechanisms triggered by endogenous adjustments in relative prices. As such, they are particularly appropriate to study the effect of taxation policies which typically entail higher order macroeconomic effects (Lofgren, Harris, & Robinson, 2002; Thurlow, 2008). When adapted to Ethiopian data, the model features 46 production activities of the economy with 50 commodities, and, particularly interesting for the present analysis, it considers multiple household types. In this exercise, rural poor, urban poor, rural non-poor, urban non-poor are considered.

2.2.1. Model extensions

That model has been extended with the following additions:

-***Inclusion of all emissions***[8] and related equations tying emissions with respective sources. GHG emissions data are derived from the Environmental Economics Policy Forum for Ethiopia (EEPFE). We treat emissions in two different ways depending on their type: stationary emissions and activity emissions. Stationary emissions (for production sectors and households) are emissions whose sources are identifiable from the SAM data. For production sectors, these emissions are inputs-based: they are associated to the amount of energy input used in the production. Emissions data allow the computation of the emission coefficient representing the amount of emissions per birr worth of energy input. Then the model computes stationary emissions from production sectors by multiplying the amount of input used by the emission coefficient. Similarly, stationary emissions from households are linked with the consumption of energy goods by the household sector, via a pre-calculated emission intensity coefficient from the emission data matrix. However, due to the fact that an enormous share of emissions of the country comes from agriculture, stationary emissions

[8] The major GHGs in the Ethiopia are (CO_2, CH_4 and N_2O) which this study covers. This is one new feature of this study as many other studies include only CO_2 in their analysis. For methodological convenience, the study used emission data measured in tones of CO_2 equivalent (CO_2e). That means, scientifically accepted conversion factors are used to convert all other classifications of GHGs in to CO_2

account negligible share of emissions. The second category of emissions, those whose sources are not identifiable from the model database (i.e. social accounting matrix or SAM), are linked to activity output/household consumption. (The calculation of emission coefficients and emission linking with the model are described in the methodological appendix)

-***<u>Inclusion of carbon taxes</u>***. Emission tax is entered into the model as a price of emission per ton of CO2e.

The price of emission multiplied by the corresponding sector and household specific emissions give rise to emission tax revenue which is zero in the baseline.

Emission tax also appears as an activity tax and added as a production cost in the activity cost function of the producer. Hence it affects the profit maximizing decision of the production activities. This variable also affects the government's budget balance. The same thing applies to the households' problem thereby affecting the households' income and consumption expenditure).

-***<u>Use of Socio- economic data for Ethiopia</u>***. In addition to emission data, all the data referring to the Ethiopian economic system have been utilized. The study makes use of the updated 2009/10 Ethiopian SAM developed by Ethiopian Development Research Institute (EDRI) and of emission data (which include CO_2, CH_4 and N_2O) consistent with SAM accounts and disaggregated by sources, developed by Environmental Economics Policy Forum for Ethiopia (EEPFE). These data (reporting a total of 174.55 mt CO_2e) are different from those reported in the CRGE strategy document (150 mt CO_2e) due to the inclusion of GHG emissions from households, not part of CRGE strategy and differences in method of computation with EEPFE.

2.3. Simulations and Results

2.3.1. Description of Simulations

In the CGE modeling exercise, we focus on the differential dynamic impacts of different levels of carbon tax relative to that of the counterfactual (baseline).

Baseline (Counterfactual) Scenario

This scenario is used as a “no additional-policy” reference point where the economy is assumed to grow along the recent economic performance and evaluated at times where the present policy environment is maintained. The time period under consideration is 2010 - 2030. For each year, the model is updated to reflect changes in population, supply of labor and land, and factor productivity.

Many different sources are available to build the baseline. An authoritative one is the IPCC scenario building exercise originating the Shared Socioeconomic Pathways or SSPs (O'Neill, et al., 2014). These provide country level prospects for population, economic growth, urbanization, land use etc. up to 2100 under different “storylines” of social economic development.

For this exercise we prefer however to use Ethiopian national sources for the projections hoping they are more adherent to the country features and also because they can be more acceptable by Ethiopian policy environments.

The assumptions are thus based on the recent economic performance and the projections of central statistical agency and ministry of finance and economic development of Ethiopia (CSA, 2011; MoFED, 2010).

Over the study period, a number of counter factual changes are expected to happen. Some of these changes, which constitute the baseline growth path of the economy, include exogenous growth in population, labour supply, total factor productivity and government spending. For instance, Population grows by 2.6% per year which is consistent with the recent average growth rate (CSA, 2011). Labor supply is assumed to grow at a slightly higher annual rate of 3% (CSA, 2011. Different growth rates of TFP are assumed to prevail in different production activities based on estimates obtained from previous studies on growth accounting in the country (Pratt & Yu, 2008; Fantu, 2012; Mulugeta, 2015). Government spending and transfers are also exogenously increased under the baseline based on their historic growth rates. The process of capital accumulation is modeled endogenously based on Thurlow (2008). GDP, Population and emission growth projections are based on MoFED, CSA and the Ethiopian Climate Resilient Green Economy strategy along with EEPFE.

The initial values of some variables of Ethiopia are summarized hereunder (Table 2.1).

Table 2.1 Initial values of GDP, population and emissions[9].

Variable Name	Initial value in 2010
GDP at factor cost (Billions of Birr)	354.95
Population (millions)	76.66
Emissions ($MtCO_2e$)	174.55
Input Based	34.16
Output Based	140.39

Source: Ethiopian 2009/10 Social Accounting Matrix, CSA[10], MoFED[11] and EEPFA[12]

Policy Scenario

An activity specific artificial (hypothetical) carbon tax is imposed on emitting agents of Ethiopia to reach the emission reduction target of -64% with respect to the baseline. With Carbon tax being imposed in all scenarios, the simulations mentioned hereunder are distinguished based on the proportion of carbon tax revenue allocation between government and households and the associated productivity gains in the health and education sectors.

[9] We assumed a 5% emission efficiency improvement per year in those sectors whose emissions were output linked which is consistent with the historical average growth rate of agricultural emission efficiency (mainly methane) (World Bank Data for Ethiopia from 1971 to 2010) (WorldBank). Assuming this rate of emission efficiency improvement could be sustained can be justified as the CRGE strategy has outlined initiatives aimed to increase the productivity of farmland and livestock without increasing the cultivated area or cattle headcount. Such initiatives include intensifying agriculture through usage of improved inputs and better residue management, introducing lower-emission agricultural techniques, ranging from the use of carbon-and nitrogen efficient crop cultivars to the promotion of organic fertilizers, increasing animal value chain efficiency to improve productivity, i.e., output per head of cattle via higher production per animal and an increased off-take rate, led by better health and marketing, supporting consumption of lower-emitting sources of protein, e.g., poultry-an increase of the share of meat consumption from poultry is believed to help reduce emissions from domestic animals, afforestation/reforestation etc (FDRE, 2015).

[10] Central Statistical Agency of Ethiopia
[11] Ministry of Finance and Economic development
[12] Environmental Economics Policy Forum for Ethiopia

Specifically, four simulations are introduced with a linearly increasing carbon tax starting at around 3 USD (40 Birr).

Simulation 1- Government Spending Scenario: This simulation is meant to represent a situation where the government uses the revenues to support government expenditure, namely: investments in health, education, and public administration& defense. This simulation tries to mimic the government of Ethiopia's decision to use any revenue from emission reduction to finance development projects (FDRE, 2011). Unfortunately, the model cannot analyze recycling at the project level, thus we approximate this conveying resources to government consumption.

Simulation 2-Compensation Scenario: In this simulation 50% of the carbon tax revenue is recycled in the form of lump sum transfers to households as compensation and 50% to government consumption. This simulation tests effects in supporting more of the urban poor than the rural poor.

Simulation 3-Government spending and productivity scenario: In this simulation, positive impacts on total factor productivity are combined with government spending scenario. That is, the impact of carbon tax revenue that was fully allotted for government spending on productivity of education and health sectors are considered in this simulation. This accounts for the potential benefits stemming from public spending on health and education. More specifically we impose a 0.063% total factor productivity increase with a year lag per 1% increase in health care spending and a 0.103% total factor productivity increase with four years lag per 1% increase in education spending. These figures are derived from Biswajit Maitra and C.K. Mukhopadhyay (2012) examining the growth potential of education and health care investment in Nepal. This has been chosen as Nepal, among the very few developing countries object of such studies, is also somewhat comparable to Ethiopia. In both countries the vast majority of the population is dependent on agriculture; more than a quarter of the population falls below the poverty line; there is comparable per capita GDP, there are more or less similar health and education per capita expenditure, there is almost the same human capital ranking (Countryeconomy.com, 2018).

Simulation 4-Compensation and productivity Scenario: Here, the second simulation is combined with productivity gains from the additional government spending on the health and education sectors. That is, government spending induced productivity gains stemmed from half of the carbon tax revenue allocated for government is accounted. Hence, the productivity gains here are less than those in the third simulation since there is less (only 50% of the carbon tax revenue) to be invested by the government.

2.3.2. Analysis of Results

In this section, the results of the simulations are analyzed with respect to the impacts of the emission reduction policy under the four simulations on selected macroeconomic variables, household income, sectoral allocation of production, and sectoral emission levels.

2.3.2.1 Effects on Selected Macroeconomic Variables

Table 2.2 Effects of simulations on selected real macroeconomic variables- all figures except initial values in 2010 represent percentage changes from the baseline.

Variable Name	Initial value in 2010 (billions of Birr)	(2) **Government spending scenario- average over (2011-2030)**	(3) **Government spending scenario- in 2030**	(4) **Compensation scenario- average over (2011-2030)**	(5) **Compensation - in 2030**	(6) **Government spending and productivity scenario - average over (2011-2030)**	(7) **Government spending and productivity scenario- in 2030**	(8) **Compensation and productivity scenario - average over (2011-2030)**	(9) **Compensation and productivity scenario- in 2030**
GDP at factor cost	354.95	-1.15	-5.44	-0.85	-5.00	-0.31	-2.80	-0.44	-3.42
Absorption	452.77	-1.12	-5.35	-0.81	-4.61	-0.41	-3.64	-0.53	-4.21
Overall Household Expenditure	338.61	-4.29	-11.23	-2.83	-8.22	-3.74	-9.38	-2.54	-7.45
Exports	51.87	0.14	-1.32	0.78	1.42	1.06	1.63	1.48	1.79
Exchange Rate	1	7.86	26.38	8.43	29.48	9.29	31.90	9.35	32.73

Source: Own Computations

As it is evident from Table 2.2, the effect of the carbon tax policy on real economic variables is negative (the full dynamic picture of the policy effects is provided by figures 1 to 4). The effect becomes more pronounced in later periods as the magnitude of tax increases. Ranking the simulations, the best (less negative) outcomes are obtained when revenues are recycled in the form of 100% support to public spending, accounting for the positive effect of investment in health care and education (GDP loss of 2.80% compared to baseline in 2030), followed by 50% recycling to government expenditure and 50% recycled lump sum to households (GDP loss of 3.42% compared to baseline in 2030).

The only variables showing some improvement are exports, which might be associated with the depreciation of domestic currency as reflected by the exchange rate. Nonetheless, in the first simulation, the effect on export becomes negative in later periods.

An interesting insight from the results is that, without accounting for government spending induced productivity gains, rebating tax revenues to households would be less penalizing economically than allocating it to government expenditure (comparison of the first two simulations).

This comparison emphasizes just distributional effects induced by the two types of expenditures, governmental and household. It appears thus that real GDP would decrease by 5% in compensation scenario as opposed to 5.44% in government spending scenario (in 2030) and absorption decreases by 4.61% in compensation scenario as opposed to 5.35% in government spending scenario (in 2030).

The situation reverses when government spending productivity gains are accounted for (comparison of the last two simulations).[13]

Anyway all the simulations point out the potential high economic cost of the policy and stress the need for (a) international support to Ethiopia for the implementation of the mitigation policy and (b) a careful design of the use of the tax revenues. A simple expansion of government expenditure is not sufficient to trigger those positive multiplicative effects on the economy to overcome the policy costs especially in the longer term. In general, an earn-marking of revenues to selected growth enhancing projects or strategies and human capital investment is essential.

We are aware that the CGE model employed here doesn't fully capture the characteristics of the Ethiopian economy. More importantly, the structural rigidities and disequilibrium in the labor market are not accounted for. However, as a first attempt in Ethiopia, the results here give insight on the economic cost of the INDC policy and the possible recycling of the policy to reduce the costs. Indeed IFPRI has developed the CGE model to be applied in developing country context reflecting some of the basic characteristics such as household consumption of non-traded (home) goods and transaction costs.

[13] We are however aware that either our assumptions on the pro-growth nature of public spending in Ethiopia is highly speculative or that the assumption of a null pro-growth effect of private consumption is quite extreme.

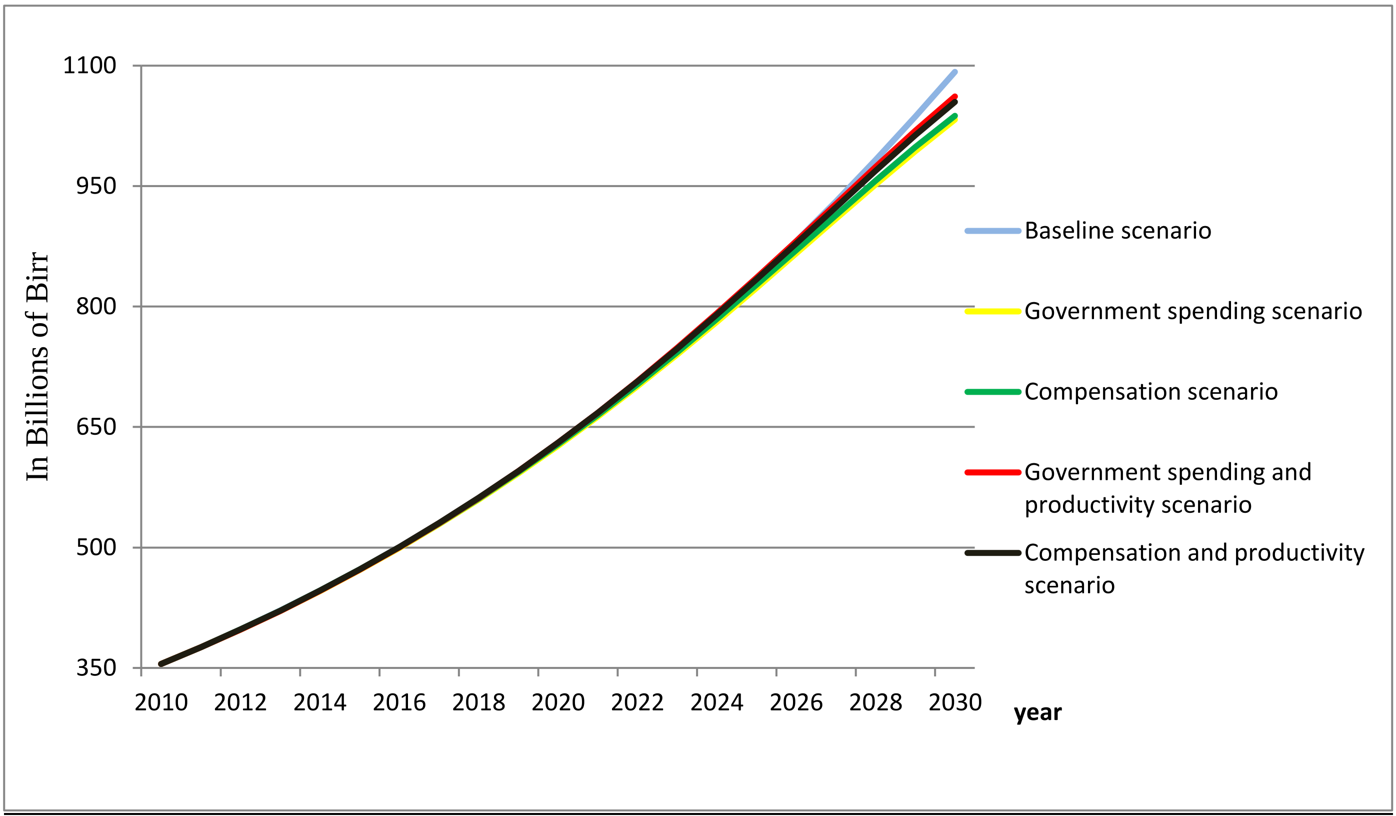

Figure 2.1 GDP trend

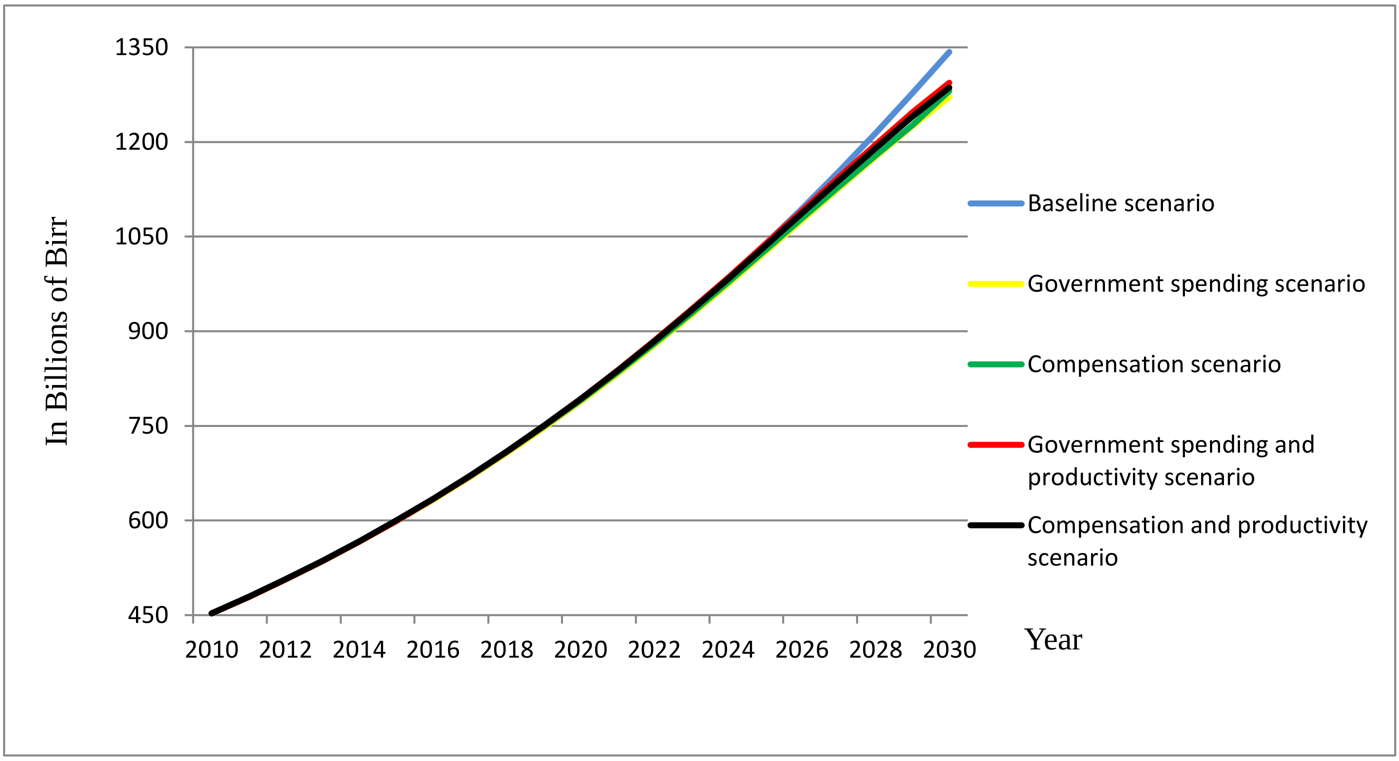

Figure 2.2 Absorption trend

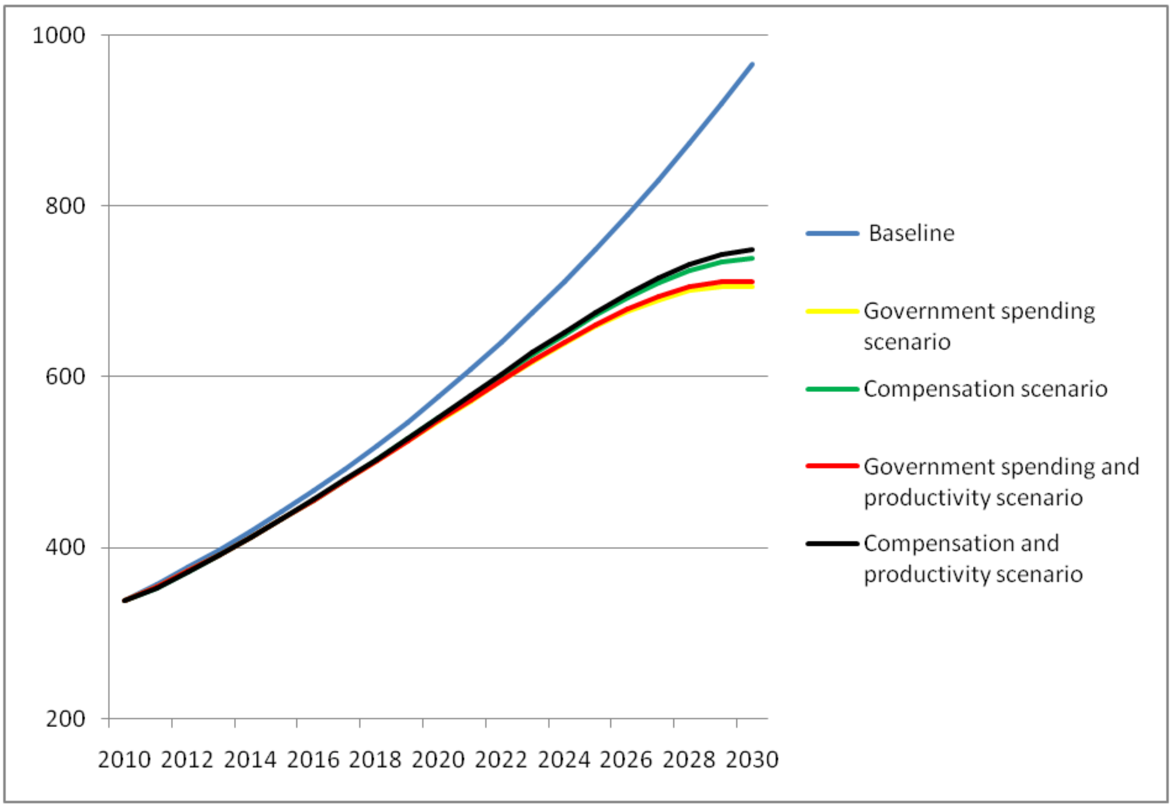

Figure 2.3 Household Expenditure trend

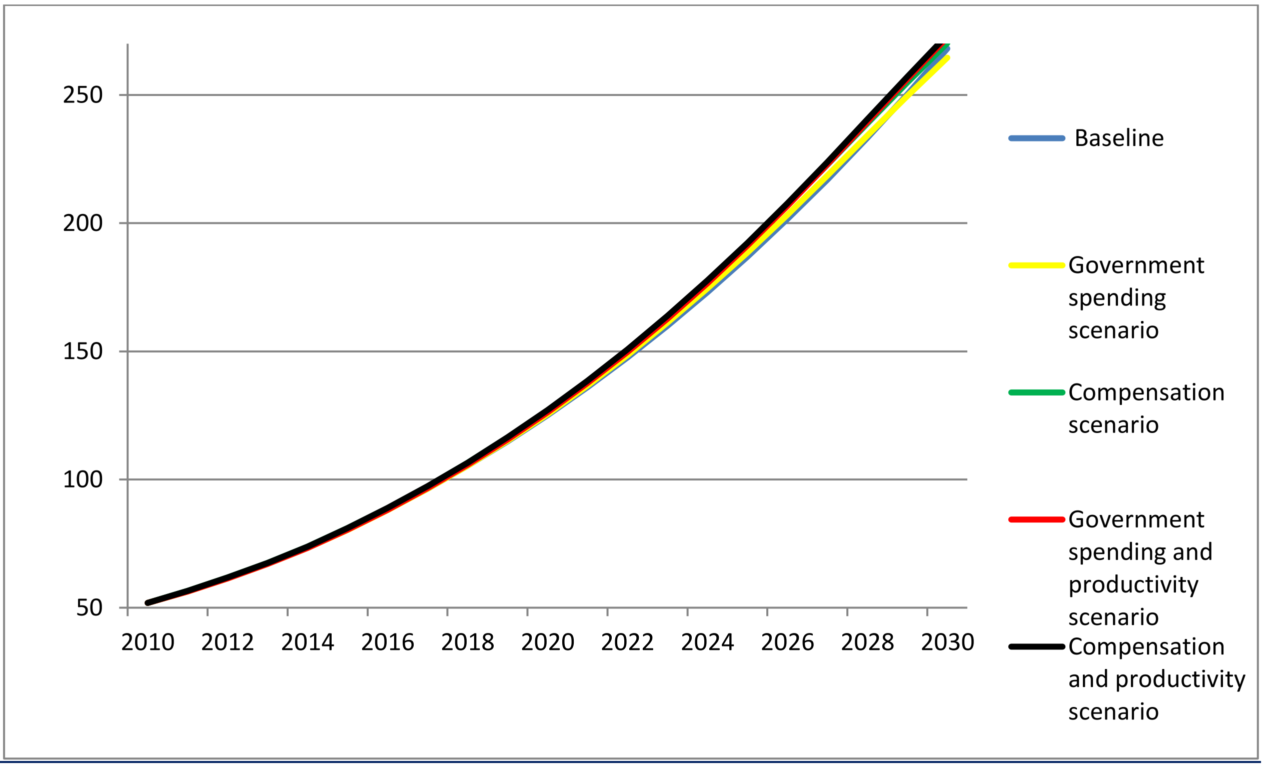

Figure 2.4 Export trend

2.3.2. 2. Effects on Sectoral value added

Turning to sectoral effects, value added shows considerable reduction compared to the baseline everywhere with the partial exception of services, with more pronounced adverse effects in 2030 (Table 2.3). Agriculture is the most adversely affected sector being also the major contributor to Ethiopian emissions. Its value added on average decreases by 6%, 5.08%, 5.54% and 4.65% under the government spending, compensation, government spending with productivity gain, and compensation with productivity gain scenarios respectively.

The sectoral picture highlights an interesting feedback mechanism: the productivity increase of education and health expenditure also increases production and, to some extent, emissions. The emission reduction target is fixed though and thus it also becomes harder to achieve. This additional burden falls for its major part on agriculture, and in particular on the livestock sector that, alone, builds more than 40% of the total country emission. Accordingly, for agriculture, it turns out that a carbon tax revenue rebate to households is preferable than expansion of government expenditure even when the associated productivity gains are accounted for. Exactly the opposite occurs for industry and services. Services in particular are positively affected by the tax policy that induces a re-allocation of the economic activity towards that low-emitting sector, and this shift is strengthened in the government spending and productivity scenario that also features higher emission reduction costs.

Table 2.3: Effects on Sectoral value added- all figures except initial values in 2010 represent percentage changes from the baseline.

Sector Name	Initial value in 2010 (billions of Birr)	(2) **Government spending scenario- average over (2011-2030)**	(3) **Government spending scenario- in 2030**	(4) **Compensation scenario- average over (2011-2030)**	(5) **Compensation scenario - in 2030**	(6) **Government spending and productivity scenario - average over (2011-2030)**	(7) **Government spending and productivity scenario- in 2030**	(8) **Compensation and productivity scenario - average over (2011-2030**	(9) **Compensation and productivity scenario- in 2030**
Agriculture	174.26	-6.00	-18.50	-5.08	-16.12	-5.54	-17.01	-4.65	-15.31
Livestock	48.77	-6.01	-19.02	-5.66	-17.15	-5.87	-18.45	-5.42	-16.23
Other Agricul.	125.49	-5.96	-16.62	-4.88	-16.01	-4.72	-16.22	-4.41	-15.77
Industry	36.19	-2.07	-6.92	-1.29	-5.32	-0.36	-1.62	-0.43	-1.88
Service	144.49	0.43	-1.84	0.88	-1.21	2.96	4.15	1.91	2.93
Overall	354.95	-1.15	-5.44	-0.85	-5.00	-0.31	-2.98	-0.44	-3.52

Source: Own computation

2.3.2.3. Effects on household income

In the simulations, the performance of household income follows, not surprisingly, that of GDP. More interesting is the study of policy effects on different household groups. In the government spending scenario (carbon tax without compensation and productivity), the policy demonstrates regressive effects. More precisely, the rural poor are affected relatively more due to the fact that they are more dependent on the largest emitter sector-agriculture (anyway in Ethiopia more than 80% of the population relies on the sector) either in term of income sources or in consumption, considering they, in general spend, a larger proportion of their income on agricultural commodities compared to the non-poor.

The compensation plan (second simulation), significantly reduces the negative impact of the carbon tax on households in general and the poor in particular. The urban poor became even better off under the compensation plan than under the baseline scenario. This is not only due to the fact the urban population is less affected by the policy than the rural population (are more connected to agricultural activities), but also because the transfer scheme tends to replicate the existing transfer allocation that favors urban poor (the government's tradition, as reflected also in the SAM, is to make more transfer to the urban than the rural population). Third simulation is less pro-poor than the second one which shows that government spending productivity gains are more beneficial to the non-poor population.

Table 2.4: Effects on household- all figures except initial values in 2010 represent percentage changes from the baseline.

Variable Name	Initial value in 2010 (billions of Birr)	(2) **Government spending scenario- average over (2011-2030)**	(3) **Government spending scenario- in 2030**	(4) **Compensation scenario- average over (2011-2030)**	(5) **Compensation scenario– in 2030**	(6) **Government spending and productivity scenario - average over (2011-2030)**	(7) **Government spending and productivity scenario- in 2030**	(8) **Compensation and productivity scenario - average over (2011-2030**	(9) **Compensation and productivity scenario- in 2030**
Household income	360.37	-2.88	-9.02	-1.61	-5.57	-2.06	-7.53	-1.47	-4.31
Rural Poor	67.55	-8.14	-25.84	-2.66	-3.85	-7.65	-24.79	-2.32	-3.75
Rural non-poor	205.47	-2.85	-8.30	-2.47	-6.52	-2.07	-6.12	-2.01	-5.96
Urban Poor	10.76	-0.36	-1.71	5.74	14.25	1.07	4.80	6.20	15.10
Urban non-poor	76.59	-0.32	-0.45	-0.28	-0.41	-0.20	-0.38	-0.22	-0.37

Source: Own Computations

2.3.2.4. Effects on Sectoral Emissions

The overall emission reduction is fixed for the Ethiopian economy and is minus 64% compared to the baseline in 2030. Agriculture, the major contributor to emissions is also the major contributor in abatement (-42.97% on yearly average peaking to -73.03% in 2030 compared to the baseline). Industrial, emissions decline annually, on average by 26.56% relative to the baseline. Emissions of the service sector follow the re-composition of the overall economic activity showing the lowest decline, especially in the initial simulation years.

Although the sectoral distribution of emission abatement does not change significantly across simulations, it is interesting to note that abatement in agriculture is a bit higher in simulation 3 than in simulation 1, showing the effect of productivity and production increase due to public spending. Similarly, when revenues are rebated to households, it is that part of the economy that expands and emits more and is eventually required for a higher mitigation effort (-62.30% compared to baseline in 2030 of compensation and productivity scenario vs the -58.65% of compensation scenario).

Table 2.5 below shows the effect of the policy on sectoral emissions.

Next, the full dynamic path of the policy effects on sectoral emissions is also provided by the figures 5-11

Table 2.5: effects on sectoral emission- all figures except initial values in 2010 represent percentage changes from the baseline.

Sector Name	Initial value in 2010 (millions of CO_2e)	(2) **Government spending scenario- average over (2011-2030)**	(3) **Government spending scenario- in 2030**	(4) **Compensation scenario- average over (2011-2030)**	(5) **Compensation scenario– in 2030**	(6) **Government spending and productivity scenario - average over (2011-2030)**	(7) **Government spending and productivity scenario- in 2030**	(8) **Compensation and productivity scenario - average over (2011-2030**	(9) **Compensation and productivity scenario- in 2030**
All Production Activities	130.32	-38.41	-64.74	-39.25	-65.91	-38.20	-65.27	-38.35	-64.93
Agriculture	106.62	-42.97	-73.03	-43.76	-73.93	-42.99	-73.22	-42.62	-72.68
Livestock	65.00	-44.97	-76.25	-45.93	-76.84	-45.27	-76.97	-45.99	-76.31
Other Agriculture	41.62	-40.51	-69.53	-39.93	-69.12	-40.30	-69.64	-39.69	-68.74
Industry	15.92	-26.56	-45.42	-26.03	-45.27	-25.61	-44.89	-25.58	-44.18
Service	7.78	-20.97	-43.24	-22.04	-45.67	-22.35	-45.88	-21.71	-44.72
Households	44.23	-32.93	-61.75	-30.63	-58.65	-33.49	-63.17	-33.22	-62.30
Overall	174.55	-36.84	-64.00	-36.78	-64.00	-36.86	-64.00	-36.67	64.00
Price of emission/tone of CO_2e in 2030 (in Birr)			2904		3329		3278		3283

Source: Own Computations

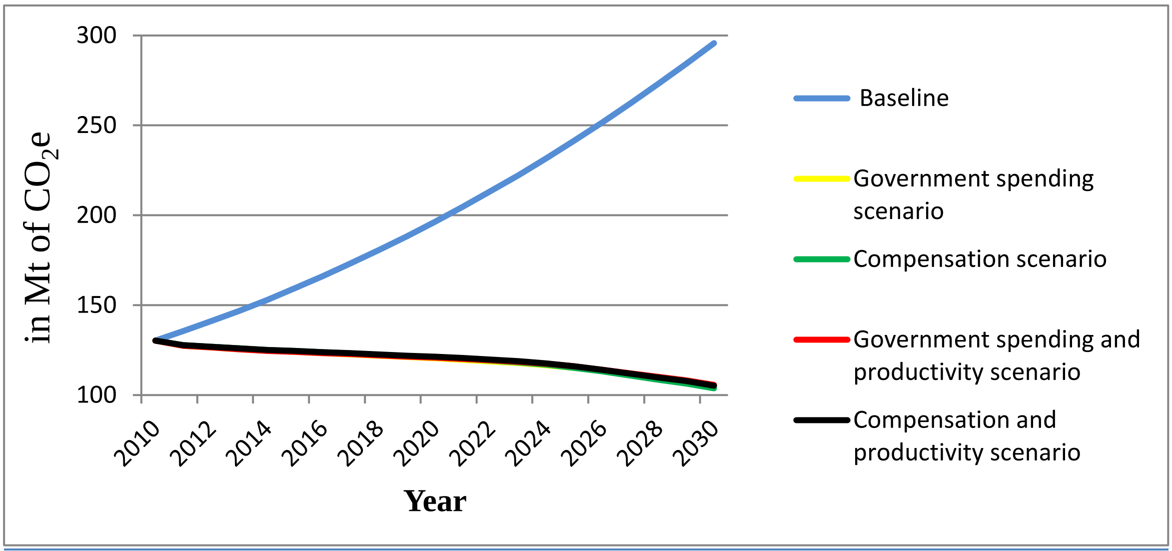

Figure 2.5 Trend of activity emission

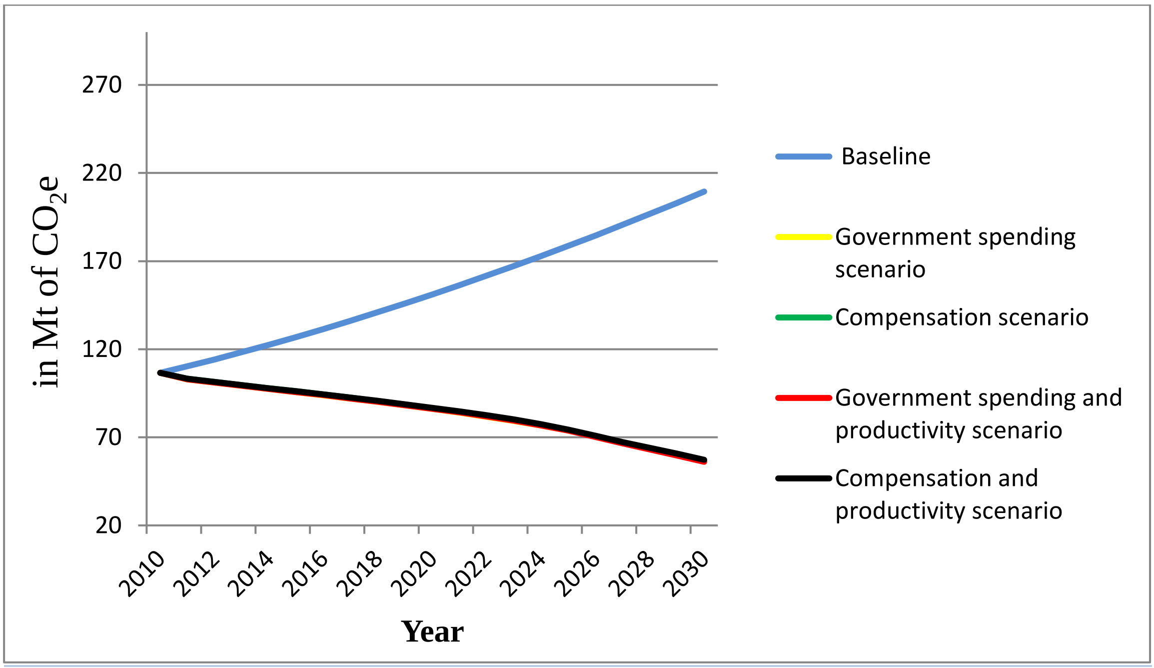

Figure 2.6 Trend of agricultural emission

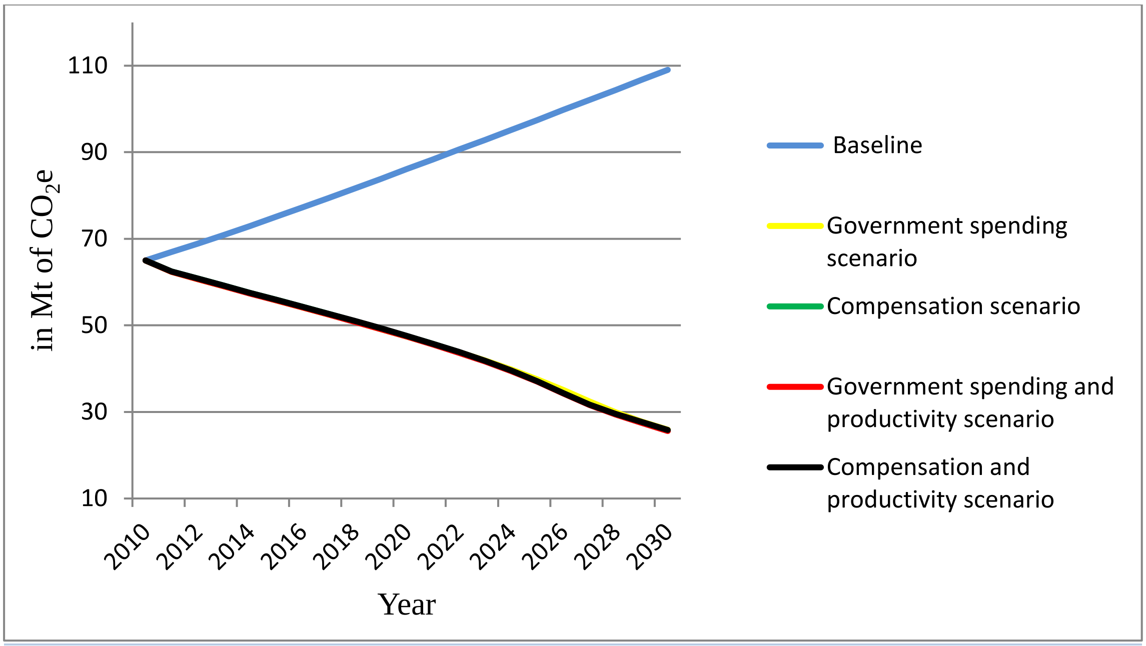

Figure 2.7 Trend of livestock emission

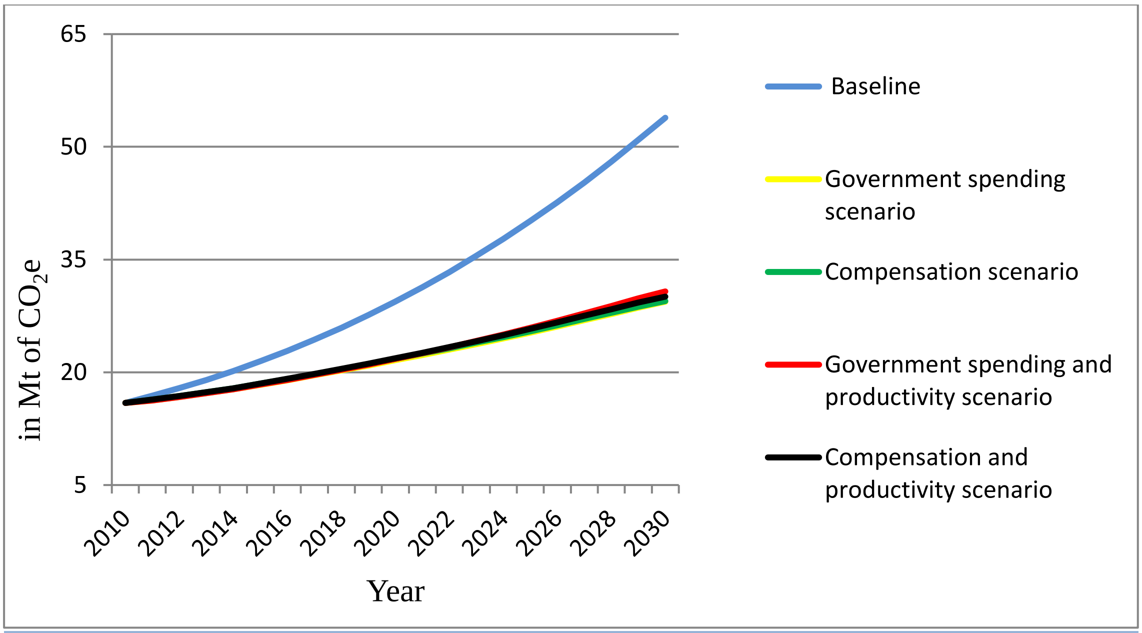

Figure 2.8 Trend of industrial emission

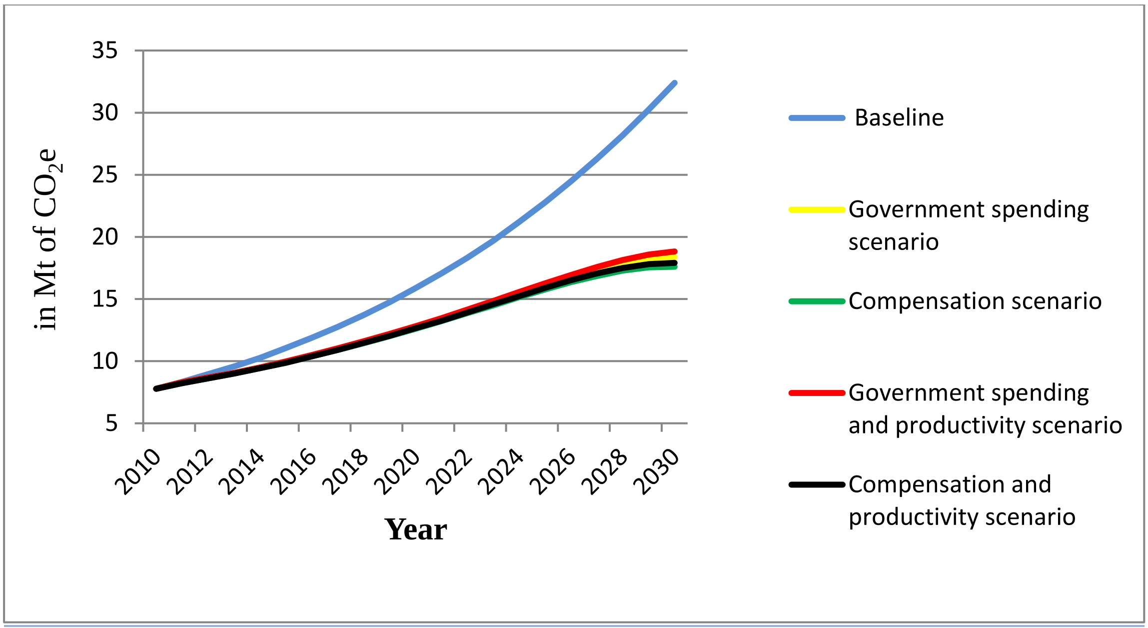

Figure 2.9 Trend of service emission

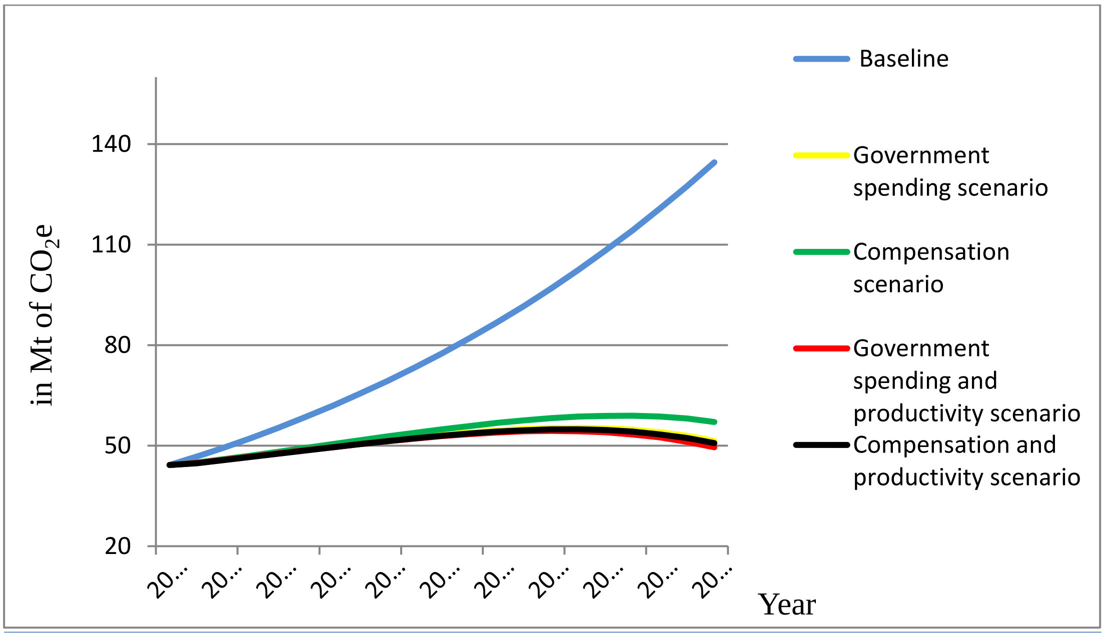

Figure 2.10 Trend of household emission

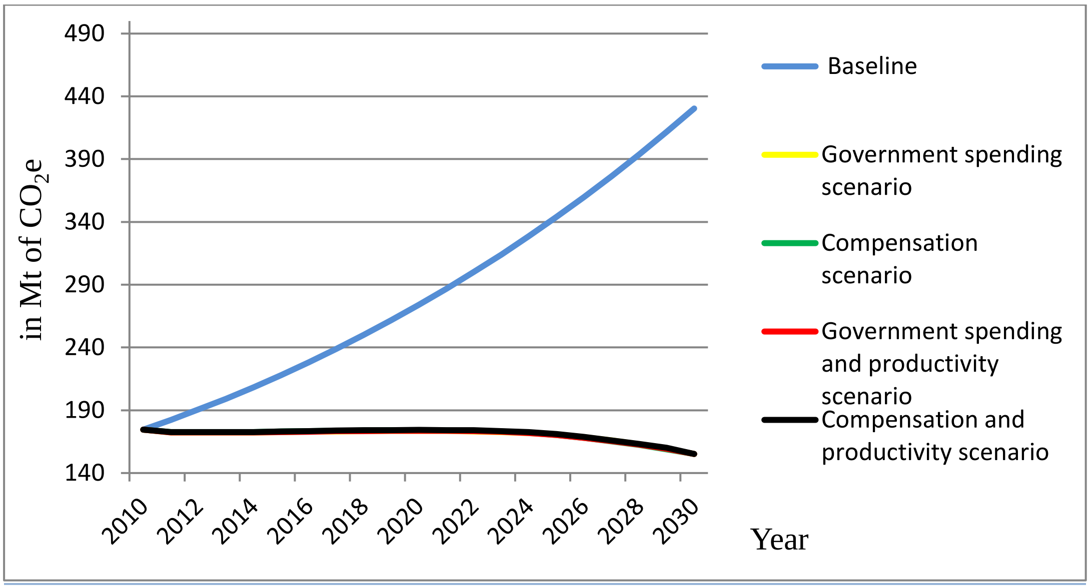

Figure 2.11 Trend of overall emission

2.4. Conclusion and Implications

Ethiopia has the objective of achieving a lower middle-income country status in a carbon neutral trajectory by 2025. To sustain the recently recorded fast and non-oil based economy, the country has launched the CRGE strategy as part of the overall development plan to reduce future emissions. Moreover, it submitted its own INDCs to the UNCCC secretariat to reaffirm its determination in fighting climate change where it sets an emission reduction target of 64% in 2030 compared to the BAU scenario. Against this background, this paper investigated the economic and environmental implications of a carbon tax implemented in Ethiopia to achieve the country's INDC. It uses a recursive-dynamic CGE model calibrated on the updated Ethiopian 2009/10 SAM and the corresponding emission data.

Four simulation experiments have been conducted. In the first simulation, carbon tax revenue has been allocated entirely for government consumption, whereas in the second simulation, the carbon tax revenue has been equally divided between government consumption and lump sum transfer to households. In the third simulation, government expenditure induced productivity gain in the health and educations sectors is combined with the first simulation. In the fourth simulation, government expenditure induced productivity gain in the health and educations sectors is combined with the second simulation. The results of simulation experiments indicate that GDP, national absorption and household consumption are adversely affected relative to the baseline scenario, the impact being higher in the first simulation. The third simulation works best to minimize the incidence of INDC policy on GDP and absorption which implies that if government expenditures are productive as assumed, using the carbon tax revenue for government consumption is more productive in terms of GDP than compensation to households.

The effect on household income is particularly negative especially under the government spending scenario (first simulation) and least affected under the compensation scheme (second simulation). As it is evident from the sectoral break down of the results, agriculture, and within agriculture, livestock, which are the largest emitting sector, are also those bearing the higher costs of the policy in terms of value added contraction. This boils down into a particularly regressive effect of the policy that hits relatively more adversely rural poor with a stronger dependence on agriculture.

All this highlights the potential high economic cost of the policy and stresses the need for (a) international support to Ethiopia for the implementation of the mitigation policy and (b) a careful design of the use of the tax revenues. Using the carbon tax revenue for simple expansion of government expenditure is not adequately enough to produce positive multiplicative effects on the economy unless productivity gains are observed. Without productivity gains, direct support to households seems, for instance, a better option, especially to contrast the clear regressivity of the carbon tax. However, when the carbon tax revenue allocated for government spending brings human capita productivity improvements, expansion of government expenditure seems better counterbalance the negative effects of the INDC policy on GDP. In general, an earn-marking of revenues to selected growth enhancing projects or strategies is essential. It can be also particularly appropriate to invest in clean technologies that are meant to improve emission efficiency in agriculture as most of the emissions emanate from that sector.

As a concluding remark, it is important to stress that the analysis presented does not consider the co-benefits benefits from emission reduction. These, be they direct or ancillary can be relevant.

As this study is the first attempt in Ethiopia, it leaves a wide room for future research potential. Firstly, the relative merits of alternative mitigation policies in attaining the INDC plan would be worth to study. Secondly, developing a multi-country CGE model or linking the current model with a multi-country model like GTAP would help deal with the changing situation in the rest of world. Thirdly, an examination of various tax revenue recycling policies would be of great interest. Fourthly, the introduction of unemployment and endogenous labour supply would contribute for the improvement of the model. Lastly, quantification of co-benefits of reduced emissions would be of great importance.

Chapter 3
The Poverty, Distributional and Welfare Implications of INDC Policies for Ethiopia

Abstract

Environmental policies relying on market-based instruments, primarily carbon taxes, are becoming more advocated to mitigate the ever increasing GHG emissions, due to their efficiency properties. However the equity implications of such policies, the impacts on poverty, on wealth distribution, and on the prospects for growth are equally important. This is particularly true for developing countries whose primary aim is to improve upon weak economic and social performances.

Ethiopia submitted its Intended Nationally Determined Contributions (INDC) to the UNFCCC secretariat with an emission reduction goal of 64% in 2030 compared to the BAU scenario. At the same time, the country is committed to reducing poverty and attaining its middle income status by 2025. As such, this study aims at analyzing the poverty, distributional and welfare consequences the implementation of Ethiopia's INDC policy in the form of carbon tax. To this end, the results from percentage changes in household consumption expenditure from the CGE model are linked to the 2010/11Ethiopian household expenditure and consumption survey micro data which covers 27,835 households (CSA 2011).

In accordance with the CGE simulations four scenarios have been considered. The first represents the implementation of a carbon tax where the revenues are entirely absorbed by government expenditure. The second represents the implementation of the carbon tax with lump sum transfer of 50% of the tax revenue to households. The third and fourth simulations add government expenditure induced productivity gains (in education and health) to the first and second simulations respectively. We found that INDC policy for Ethiopia would be costly to households under the first and third simulations. With the second and fourth simulations, we found sensible results whereby an improvement in poverty; inequality and welfare have been observed. The urban poor have benefited more from both the compensation plan and productivity gains than the rural non-poor. More importantly, compensation to households is more equitable than allocating the carbon tax revenue for government expenditure.

The results suggest that compensation of carbon tax revenue transfers should be structured such that the rural poor are more beneficiary as they are much larger in number and they are more affected by the carbon tax policy. Lastly, a huge international support is required to help the country achieve its emission reduction target at modest Poverty, welfare and distributional costs.

Keywords: Emission, carbon tax, poverty, inequality, welfare, Simulation, base, expenditure, Ethiopia

3.1. Background and Motivation

There is growing evidence that climate change is one of the planetary challenges our societies have to face in the next future (IPCCb, 2007). Its mitigation is an unavoidable discussion item in policy making agendas not only in countries that are increasingly integrating it into national development policies and plans, but also in those countries resisting committing against it. Developing countries joined the international community in reducing emissions since the 1992 United Nations Framework Convention on Climate Change (UNFCCC) initially adhering to the principle of common, but differentiated responsibilities. Indeed, within the context of the 1997 Kyoto Protocol, the first, and at the moment only, internationally binding emission reduction treaty, developing nations were not imposed binding emission reduction limits rather were given opportunity to get climate finance in exchange for their voluntary efforts to reduce emissions. A turning point in international climate negotiations is, however, the 2015 Paris Climate Conference, corresponding to the 21st international negotiation round on climate policies. There, many developing countries, including Ethiopia, finally submitted their Nationally Determined Contributions (NDC) to the UNFCCC secretariat setting specific, albeit voluntary, mitigation and adaptation targets. Ethiopia proposes the ambitious greenhouse gas emission reduction goal of 64% in 2030 compared to the BAU scenario (FDRE, 2015; UNFCCC, 2015).

As environmental concerns are receiving widespread attention, environmental policies relying on market-based instruments, primarily carbon taxes, are becoming more advocated, due to their efficiency properties (Baranzini, Goldemberg, & Speck, 2000; Barker & Johnstone, 1998; Shah & Larsen, 1992). However the equity implications of such policies, the impacts on poverty, on wealth distribution, and on the prospects for growth are equally important. This is particularly true for developing countries whose primary aim is to improve upon weak economic and social performances. Indeed, these concerns are among the typical motivations inducing countries to hesitate adopting emission reduction policies implemented through carbon taxes and a major obstacle to the smooth development of international climate change negotiations (Shah & Larsen, 1992; Ved & Javier, 1998; Yusuf & Resosudarmo, 2015).

The available empirical literature on the distributional implications of carbon taxes is quite ample, but concentrated mostly on developed countries (see for example: (Baranzini, Goldemberg, & Speck, 2000; Callan, Lyons, Scott, Tol, & Verde, 2009; Cornwell & Creedy, 1996; Flues & Thomas, 2015; Hamilton & Cameron, 1994; Jorgenson, Slesnick, Wilcoxen, Joskow, & Kopp, 1992; Klinge, Birr-Pedersen, & Wier, 2003; Leach, 2009; Poterba, 1991; Symons, Proops, & Gay, 1994); (Tiezzi, 2005; Wier, Birr-Pedersen, Jacobsen, & Klok, 2005)). It is suggested that carbon taxes have proved to be mostly regressive, i.e. their cost is borne more by lower rather than higher income households. However, distributional outcomes are found to depend on the mode for recycling carbon tax revenues, for example, whether revenues go to the government or to households (Bureau, 2011; Callan, Lyons, Scott, Tol, & Verde, 2009; Keohane, Revesz, & Stavins, 1997). Nonetheless, such analyses are extremely limited in developing countries. There is in fact some literature analyzing the potential consequences of removing fossil fuel subsidies in developing countries which can be viewed with some affinity to the introduction of carbon/energy taxes. In this vein, (Durand-Lasserve, Campagnolo, Chateau, & Dellink, 2015) noted that if Indonesia were to remove fossil fuel subsidies, it would record real GDP and welfare gains. At the same time they underline again the importance of properly designed compensating schemes for households that could turn potential welfare losses into gains. Recycling in the form of Cash transfers is found to make the reform more attractive for poorer households and reduce poverty. Eventually, it is the re-distribution scheme that matters in determining the overall distributional effect of such reforms.

Indonesia is also one of the few developing countries where the distributional implication of a carbon tax has been explicitly studied. Yusuf & Resosudarmo (2015), using a static Computable

General Equilibrium (CGE) model investigated the effects of introducing a carbon tax aiming to achieve a 6% emission reduction compared to the business as usual scenario in 2004.The results suggest that, unlike most studies on developed countries, the distributional effects in Indonesia are not necessarily regressive. This outcome is determined by both the income and the expenditure patterns of households where the resource reallocation due to the introduction of a carbon tax is in favour of factors endowed more proportionally by rural, and lower income class households

Indeed already at the beginning of the 1990s, Shah & Larsen (1992) pointed to many peculiar characteristics of developing countries such as agricultural dominance, industrial characteristics and household expenditure patterns which naturally differ from that in rich countries that could determine different results from these policies.

Against this background, it would be interesting and relevant to test whether a similar conclusion could be drawn with reference to Ethiopia. Its economic structure is highly representative of a developing tropical country. With a GDP per capita of around USD 380 as of 2010, Ethiopia is still one of Africa's poorest countries. With only 17% of the Ethiopia’s population living in urban centres and nearly half of them live in the capital, Addis Ababa, more than 80% of employment is still concentrated in agriculture. Agriculture is also the major source of emission with the livestock sector alone accounting for more than 40% of the total emission (FDRE, 2015). In addition to setting an ambitious emission reduction plan, the Ethiopia government, puts at the same time poverty reduction and economic growth at the top of priority.

This chapter is intended to assess the potential distributional implications for Ethiopia of pursuing the emission reduction target part of its NDCs, implemented through a carbon tax. The study couples the results from a recursive-dynamic CGE analysis investigating the economic implication of Ethiopia’s INDCs (chapter 2) with micro data from Ethiopian household survey (CSA, 2011).

The CGE analysis, that considers explicitly 4 household types, i.e. urban rich and poor, rural rich and poor, already emphasized that the mitigation policy can be regressive, as the costs are borne mostly by the poorer rural population being emissions primarily originated by the agricultural sector, especially livestock. At the same time, it stressed that an important role to reduce costs and regressive impacts is played by the use of the revenues from the carbon tax.

Starting from these results, exploiting the much richer household stratification provided by Ethiopian household survey, the objective of this work is to expand chapter 2 to provide a quantitative estimate of the effects of Ethiopia's mitigation NDCs implemented with a carbon tax on:

- ✓ Poverty
- ✓ Inequality
- ✓ Welfare.

In what follows, section 2 introduces the methodology, section 3 summarizes the results and section 4 wraps up the study with the conclusion and implications.

3.2. Methodology

3.2.1. Database and Linkages

In chapter two of this thesis, we developed an extended version of the core CGE model structure used by the International Food Policy Research Institute (Lofgren, Harris, & Robinson, 2002), calibrating it on the Ethiopian data for 2009/10 and adding a CO_2 emission and carbon tax module. The model was then applied to investigate the macroeconomic impacts on Ethiopia of introducing a carbon tax enabling the country to achieve a 64% emission reduction target compared to the Business as Usual scenario in 2030 as set out in the INDC of the country. To recall, four policy scenarios were considered, all which imposed 64% emission reduction in 2030:

Simulation 1-Government spending scenario: carbon tax scenario where government collects all the carbon tax revenues and uses them for its consumption. This complies with the Ethiopian government plan intending to use finances gained from any climate change intervention policy to support big nation-wide development projects (FDRE, 2011).

Simulation 2- Compensation scenario: 50% of the carbon tax revenue is recycled in the form of lump sum transfers to poor households and the remaining part continues to be used for government expenditure.

Simulation 3- Government spending and productivity scenario: The first simulation plus Productivity effects of the carbon tax revenue used for government expenditure. For this, the impact of 1% increase in education and health expenditures from the study for Nepal's economy, an economy with similar characteristics with the Ethiopian economy, is adopted (please see chapter 2 for more details).

Simulation 4- Compensation and productivity scenario: The second Simulation plus productivity effects of the carbon tax revenue used for government expenditure in that simulation. The mechanism is the same as the third simulation except here only 50% of the carbon tax revenue is spent for government consumption.

Table 3.1 summarizes major results from chapter 2. Those more relevant for this chapter refer to household consumption expenditure. In spite of being aware of the huge approximation with it, we use the yearly average percentage changes over 20 years from the CGE model and apply them to the 2010/11 survey data.

We understand that there would be a huge approximation associated with imposing a 20 years average percentage changes on 2010/11 survey data to study the distributional impact of the policy. However, the effect of the policy in 2011 is almost null, and that in 2030, extremely high. So we deem anyway useful to try to provide the average figure. This is preferred to use the 2011 impacts from the CGE model as they are negligible, at the same time, using the 2030 result could overestimate the distributional costs of the policy. On the other hand it would be quite easy to introduce alternative evolution of the household expenditure structure along time; however this would introduce a further element of subjectivity that we prefer to avoid.

Table 3.1: Effects of simulations on GDP, absorption, Household consumption expenditure: Simulation growth (% change) relative to the baseline- average over (2011-2030)

Variable Name	Initial value in 2010 (billions of Birr)	Government spending scenario	Compensation Scenario	Government spending and productivity scenario	Compensation and productivity scenario
GDP at factor cost	354.95	-1.15	-0.85	-0.31	-0.44
Absorption	452.77	-1.12	-0.81	-0.41	-0.53
Overall Household Expenditure	338.61	-4.29	-2.83	-3.74	-2.54
Rural poor	63.64	-8.13	-1.92	-7.01	-1.28
Rural non-poor	197.25	-3.56	-3.45	-2.98	-2.59
Urban Poor	9.97	-1.60	4.70	0.78	5.81
Urban non-poor	67.76	-1.26	-1.13	-0.99	-0.74
Rural total	260.89	-5.07	-3.25	-3.93	-2.14
Urban total	77.73	-1.31	0.40	-0.36	0.59

* In 2011, one Euro corresponded to 24.5 Birr
Source: Own computations from CGE model

The last four columns of table 3.1, show that GDP, Absorption and household consumption expenditure would decrease. On average, over the period 2011- 2030, the household consumption declines by 4.29%, 2.83%, 3.74% and 2.54% respectively under the first, second, third and fourth simulations respectively. Without support to low income households, the policy is acutely regressive especially in rural area, bearing the higher cost in terms of consumption contraction. This outcome is driven either by the still high emission share of the agricultural sector in the country, or by the traditionally higher dependence of poor rural communities on that sector. Interestingly, in urban area, where the direct dependence on agriculture is lower, poor and non-poor households experience much similar percent consumption losses under government spending scenario. As expected, the tax revenue rebate on poor households reverts the picture with urban poor even increasing their consumption levels. This may suggest an even more targeted recycling scheme with a stronger facilitation to rural poor. On top of this, poor households benefit more from direct transfers than the productivity gains from government expenditure in the education and health sectors. On the other hand, the results under government spending with productivity and compensation with productivity scenarios suggest that non-poor households benefit more from productivity gains than from direct transfers.

The percentage changes in household consumption expenditure from the CGE model are then linked to the 2010/11Ethiopian household expenditure and consumption survey (CSA 2011).This multiple household micro dataset covers 27,835 households among which 10,322 rural and 17,513 urban. In this top-down sequential approach (see Figure 2.1) the CGE model outcomes are mapped to the Ethiopian micro data.

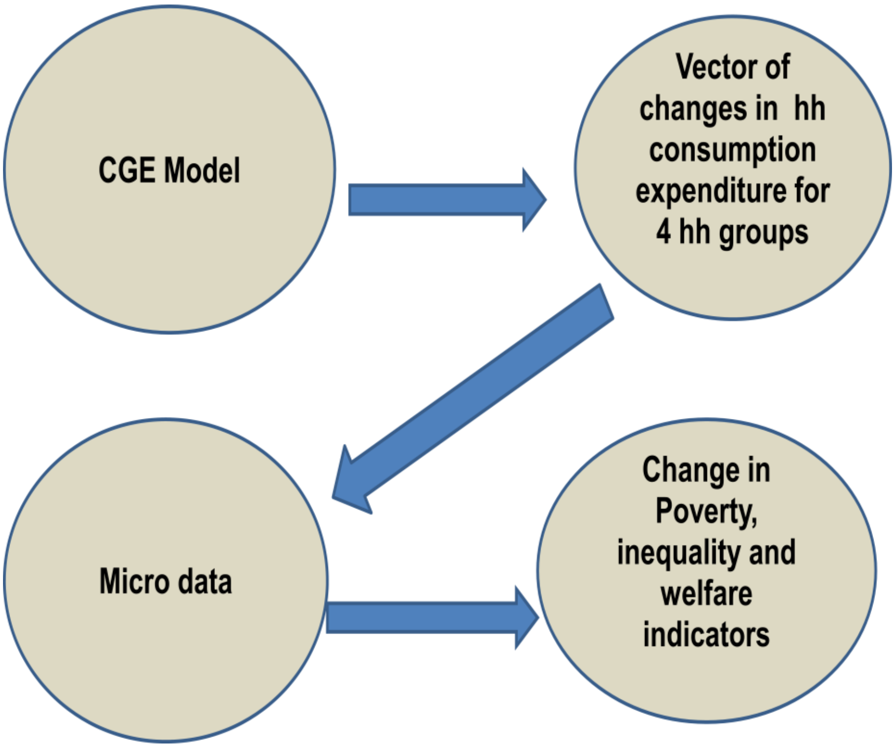

Figure 2.1: The top-down sequential approach.
Adapted from Aredo, Fekadu, & Workneh (2007); Colombo (2008)

The mapping procedure is the following (see also (Aredo, Fekadu, & Workneh, 2007; Colombo, 2008)) for similar methodology).

As a first step we identify the number of rural and urban poor and non-poor in the household survey data using the expenditure shares from the CGE. For instance, the share of consumption accounted by the total poor is 21.74% in the CGE data matrix. Accordingly, after ranking households in descending expenditure order in the household survey, those contributing to the bottom 21.74% are considered poor. Sampling weights are duly considered to compute the cumulative household expenditure which is used to demarcate the number of poor households that correspond to their appropriate share to total expenditure in the country. This also allows identifying the poverty line corresponding to the consumption expenditure level of the richest household within the 21.74%. This poverty line is used to identify both the urban and rural poor. The same procedure was then applied to identify all the four types of households as the survey also reports urban and rural origin.

In the next step, by applying to the household survey data the percentage changes in consumption expenditure of each of the household categories from the CGE model, it is then possible to compute how many households are crossing that poverty line in either directions.

This is our starting point to compute policy impacts on poverty, inequality and welfare.

3.2.2. Measuring impacts on poverty

The policy impact on poverty is measured by three different poverty indexes as defined by (Foster, Greer, & Thorbecke, 1984).

The general class of the Foster, Greer, and Thorbecke (FGT thereafter) indexes is the following.

$$FGT(\alpha) = \sum_{i=1}^{n} f_i \left[(z - y_i)/z \right]^{\alpha} I_i \ldots\ldots(1)$$

$i = 1,...,n$, is the population, with consumption expenditure y_i .z is the poverty line, and $\max(0, z - y_i)$ is the poverty gap for person i. $f_i = w_i / N$, is a "weighting" function with w_i sampling weight and $N = \sum_{i=1}^{n} w_i$. Accordingly, "no weighting" (or to be precise "all equals") occurs when $w_i = 1$ & $N = n$.

The last term in equation (1) is an indicator function with $I_i = 1$ it $y_i < z$ and $I_i = 0$ otherwise. The exponent α is a poverty aversion parameter. The larger α is, the greater the degree of poverty aversion (or, said differently, the sensitivity to large poverty gaps).

Three poverty measures can be drawn from equation (1) depending on the values of α.

Head Count Ratio [FGT(0)]: This is the case when $\alpha = 0$.

$$FGT(0) = \sum_{i=1}^{n} \frac{w_i}{N} I_i = \frac{q}{N} \ldots\ldots(2)$$

Where q represents the number of poor people and N is the total population. It gives the proportion of the population whose incomes fall below the poverty line thereby measuring the prevalence (incidence) of poverty. The principal advantage of this index is that it is easy to construct and interpret. However, it does not show the "extent" to which the poor fall below the poverty line; hence it does not change if people below the poverty line become poorer.

The Average Normalized poverty Gap [FGT(1)]: This is the case when $\alpha = 1$.

$$FGT(1) = \sum_{i=1}^{n} f_i \left[(z - y_i)/z\right] I_i \quad \text{.....(3)}$$

This measure captures the acuteness (depth) of poverty as it measures the total shortfall of the poor from the poverty line. It also signals the cost of eliminating that poverty. This measure has the drawback that it does not consider the importance of the number of people who are below the poverty line. The measure does not reflect changes in inequality among the poor.

The Average Squared Normalized poverty Gap [FGT(2)]: This is the case when $\alpha = 2$.

$$FGT(2) = \sum_{i=1}^{n} f_i \left[(z - y_i)/z\right]^2 I_i \quad \text{.....(4)}$$

This measure of poverty takes into account not only the poverty gap but also the intra-poor inequality since the poor also have differences in status. By squaring the poverty gap, this measure implicitly puts more weight on observations that fall farther below the poverty line.

3.2.3. Measuring impacts on inequality

Distributional impacts of the policy are summarized by the Gini coefficient a widespread measure of inequality of a distribution. Developed by the Italian statistician Corrado Gini and published in (1912) in his paper "Variabilità e mutabilità" ("Variability and Mutability"), it ranges, by construction, between 0 and 1. 0 corresponds to perfect income equality (i.e. everyone has the same income) and 1 corresponds to perfect income inequality (i.e. one person has all the income, while everyone else has zero income).

There are slightly different versions of the Gini index (G). That used here is:

$$G = 1 + (1/N) - \left(\frac{2}{mN^2}\right)\sum_{i=1}^{n}(N - i + 1)y_i \text{ ....(5)}$$

The notation is as before. Persons are ranked in ascending order of y_i and m is the arithmetic mean expenditure.

3.2.4. Measuring impact on Social Welfare

There is a huge debate on measuring social welfare, starting from the intrinsic difficulty to define welfare itself (Atkinson, 1983; Jenkins, 1997; Jorgenson, Slesnick, Wilcoxen, Joskow, & Kopp, 1992; Stiglitz & Fitoussi, 2009). A possible procedure, once a given welfare source/indicator like income or consumption has been defined, is to apply so-called social welfare functions (SWFs) to measure the welfare embodied in a given allocation of those sources within a population. SWFs are typically dependent on both the total (or mean) values, their distribution across the members of the population, attitudes towards equitable distributions. At the two polar cases there are the utilitarian SWFs, with zero inequality aversion[14], and the Rawlsian SWFs, with infinite inequality aversion[15].

Another corner-stone methodology in welfare measurement, the one followed in this research, is to compute the Equally Distributed Equivalent (EDE) expenditure/income. EDE expenditure/income is that level of expenditure/income that, if given to every individual in the population after a policy shock, would generate the same level of social welfare as the current distribution (Mnally, 2013).

[14]In these functions total societal welfare increases uniformly, irrespectively from whom within the society increases her/is income or consumption level.
[15]In these functions total societal welfare increases if and only if the poorest component of the society increases her/his income or consumption level.

EDE expenditure/income is at the basis of the computation of the social welfare index by (Jenkins, 1997), w_e ,used in this work. It is defined as:

$$w_e = \frac{1}{1-e}\left[Y_{ede}(e)\right]^{1-e}, \quad e > 0, e \neq 1 \text{...(6)}$$

where e is the inequality aversion parameter which takes a standard value equal to 0.5.*Yede* is the Equally Distributed Equivalent (EDE) Income/Expenditure. Using the previous notation, over an entire population, it is computed as:

$$Y_{ede}(e) = \left[\sum_{i=1}^{n} f_i (y_i)^{1-e}\right]^{1/1-e} \quad , e > 0, e \neq 1 \text{...(7)}$$

If *e* were equal to 1, (6) and (7) would collapse to (8) and (9) respectively.

$$w_1 = \log\left[Y_{ede}(1)\right] \quad e = 1 \text{...(8)}$$

$$Y_{ede}(1) = \sum_{i=1}^{n} f_i \log(y_i) \quad , e = 1 \text{..(9)}$$

We also compute the other commonly used welfare measure: the Sen welfare index (A. Sen, 1976). It is defined as:

$$S = m(1-G) \text{...(10)}$$

Where m and G are the mean per capita expenditure and the Gini coefficient respectively.

Sen's index is negatively related to the Gini coefficient and positively related to the per capita expenditure. As G approaches to 1, maximum inequality, S tends to zero.

3.3. Data Analysis and Results

3.3.1. The starting Point: Impacts on household consumption from the CGE Analysis

To analyze the poverty changes, we used the DAD[16] distribution analysis software that allows a micro simulation analysis of the FGT decomposable poverty indices using 2010/11 HCE survey. As anticipated in the methodology section, to compute the FGT poverty indices, we used the percentage changes in consumption expenditure of household groups produced by the CGE analysis.

3.3.2. Impacts on Poverty

Among the 27,835 households at national level, we found that 10,322 were rural and 17,513 were urban[17] (CSA, 2011).One point to note is that, based on the information provided by the Central Statistical Agency (CSA) for 2010/11, we changed the household consumption expenditures in the survey into consumption expenditure per adult equivalent[18] instead of taking per capita expenditure. The rationale for using adult equivalent comes from (Deaton & Zaidi, 2002), in their cornerstone work in consumption analysis. Since children often require less expenditure than adults, it could be misleading to treat them like adults. Moreover, there are certain household goods that could be considered quasi-public goods, such as housing, that do not increase incrementally with the number

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[16]The DAD (distribution analysis) software is "designed to facilitate the analysis and the comparisons of social welfare, inequality, poverty and equity across distributions of living standards. Its features include the estimation of a large number of indices and curves that are useful for distributive comparisons as well as the provision of asymptotic standard errors to enable statistical inference. The features also include basic descriptive statistics and provide simple non-parametric estimations of density functions and regressions." (Duclos, Araar, & Fortin, 2010)

17The number of urban households is larger in the survey. However, the sampling weight attached to each household is much larger for rural households compared to urban households. With the attached sampling weight, the total population of the country (less the non-sedentary populations that were excluded from the survey for practical reasons) is estimated to be 76.1 million people in the survey year.

18The computation of adult equivalent (AE) is as follows: $AE = (A + \alpha K)\,\theta$; where A is the number of adults (>=15 years old), K is the number of children (<15 years old), α is the cost of kids relative to adults, and θ is an estimate of the household economies of scale. Based on (Deaton & Zaidi, 2002), recommendations for developing economies, $\alpha=0.25$, implying that children cost a quarter of adults on average, and $\theta=0.9$, a low level of economies of scale given that most expenditures in developing economies are on private goods rather than public goods (for example, the high proportion of food expenditure (CSA, 2011).

of household members. Hence, larger households take more advantage of the economies of scale from these public goods. Therefore, adult equivalents accounts for demographic differences in household composition (the difference between the cost of children and adults) as well as consider economies of scale.

Then, we took approximate levels of consumption expenditure at the demarcation line (as anticipated in section 2) to represent cut points for poor and non-poor households. In doing so, we found the poverty line to be Birr 3495 (EUR 142 in 2011), which is slightly different from the national poverty line (Birr 3781 or EUR 154 in 2011) as officially reported by the 2010/11 HCE analytical report.

We then introduced the consumption percentage changes on the base values of the four household groups derived from the CGE model simulations. Table 3.2 presents the results for the three poverty indices.

Table 3.2: Impacts of Ethiopia NDC on the country's poverty indices: yearly 2011-2030 average.

		Base*	Government spending scenario'	Compensation Scenario'	Government spending and productivity scenario'	Compensation and productivity scenario'
Headcount Ratio FGT(0)	National	29.16	9.88	1.34	9.19	0.01
	Rural	30.03	11.46	3.57	11.13	2.59
	Urban	23.06	3.60	-8.98	-0.30	-11.88
Poverty depth FGT(1)	National	7.52	22.20	2.39	17.82	0.53
	Rural	7.96	25.88	5.53	22.11	3.64
	Urban	5.90	4.75	-12.70	-2.37	-15.42
Poverty severity FGT(2)	National	2.94	25.55	2.38	20.07	0.68
	Rural	3.13	29.39	6.07	24.92	4.15
	Urban	2.23	5.38	-14.80	-2.69	-17.49

Source: Own Computation from Micro data, Notes:* percent of poor in the no-policy case; 'percentage change NDCs vs no-policy

In the first simulation scenario, we see that national headcount ratio increases by 9.88% from the baseline. The effect becomes much smaller under the second simulation witnessing the effectiveness of the compensation scheme especially for the urban poor that demonstrate a decline in headcount ratio by 8.98%.

Accounting for the productivity enhancing effect of public expenditure, does not change substantively the picture. This result partly captures a characteristic of rural Ethiopia that is sparsely populated with households living in remote areas with scarce access to education and health facilities thus probably with less capacity to benefit from their improvement[19]. However, government spending with productivity (simulation 3) does decrease headcount ratio in the urban areas, which might be related to low dependence on agriculture, and to the existence of better awareness, and dense settlement. Compensation with productivity (simulation 4) almost fully curtails the adverse effects of the INDC policy on poverty. Hence, government expenditure induced productivity gains combined with the compensation plan seem successful in attaining INDC target with no adverse impact on poverty. The urban population becomes even better off under compensation with productivity (simulation 4) than the rest of the simulations. We can see from this that direct transfer to households need anyway to be put in place to alleviate poverty even when productivity gains are accounted for.

Poverty depth and poverty severity follow the same patterns of the headcount ratio.

What is apparent from table 3.2 is that the magnitude of the percentage changes from the base values of the indexes increases when we move from the headcount index to the poverty severity index. This is because the poverty depth and severity tend to emphasize the effects on poorer households.

[19]In addition, every member of the household in rural Ethiopia, starting at the early age, shoulders responsibility and works full time in the agricultural sector. Rural households are not willing to send children to school as there is high labor demand for farming

Concluding, pursuing Ethiopian INDCs without any compensation to households increases overall poverty and the number of poor. The negative effect is particularly strong on rural households as the burden of the policy hits especially the agricultural sector, the major emitter in Ethiopia, on which the rural population relies upon.

The adverse incidence of the policy could be significantly reduced if the revenue from carbon tax is transferred back to households. If the rebate is undifferentiated across rural and urban population, the latter could be even better off with than without the mitigation policy. Our result points out a clear need, and room, to target the recycling mechanism toward rural poor.

3.3.3. Effects on Inequality

Table 3.3: Impacts of Ethiopia NDC on the country's Gini index: yearly 2011-2030 average.

	GINI coefficient				
	Base*	Government spending scenario'	Compensation Scenario'	Government spending and productivity scenario'	Compensation and productivity scenario'
National	0.309	2.43	-1.06	1.82	-1.11
Rural	0.275	2.71	-1.01	2.03	-1.02
Urban	0.370	0.26	-1.41	-0.26	-1.53

Source: Own Computation from Micro data
Notes:* Gini coefficient in the no-policy case; 'per-cent change NDCs vs no-policy

In the base year, the Gini coefficient is found to about 0.31, 0.28 and 0.37 at the national, rural and urban levels respectively. Interestingly, inequality in the urban areas is much higher than in rural areas that although poorer, are also characterized by a more uniform income distribution. In the first simulation (government spending scenario-without compensation scheme), it is evident that inequality increases from the base year values for all classes of population. The effects reversed with the compensation plan under the second and fourth simulations (compensation and compensation with productivity scenarios).

3.3.4. Effects on Welfare

Table 3.4: Impacts of Ethiopia NDC on the country's welfare indices: yearly 2011-2030 average.

		Base*	Government spending scenario'	Compensation Scenario'	Government spending and productivity scenario'	Compensation and productivity scenario'
W(e) (Jenkin's Social swelfare)	National	143.15	-1.98	-1.20	-1.63	-0.83
	Rural	138.25	-2.39	-1.50	-2.00	-1.14
	Urban	161.10	-0.66	-0.13	-0.37	0.11
Sen's welfare Index	National	3790	-4.75	-2.37	-3.95	-1.58
	Rural	3630	-5.23	-2.75	-4.41	-1.93
	Urban	4540	-1.32	0.22	-0.66	0.66

Source: Own Computation from Micro data

Notes:* Welfare indices in the no-policy case; 'per-cent change NDCs vs no-policy

When we look at the Jenkin's social welfare effects, the first simulation brings a reduction of the base year values by 1.98%, 2.39% and 0.66% for the national, rural and urban population respectively. The adverse effect of the policy on social welfare becomes smaller under the second and third simulation. We can see from the above table that the compensation plan results in a decline of national, rural and urban social welfare by 1.20%, 1.50% and 0.13% from the baseline respectively. Government spending with productivity scenario (simulation 3) has lower negative impact on welfare than government spending without productivity scenario (simulation 1). Also, compensation with productivity (simulation 4) better offsets the negative effects of the carbon tax policy better than compensation without productivity (simulation 2).

Sen's welfare index shows a decline of base year values by 4.75%, 5.23%, and 1.32% for national, rural and urban households respectively under the first simulation. Under the second simulation, the national and rural index decreases by 2.37% and 2.75% from the base respectively, whereas the index for the urban population has shown a slight increase of the base value by 0.22% respectively. The introduction of government expenditure induced productivity gains (as in the last two simulations) has improved welfare compared to their respective counterparts in the first two simulations. Although the compensation scheme does not totally offset the negative impacts of carbon tax, it significantly reduces the incidences on welfare. The combination of compensation and productivity gains produce better results in offsetting the adverse effect of the policy on welfare. Despite the decrease in inequality under compensation and compensation with productivity (simulations 2 &4), the negative effect on welfare still prevails because welfare is also dependent on the mean expenditure level.

3.4. Conclusion and Implications

Ethiopia, in its INDC plan, sets an ambitious emission reduction target of 64% compared to the baseline in 2030. At the same time, the country plans to reduce poverty and enhance economic growth. This study is the first attempt proposing an assessment of the potential poverty and distributional consequences of achieving this target. The study starts from the results produced by a CGE model simulation in chapter 2 and link them to micro data provided by the 2010/11 HCE multiple household survey dataset to estimate impacts on a set of poverty, inequality and welfare indicators.

Four scenarios have been considered. The first represents the implementation of a carbon tax where the revenues are entirely absorbed by government expenditure. The second represents the implementation of the carbon tax with lump sum transfer of 50% of the tax revenue to households and the remaining 50% to government expenditure. The third and fourth simulations introduce productivity changes that may arise from government expenditure in education and health sectors. We found that INDC policy for Ethiopia worsens all indicators even when positive effects from a "productive" government expenditure is considered. Adverse effects are more pronounced for the rural poor. The compensation plan produces a detectable reduction in adverse effects on poverty, and welfare, which, almost disappear in the fourth simulation.

The results also highlight the particular vulnerability of the rural poor population. On one hand they are those which are hit most adversely by the policy due to their higher dependence of their income and then consumption upon emission intensive activities (agriculture and livestock), on the other hand they are also those who gain less from the redistribution scheme. This is because the existing government transfer allocation favors the urban poor which our exercise replicates. More in general, this points out the need to design appropriate measures to support rural households that, for instance, are much less able than the urban population to access and participate to education and health care projects.

In conclusion, Ethiopia set an ambitious emission reduction objective that could imply a relevant cost in term of poverty increase, welfare and equality decrease. The impact on poverty and welfare can be partly, or even fully, offset by appropriate compensation schemes. But it is important to consider that this occurs mostly through a redistribution of resources within the society rather than through a lower contraction of the Ethiopian economic activity. Accordingly, more equity can be achieved, but within a poorer economy. This stresses the need for a substantive international support to Ethiopia mitigation policy that should be backed by solid pro-development policies.

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METHODOLOGICAL APPENDIX

Appendix A. Model Basic Structure

The starting core structure of the model used in this study is the International Food Policy Research Institute (IFPRI) CGE model (Lofgren, Harris, & Robinson, 2002).The model follows the neoclassical-structuralism modeling tradition. It is formulated as a set of simultaneous linear and non-linear equations, which define the behaviour of economic agents, as well as the economic environment in which these agents operate. This environment is described by market equilibrium conditions, macroeconomic balances, and dynamic updating equations. The model belongs to the recursive strand of the dynamic CGE literature, which implies that the behaviour of its agents is based on adaptive expectations, rather than on the forward-looking expectations that underlie alternative inter-temporal optimization models (Thurlow, 2008).

Since a recursive model is solved one period at a time, it is possible to separate the within-period component from the between-period component, where the latter governs the dynamics of the model.

Within Period Specification[20]

The within period component of the model describes a one period static CGE model. The standard CGE model explains all of the payments recorded in the country's Social Accounting Matrix (SAM[21]). The model therefore follows the SAM disaggregation of factors, activities, commodities,

[20] This part entirely describes IFPRI's standard CGE model, as described in (Lofgren, Harris, & Robinson, 2002).

[21] A SAM is a comprehensive and consistent, economy wide data framework or set of accounts that has detailed quantification for economic flows of incomes and expenditures in an economy, usually a nation, for a given period of time, mostly a year. It is the main data used for calibration in CGE modeling is the Social Accounting Matrix (SAM) (Thurlow & Van Seventer, 2002). Not only does a CGE take as its initial conditions the values appearing in the base-year SAM but also the parameters and coefficients of the various equations of the CGE are calibrated on the base-year SAM. In this sense, it can be said that a SAM provides the "navigation table" for a CGE (Thorbecke, 2000). It is an nxn square matrix in which each account is represented by a row and a column, which describes the flow of income among four different agents in the

and institutions written as a set of linear and non-linear simultaneous equations. The equations, most of which are non-linear, define the behaviour of the different actors in the economy. In part, this behaviour follows simple rules captured by fixed coefficients (for example, ad valorem tax rates). For production and consumption decisions, behaviour is captured by nonlinear, first-order optimality conditions-that is, production and consumption decisions are driven by the maximization of profits and utility, respectively. The equations also include a set of constraints that have to be satisfied by the system as a whole but are not necessarily considered by any individual actor. These constraints cover markets (for factors and commodities) and macroeconomic aggregates (balances for Savings-Investment, the government, and the current account of the rest of the world). Eventually, the equations in the model can be categorized under four blocks: prices, production and trade, institutions, and system constraints. The brief description of the blocks is presented below. The full and detailed description of the model is found in (Lofgren, Harris, & Robinson, 2002).

Price Block

The price block is made up of a rich system of equations in which endogenous model prices of commodities of different origins (imports, exports, domestically produced and sold goods) are linked to other (endogenous or exogenous) prices and to non-price model variables. The prices under this category include: import price, export price, demand price of domestic non-traded goods, absorption, marketed output value, activity price, aggregate intermediate input value, activity revenue and costs, and consumer price index and producer price index for non traded market output. Export and import prices are expressed in terms of local currency units. Absorption, which is the total domestic spending on a commodity, is valued at domestic demander prices.

economy namely; the household, government, enterprises and rest of the world. Each cell in the SAM represents the payment from the column account to the row account. Given a double entry accounting principle, total income (row total) must equal total expenditures (column total) for each account (Lofgren, Harris, & Robinson, 2002).

Production and Trade Block

This block covers four categories of equations: domestic production and usage of input; the allocation of domestic output to home consumption, the domestic market, and exports; the aggregation of supply to the domestic market; and the definition of the demand for trade inputs, that is generated by the distribution process.

Production is carried out by activities that are assumed to maximize profits in a perfectly competitive market setting. The CGE model includes the first-order optimality conditions for profit-maximization. A Leontief specification is chosen at the top level of the technology nest that determines the producer's demand for the aggregate value added and intermediate inputs so that their quantitative shares remain constant. CES[22] functions are specified for the rest of the technology nest at lower levels. Since the standard IFPRI model is not environmental CGE, we modified the production function for value added such that energy commodities are included as a composite input like other primary factors where composite energy in turn has a CES specification of energy inputs. In fact, such modification may seem less relevant for an economy where more than 80% of emissions are output based (in Ethiopia, emissions from energy commodities that are identifiable from the SAM are less than 20 %).

The composite supply (Armington) function characterizes the aggregation of supply to the domestic market in which imperfect substitutability between imports and domestic output sold domestically is captured by a CES aggregation function. The composite commodity that is supplied domestically is produced by domestic and imported commodities entering this function as inputs.

[22] CES stands for Constant Elasticity of Substitution. The various elasticity parameters are taken from GTAP (Global Trade Analysis Project) database and other studies.

Institutions Block

The primary source of income for households and enterprises are factor returns generated during production. Households and enterprises earn factor incomes in proportion to the implied share that they control of each factor stock. Enterprises or firms are the sole recipient of capital income, which they transfer to households after having paid corporate taxes (based on fixed tax rates), saved (based on fixed savings rates), and remitted profits to the rest of the world. In addition to factor returns, which represent the bulk of household incomes, households also receive transfers from the government, other domestic institutions, and the rest of the world. Thus, the total income of any domestic nongovernment institution is the sum of factor incomes, transfers from other domestic nongovernment institutions, transfers from the government, and transfers from the rest of the world.

It is assumed that each household maximizes a ‘’Stone-Geary’’ utility function subject to a consumption expenditure constraint. The CGE model is fed the corresponding first-order conditions, also called LES (linear expenditure system) functions.

The government earns most of its income from taxes, and then spends it on consumption and transfers to households.

System Constraints and Closure Rules

Equilibrium in the goods market requires that demand for commodities equal supply. Aggregate demand for each commodity comprises household and government consumption spending, investment spending, and export and transaction services demand. Supply includes both domestic production and imported commodities. Equilibrium is attained through the endogenous interaction of domestic and foreign prices, and the effect that shifts in relative prices have on sectoral production and employment, and hence institutional incomes and demand.

The model includes three broad macroeconomic accounts: the current account, the government balance, and the savings and investment account. In order to bring about equilibrium in the various macro accounts and factor markets it is necessary to specify a set of closure rules, which provide a mechanism through which adjustment is assumed to take place. The choices made have no influence on the solution to the base simulation but will typically influence the results for other simulations.

Government balance: Government balance is attained with Government savings (the difference between current government revenues and current government expenditures) being a flexible residual, while all tax rates are fixed.

External accounts balance Real exchange rate is flexible while foreign savings (the current account deficit) is fixed. Given that all other items are fixed in the external balance (transfers between the rest of the world and domestic institutions), the trade balance is also fixed. If, *ceteris paribus*, foreign savings are below the exogenous level, a depreciation of the real exchange rate would correct this situation by simultaneously (i) reducing spending on imports (a fall in import quantities at fixed world prices) and (ii) increasing earnings from exports (an increase in export quantities at fixed world prices).

Saving-investment balance: For the saving-investment balance, a saving driven investment closure is selected. In this closure rule, all non-government saving rates are fixed while investment adjusts to match the existing level of saving. The quantity of each commodity in the investment bundle is multiplied by a flexible scalar to ensure that the investment cost equals the savings value.

Factor markets: Skilled labour is assumed fully employed while for unskilled and semiskilled labour categories, wages are fixed and the employment level adjusts to reach equilibrium in the labour market. All labour categories are mobile across sectors. Capital is fully employed and sector specific, so that capital returns adjust to reach equilibrium in the sector-specific market for capital.

***The Between-Period Specification*[23]**

While the static model describes the economy within a particular time-period, its inability to account for second-period considerations limits its assessment of the full effect of policy and non-policy changes. For example, the model is unable to account for the second-period effect that changes in current investment have on the subsequent availability of capital. In attempting to overcome these limitations, the static model is extended to a recursive dynamic model in which selected parameters are updated based on the modeling of inter-temporal behaviour and results from previous periods. Current economic conditions, such as the availability of capital, are thus endogenously dependent on past outcomes, but remain unaffected by forward-looking expectations. The dynamic model is also exogenously updated to reflect demographic and technological changes that are based on observed or separately calculated projected trends.

Over the time period being analyzed a number of policy-independent changes are assumed to take place. Together these effects form a projected or counterfactual growth path for the economy. These inter-period adjustments include population and labour force growth, capital accumulation, factor productivity changes, and changes in government expenditure. This section describes the dynamic extensions of the static model.

Population Growth

Population growth is exogenously imposed on the model based on separately calculated growth projections. It is clear that a growing population generates a higher level of consumption demand. There is assumed to be no change in the marginal rate of consumption for commodities, showing that new consumers have the same preferences as existing consumers.

[23] This part entirely describes the dynamic CGE model in (Thurlow, 2008).

Capital Accumulation

The process of capital accumulation is modeled endogenously, with previous-period investment generating new capital stock for the subsequent period. Although the allocation of new capital across sectors is influenced by each sector's initial share of aggregate capital income, the final sectoral allocation of capital in the current period is dependent on the capital depreciation rate and on sectoral profit-rate differentials from the previous period (please see last part of the methodological appendix-dynamic updating of capital- for details). Sectors with above-average capital returns receive a larger share of investible funds than their share in capital income. The converse is true for sectors where capital returns are below-average.

Labour Supply

The method of updating the relevant parameters to reflect changes in labour supply in the current model depends on the labour market closure adopted for each labour category. Four alternative closure options are possible for each factor market. In the first case, labour supply is flexible but constrained in its ability to adjust by the real wage elasticity of labour supply. No exogenous updating of labour supply is necessary, since labour supply adjusts endogenously to determine final employment and wages. In the second closure option, sectoral demand for a labour category is held fixed, and any adjustments in demand following changes in labour supply are exogenous. In this case it is assumed that growth in supply is the same across all sectors. In the third closure option, labour is assumed to be unemployed at a fixed real wage. This represents a special case of the first closure option when the wage elasticity of labour supply is infinity. Therefore the exogenous adjustment of labour supply is unnecessary since there are no constraints on factor supply. Rather it is necessary to exogenously adjust real wages. The fourth closure option assumes that factor supply is fixed and the real wage adjusts to equate demand and supply. This final closure, the one selected in this study, implies full employment. Between-periods the fixed level of labour supply is adjusted exogenously. This also represents a special case of the first closure where the wage elasticity of labour supply is zero.

Total Factor Specific Productivity Growth

Along with changes in factor supply, the dynamic model also takes into consideration changes in factor productivity. This is done by multiplying the efficiency parameter in the CES value-added function by the percentage change in total factor productivity (TFP).

Government Consumption and Transfer Spending

Since government consumption spending and transfers to households are fixed in real terms within a particular period, it is necessary to exogenously increase these payments between periods. This is done by increasing the value of the base year quantity of government demand and the amount of transfer from government to institutions, such as households.

A. Stationary emissions

- From production activities: $coefEA_{ea} = \frac{EMISEA0_{ea}}{ENERGYEA0_{ea}}$

where $coefEA_{ea}$ is input emission coefficient, $EMISEA0_{ea}$ is quantity of emission by activity a from using energy commodity e (initial value), and $ENERGYEA_{ea}$ is value of energy commodity e used by activity a (initial value).

- From households $coefEH_{eh} = \frac{EMISEH0_{eh}}{ENERGYEH0_{eh}}$

Where $coefEH_{eh}$ is household stationary emission coefficient, $EMISEH0_{eh}$ is (initial) quantity of carbon emission by household h from consuming commodity e, and $ENERGYEH0_{eh}$ is value of energy commodity e consumed by household h.

B. Activity emissions

- For production activities (producers): $coefA_a = \frac{EMISA0_a}{QA0_a}$

where $coefA_a$ is activity emission coefficient per birr worth of output produced; $EMISA0_a$ is (initial) value of carbon emission by activity a (initial value) whose sources are not found in the commodity accounts of the SAM; and $QA0_a$ is output (initial value) produced by activity a.

- For households: $coefH_h = \frac{EMISH0_h}{QH0_h}$

where $coefH_h$ is household activity emission coefficient per birr worth of consumption; $EMISH0_h$ is the (initial) quantity of carbon emission by households whose sources are not found in the commodity accounts of the SAM; and $QH0_h$ is consumption (initial value) of household h.

As noted earlier, the emission coefficients are calculated from the emission matrix and SAM data. Then the model uses these emission coefficients to generate producer and household emissions.

The following blocks of equations are the newly added ones to the standard IFPRI model equations.

Stationary emissions:

For producers: $EMISEA_{ea} = coefEA_{ea} * ENERGYEA_{ea}$

For Consumers: $EMISEH_{ea} = coefEH_{ea} * ENERGYEH_{eh}$

Activity emissions:

For producers: $EMISA_a = coefA_a * QA_a$

For consumers: $EMISH_h = coefH_a * QH_h$

Total quantity of emissions of producer a ($TEMISA_a$):

$$TEMISA_a = \sum_e EMISEA_{ea} + EMISA_a$$

Total quantity of carbon emissions of household h ($TCEMISH_h$):

$$TEMISH_h = \sum_e EMISEH_{eh} + EMISH_h$$

Total quantity of emissions of all production activities ($TEMISA$):

$$TEMISA = \sum_a TEMISA_a$$

Total quantity of emissions of all households ($TEMISH$):

$$TEMISH = \sum_h TEMISH_h$$

Total quantity of emissions in the economy ($TEMIS$):

$$TEMIS = TEMISA + TEMISH$$

Appendix B: Mathematical Summary statement for CGE Model

Static Model Specification (Extended IFPRI's Standard Computable General Equilibrium Model)

Definition of Sets, Parameters and Variables

SETS

α ∈ A	activities
α ∈ ACES(⊂ A)	activities with a CES function at the top of the technology nest
α ∈ ALEO(⊂ A)	a ctivities with a Leontief function at the top of the technology nest
c ∈ C	commodities
c ∈ CD(⊂ C)	commodities with domestic sales of domestic output
c ∈ CDN(⊂ C)	commodities not in CD
c ∈ CE(⊂ C)	exported commodites
c ∈ CEN(⊂ C)	commodities not in CE
c ∈ CM(⊂ C)	imported commodities
c ∈ CMN(⊂ C)	commodities not in CM
c ∈ CT(⊂ C)	transactions service commodities
c ∈ CX(⊂ C)	commodities with domestic production

$f \in$ F	factors
$e \in E(\subset$ F)	energy factors
$i \in$ INS	institutions (domestic and rest of the world)
$i \in$ INSD($\subset$ INS)	domestic institutions
$i \in$ INSDNG($\subset$ INSD)	domestic nongovernment intuitions
en∈EN($\subset$ INSDNG)	Enterprises
h∈H($\subset$ INSDNG)	households

PARAMETERS

Latin Letters

$cwts_c$	weight of commodity c in the CPI
$dwts_c$	weight of commodity c in the producer price index
ica_{ca}	quantity of c as intermediate input per unit of activity *a*
$icd_{cc'}$	quantity of commodity c as trade input per unit of c' produced and sold domestically
$ice_{cc'}$	quantity of commodity c as trade input per exported unit if c'
$icm_{cc'}$	quantity of commodity c as trade input per imported unit of c'
$inta_a$	quantity of aggregate intermediate input per activity unit
iva_a	quantity of value-added per activity unit
$\overline{mps_i}$	base saving rate for domestic institution *i*
$mps01_c$	0-1 parameter with 1 for institutions with potentially fixed direct tax rates
pwe_c	export price (foreign currency)
pwm_c	import price (foreign currency)
$qdst_c$	quantity of stock change
$\overline{qg_c}$	base-year quantity of government demand
$\overline{qinv_c}$	base-year quantity of private investment demand
$Shif_{i\,f}$	share of domestic institution *i* in income of factor *f*
$Shii_{ii'}$	share of net income of *i'* to *i* (*i'* ∈ INSDNG'; *i* ∈ INSDNG)
Shareh	share of carbon tax revenue allocated for households
Sharegh	transfer share of household h to total household transfer by government

Shg	share of allocated carbon tax revenue to total government consumption
$t\alpha_{\alpha}$	tax rate for activity *a*
te_c	export tax rate
tf_f	direct tax for factor *f*
$\overline{tins_i}$	exogenous tax rate for domestic institution *i*
$tins01_i$	0-1 parameter with 1 for institutions with potentially fixed tax rates
tm_c	import tariff rate
tq_c	rate of sales tax
$trnsfr_{if}$	transfer from factor *f* to institution *i*
tva_a	rate of value-added tax for activity *a*

Greek Letters

α_{α}^{α}	efficiency parameter in the CES activity function
$\alpha_{\alpha}^{v\alpha}$	efficiency parameter in the CES value-added function
α_{a}^{e}	efficiency parameter in the CES energy aggregation function
$\alpha_{\alpha}^{\alpha c}$	shift parameter for domestic commodity aggregation fuction
α_{c}^{q}	Armington function shift parameter
α_{c}^{t}	CET function shift parameter
β_{ach}^{h}	marginal share of consumption spending on home commodity c from activity a for household h
δ_{a}^{a}	CES activity function share parameter
$\delta_{a\,c}^{ac}$	share parameter for domestic commodity aggregation function
δ_{c}^{q}	Armington function share parameter
δ_{c}^{t}	CET function share parameter
δ_{fa}^{va}	CES value-added function share parameter for factor *f* in activity a
δ_{ea}^{ea}	CES energy function share parameter for energy e in activity a
$\Upsilon_{c\,h}^{m}$	subsistence consumption of marketed commodity c for household h
$\Upsilon_{ac\,h}^{h}$	subsistence consumption of home commodity c from activity a for household h
θ_{ac}	yield of output c per unit of activity a
ρ_{a}^{a}	CES function exponent
ρ_{a}^{va}	CES value-added function exponent

ρ_a^{ea}	CES energy aggregation function exponent
ρ_c^{ac}	domestic commodity aggregation function exponent
ρ_c^{q}	Armington function exponent
ρ_c^{t}	CET function exponent
pemis	price of emission
$coefEA_{ea}$	emission coefficient of activity a from using energy commodity e to produce Qa
$coefEH_{eh}$	emission coefficient of household h from using energy commodity e
$coefA_a$	emission coefficient of activity a to produce QA whose sources are not precisely known in the SAM
$coefH_h$	emission coefficient of household h from using energy commodity e whose sources are not precisely known in the SAM

EXOGENOUS VARIABLES

$\overline{CPI}$	consumer price index
$\overline{DTINS}$	change in domestic institution tax share (= 0 for base; exogenous variable)
$\overline{FSAV}$	foreign savings (FCU)
$\overline{GADJ}$	government consumption adjustment factor
$\overline{IADJ}$	investment adjustment factor
$\overline{MPSADJ}$	savings rate scaling factor (= 0 for base)
$\overline{QFS}_f$	quantity supplied of factor
$\overline{TINSADJ}$	direct tax scaling factor (= 0 for base; exogenous variable)
$\overline{WFDIST}_{fa}$	wage distortion factor for factor f in activity a

ENDOGENOUS VARIABLES

DMPS	change in domestic institution saving rates (= 0 for base; exogenous variable)
DPI	produce price index for domestic marketed output
EG	government expenditures
EH_h	consumption spending for household
EXR	exchange rate (*LCU* per unit of *FCU*)

GOVSHR	government consumption share in nominal absorption
GSAV	government savings
INVSHR	investment share in nominal absorption
MPS_i	marginal propensity to save for domestic non-government institution (exogenous variable)
PA_a	activity price (unit gross revenue)
PDD_c	domestic for commodity produced and sold domestically
PDS_c	supply price for commodity produced and sold domestically
PE_c	export price (domestic currency)
$PINTA_c$	aggregate intermediate input price for activity *a*
PM_c	import price (domestic currency)
PQ_c	composite commodity price
PVA_a	value-added price (factor income per unit of activity)
PX_c	aggregate producer price for commodity
$PXAC_{ac}$	producer price of commodity c for activity *a*
$PENEAe_a$	Price of energy input *e* from used by activity *a*
$PENA_a$	aggregate price of energy input used by activity a
QA_a	quantity (level) of activity
QD_c	quantity sold domestically of domestic output
QE_c	quantity of exports
QF_{fa}	quantity demanded of factor *f* from activity *a*
$QENEAe_a$	quantity demanded of energy input *e* from activity *a*
$QENA_a$	quantity aggregate energy input
QG_c	government consumption demand for commodity
QH_{ch}	quantity consumed of commodity c by household h
QHA_{ach}	quantity of household home consumption of commodity c from activity *a* for household h
$QINTA_a$	quantity of aggregate intermediate input
$QINTA_{ca}$	quantity of commodity c as intermediate input to activity *a*
$QINV_c$	quantity of investment demand for commodity
QM_c	quantity of imports of commodity
QQ_c	quantity of goods supplied to domestic market (composite supply)

QT_c	quantity of commodity demanded as trade input
QVA_a	quantity of (aggregate) value-added
QX_c	aggregated marketed quantity of domestic output of commodity
$QXAC_{ac}$	quantity of marketed output of commodity c from activity *a*
$TABS$	total nominal absorption
$TINS_i$	direct tax rate for institution *i* (*i* ∈ INSDNG)
$TRII_{ii'}$	transfers from institution *i'* to *i* (both in the set INSDNG)
WF_f	average price of factor *f*
YF_f	income of factor *f*
YG	government revenue
Y_{en}	income of enterprises
Y_h	income of households
YIF_{if}	income of domestic institution *i* from factor *f*
EMISSA(a)	emission by activity a from using commodity c
EMISSH(h)	emission by household h fro consuming commodity c
EMISA(a)	emission by activity a not in EMISSA(a)
EMISH(h)	emission by household h not in EMISSH(h)
TEMISA(a)	Total emission of activity a
TEMISH(h)	Total emission of household h
TEMISA(a)	Total emission of all activities
TEMISH(h)	Total emission of all households
TEMIS	total emission in the economy
ATAXCa(a)	carbon tax collected from activity a
ATAXCh(h)	Carbon tax collected from household h
TOTREVC	total environmental tax revenue

EQUATIONS

Price Block

Import Price

$$PM_c = pwm_c \,.\, (1 + tm_c) \,.\, EXR + \sum_{c' \in CT} PQ_{c'} \,.\, icm_{c'c} \,; \quad c \in CM \qquad (1)$$

Export Price

$$PE_c = pwe_c \,.(1 - te_c\,) \,.\; EXR \; - \sum_{c' \in CT} PQ_{c'} \,. ice_{c'c}\,; \qquad c \in CE \qquad (2)$$

Demand price of domestic non traded goods

$$PDD_c = PDS_c + \sum_{c' \in CT} PQ_{c'} \,. icd_{c'c}\,; \qquad c \in CD \qquad (3)$$

Absorption

$$PQ_c.(1 - tq_c).QQ_c = PDD_c \,.\; QD_c + PM_c \,.\; QM_c; \quad c \in (CD \cup CM) \qquad (4)$$

Marketed output value

$$PX_c \,.\; QX_c = PDS_c.QD_c + PE_c.QE_c; \qquad c \in CX \qquad (5)$$

Activity price

$$PA_a = \sum_{c \in C} PXAC_{ac} \,.\, \theta_{ac}\,; \qquad a \in A \qquad (6)$$

Aggregate intermediate input price

$$PINTA_a = \sum_{c \in C} PQ_c \,.\, ica_{ca}\,; \qquad a \in A \qquad (7)$$

Activity revenue and costs

$$PA_a \,.\; (1 - ta_a) \,.\; QA_a = PVA_a.\; QVA_a + PINTA_a \,.\; QINTA_a;$$

where $ta_a = \text{ATAXCA(a)/QA(a)}$ (8)

Consumer price index

$$\overline{CPI} = \sum_{c \in C} PQ_c \,.\, cwts_c\,; \qquad (9)$$

Producer price index for nontrade market output

$$DPI = \sum_{c \in C} PDS_c \,.\, dwts_c\,; \qquad (10)$$

Production and Trade Block

CES technology: Activity production function

$$QA_a = \alpha_a^a \,.(\delta_a^a.\; QVA_a^{-\rho_a^a} + (1 - \delta_a^a) \,. QINTA_a^{-\rho_a^a}\,)^{\frac{1}{\rho_a^a}}; \quad a \in ACES \qquad (11)$$

CES technology: Value-added intermediate input quantity ratio

$$\frac{QVA_a}{QINTA_a} = \left(\frac{PINTA_a}{PVA_a} \,.\, \frac{\delta_a^a}{1 - \delta_a^a}\right)^{\frac{1}{1-\rho_a^a}}; \qquad a \in ACES \qquad (12)$$

Leontief technology: Demand for aggregate value-added

$$QVA_a = iva_a \,. QA_a; \qquad a \in ALEO \qquad (13)$$

Leontief technology: Demand for aggregate intermediate input

$$QINTA_a = inta_a \,. QA_a; \qquad a \in ALEO \qquad (14)$$

Value added and factor demands

$$QVA_a = \alpha_a^{va} . \left(\sum_{f \in F} \delta_{fa}^{va} . QF_{fa}^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} ; \qquad a \in A \qquad (15)$$

Energy aggregation

$$QENA_a = \alpha_a^{e} . \left(\sum_{e \in E} \delta_{ea}^{ea} . QENEA_{ea}^{-\rho_a^{ea}} \right)^{-\frac{1}{\rho_a^{ea}}} \qquad e \in E \subset \text{F}; a \in A \qquad (16)$$

Energy input demand

$$PENEA_{e\,a} = PENA_a . QENA_a .$$

$$\left(\sum_{e \in E} \delta_{ea}^{ea} . QENEA_{ea}^{-\rho_a^{ea}} \right)^{-1} . \delta_{ea}^{ea} . QENEA_{ea}^{-\rho_a^{ea}-1} \qquad e \in E \subset \text{F}; a \in A \qquad (17)$$

Factor demand

$$WF_f . \overline{WFDIST}_{f\,a} = PVA_a(1 - tva_a) . QVA_a$$

$$\left(\sum_{f \in F} \delta_{fa}^{va} . QF_{fa}^{-\rho_a^{va}} \right)^{-1} . \delta_{fa}^{va} . QF_{fa}^{-\rho_a^{va}-1} ; \qquad a \in A ; f \in F \qquad (18)$$

Aggregate intermediate input demand

$$QINT_{c\,a} = ica_{c\,a} . QINTA_a ; \qquad a \in A; c \in C \qquad (19)$$

Commodity production and allocation

$$QXAC_{a\,c} + \sum_{h \in H} QHA_{a\,c\,h} = \theta_{ac} . QA_a ; \qquad a \in A; c \in CX \qquad (20)$$

Output aggregation function

$$QX_{\text{c}} = \alpha_c^{ac} . \left(\sum_{a \in \text{A}} \delta_{ac}^{ac} . QXAC_{a\,c}^{-\rho_c^{ac}} \right)^{\frac{1}{\rho_c^{ac}-1}} ; \qquad c \in CX \qquad (21)$$

First order condition for output aggregation function

$$PXAC_{\text{ac}} = PX_{\text{c}} . QX_{\text{c}} \left(\sum_{a \in A'} \delta_{ac}^{ac} . QXAC_{a\,c}^{-\rho_c^{ac}} \right)^{-1} .$$

$$\delta_{ac}^{ac} . QXAC_{a\,c}^{-\rho_c^{ac}-1} ; \qquad a \in A; \ c \in CX \qquad (22)$$

Output transformation (CET) function

$$\text{QX}_{\text{c}} = \alpha_c^t \left(\delta_c^t . QE_c^{\rho_c^t} + (1 - \delta_c^t) . QD_c^{\rho_c^t} \right)^{\frac{1}{\rho_c^t}} ; \qquad c \in (CE \subset CD) \qquad (23)$$

Export-domestic supply ratio

$$\frac{QE_{\text{c}}}{QD_{\text{c}}} = \left(\frac{PE_{\text{c}}}{PDS_{\text{c}}} . \frac{1-\delta_c^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t - 1}} ; \qquad c \in (CE \cap CD) \qquad (24)$$

Output transformation for non-exported commodities

$$QX_c = QD_c + QE_c ; \qquad c \in (CD \cap CEN) \cup c \in (CE \cap CDN) \qquad (25)$$

Composite supply (Armington) function

$$QQ_c = \alpha_c^q \left(\delta_c^q \,.\, QM_c^{-\rho_c^q} + \left(1-\delta_c^q\right).QD_c^{-\rho_c^q}\right)^{\frac{1}{\rho_c^q}}; \quad c \in (CM \cap CD) \qquad (26)$$

Import-domestic demand ratio

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \,.\, \frac{\delta_c^q}{1-\delta_c^q}\right)^{\frac{1}{1+\rho_c^q}}; \qquad c \in (CM \cap CD) \qquad (27)$$

Composite supply for non-imported outputs and non-produced imports

$$QQ_c = QD_c + QM_c; \qquad c \in (CD \cap CMN) \cup c \in (CM \cap CDN) \qquad (28)$$

Demand for transactions services

$$QT_c = \sum_{c' \in C'} (icm_{cc'} . QM_{c'} . ice_{cc'} . QE_{c'} + icd_{cc'} . QD_{c'}) \; ; \qquad c \in CT \qquad (29)$$

Institution Block

Factor income

$$YF_f = \sum_{a \in A} WF_f \; . \overline{WFDIST}_{f\,a} . QF_{f\,a}; \qquad f \in F \qquad (30)$$

Institutional factor incomes

$$YIF_{if} = shif_{if} \,.\, \left[\left(1-tf_f\right) . YF_f - trnsfr_{row\,f} \,.\, EXR\right]; i \in INSD; \; f \in F \qquad (31)$$

Income of domestic, nongovernment institutions

$$Y_{en} = \sum_{f \in F} YIF_{enf} + \sum_{en' \in INSDNG'} TRII_{i\,i'} + trnsfr_{en\;gov} .$$
$$\overline{CPI} + trnsfr_{en\,row} . EXR +; \qquad i \in INSDNG \qquad (32)$$

$$Y_h = \sum_{f \in F} YIF_{hf} + \sum_{i' \in INSDNG'} TRII_{i\,i'} + (trnsfr_{h\;gov} + shareh.s□areg□.TOTREVC)$$
$$\overline{CPI} + trnsfr_{h\,row} . EXR \qquad h \in INSDNG \qquad (33)$$

Intra-institutional transfers

$$TRII_{i\,i'} = shii_{i\,i'} \,.\, (1 - MPS_{i'}) \,.\, (1 - TINS_{i'}) \,.\, YI_{i'}; \quad i \in INSDNG \qquad (34)$$

Household consumption expenditure

$$EH_h = (1 - \sum_{i \in INSDNG} shii_{i\,h}) \,.\, (1 - MPS_h) \,.$$
$$(1 - TINS_h).(YI_h - ATAXCH(h)); \qquad h \in H \qquad (35)$$

Household consumption demand for marketed commodities

$$PQ_c \,.QH_{c\,h} = PQ_c . \gamma_{c\,h}^m + \beta_{c\,h}^m \,. \quad \left(EH_h - \sum_{c' \in C} PQ_{c'} \,.\, \gamma_{c\,h}^m - \right.$$
$$\left. \sum_{a \in A} \sum_{c' \in C} PXAC_{a\,c'} . \gamma_{a\,c'\,h}^h\right); \quad c \in C \,;\, h \in H \quad (36)$$

Household consumption demand for home commodities

$$PXAC_{a\,c} \; QHA_{ac\,h} = PXAC_{ac} . \gamma_{a\,c\,h}^h + \beta_{a\,c\,h}^h .$$
$$\left(EH_h - \sum_{c' \in C} PQ_{c'} \,.\, \gamma_{c\,h}^m - \sum_{a \in A} \sum_{c' \in C} PXAC_{a\,c'} . \gamma_{a\,c'\,h}^h\right); \; c \in C; \in H \qquad (37)$$

Investment demand

$$QINV_c = \overline{IADJ} \, . \overline{qinv_c} \; ; \qquad c \in C \qquad (38)$$

Government consumption demand

$$QG_c = \overline{((1+shg).GADJ} \, . \overline{qg_c} \; ; \qquad c \in C \qquad (39)$$

Government revenue

$$YG = \sum_{i \in INSDNG} TINS_i \, . \, YI_i + \sum_{f \in F} tf_f \, . \, YF_f + \sum_{a \in A} tva_a \, .$$
$$PVA_a \, . \, QVA_a + \sum_{a \in A} ta_a \, . \, PA_a \, . \, QA_a + \sum_H \text{ATAXCh(h)} + \sum_{c \in CM} tm_c \, . \, pwm_c$$
$$. QM_c \, . \, EXR + \sum_{c \in CM} te_c \, . \, pwe_c \, . \, QE_c \, . \, EXR + \sum_{c \in C} tq_c \, . \, PQ_c$$
$$. \, QQ_c + \sum_{c \in C} YIF_{gov\ f} + trnsfr_{gov\ \ row} \, . \, EXR \qquad (40)$$

Government expenditures

$$EG = \sum_{c \in C} PQ_c \, . \, QG_c + \sum_{i \in INSDNG} trnsfr_{i\ gov} \, . \, \overline{CPI} \qquad (41)$$

System Constraint Block

Factor market

$$\sum_{a \in A} QF_{f\ a} = \overline{QFS_f} \; ; \qquad f \in F \qquad (42)$$

Composite commodity markets

$$QQ_c = \sum_{a \in A} QINT_{c\ a} + \sum_{h \in H} QH_{c\ h} + QG_c$$
$$+ QINV_c + qdist_c + QT_c \, ; \qquad c \in C \qquad (43)$$

Current account balance for rest of the world (in foreign currency)

$$\sum_{c \in CM} pwmc_c \, . \, QM_c + \sum_{f \in F} trnsfr_{row\ \ f} = \sum_{c \in CE} pwe_c \, .$$
$$QE_c + \sum_{c \in CE} trnsfr_{i\ row} + \overline{FSAV} \; ; \qquad (44)$$

Government balance

$$YG = EG + GSAV \qquad (45)$$

Direct institutional tax rates

$$TINS_i = \overline{tins_i} \, .(1 + \overline{TINSADJ} \, . \, tins01_i \,) + \overline{DTINS}.t_i \, ; \; i \in INSDNG \qquad (46)$$

Institutional savings rates

$$MPS_i = \overline{mps_i} \, .(1 + \overline{MPSADJ}.mps01_i \,) + DMPS.mps01_i \, ; \, i \in INSDNG \qquad (47)$$

Savings-Investment Balance

$$\sum_{i \in INSDNG} MPS_i \, . \, (1 - TNS_i \,) \, . YI_i + GSAV +$$
$$EXR \, . \overline{FSAV} = \sum_{c \in C} PQ_c \, . QINV_c + \sum_{c \in C} PQ_c \, . qdst_c \qquad (48)$$

Total absorption

$$TABS = \sum_{h\in H}\sum_{c\in C} PQ_c \,.QH_{c\,h} + \sum_{a\in A}\sum_{c\in C}\sum_{h\in H} PXAC_{a\,c}\,. QHA_{a\;c\,h} + \sum_{c\in C} PQ_c \,.QG_c + \sum_{c\in C} PQ_c \,.QINV_c + \sum_{c\in C} PQ_c \,.qdist_c \quad (49)$$

Ratio of investment to absorption

$$INVSHR\,.TABS = \sum_{c\in C} PQ_c \,.\; QINV_c + \sum_{c\in C} PQ_c \,.\; qdst_c \quad (50)$$

Ratio of government consumption to absorption

$$GOVSHR\,.TABS = \sum_{c\in C} PQ_c \,.\; QG_c \quad (51)$$

Emission Block

$$EMISEA_{ea} = coefEA_{ea} * ENERGYEA_{ea} \quad (52)$$

$$EMISEH_{ea} = coefEH_{ea} * ENERGYEH_{eh} \quad (53)$$

$$EMISA_{a} = coefA_{a} * QA_{a} \quad (54)$$

$$EMISH_{h} = coefH_{a} * QH_{h} \quad (55)$$

$$TEMISA_{a} = \sum_{e} EMISEA_{ea} + EMISA_{a} \quad (56)$$

$$TEMISH_{h} = \sum_{e} EMISEH_{eh} + EMISH_{h} \quad (57)$$

$$TEMISA = \sum_{a} TEMISA_{a} \quad (58)$$

$$TEMISH = \sum_{h} TEMISH_{h} \quad (59)$$

$$TEMIS = TEMISA + TEMISH \quad (60)$$

$$\text{ATAXCa(a)} = \text{PEMIS} * (\sum_{c} EMISCA_{ca} + EMISA) \quad (61)$$

$$\text{ATAXCh(h)} = \text{PEMIS} * (\sum_{c} EMISCH_{ch} + EMISH_{h}) \quad (62)$$

$$\text{TOTREVC} = \sum_{\text{A}} \text{ATAXCa(a)} + \sum_{\text{H}} \text{ATAXCh(h)} \quad (63)$$

Dynamic Updating of Capital

Economy-wide rental rate of capital

$$AWF_{ft}^{a} = \sum_{a}\left[\left(\frac{QF_{fat}}{\sum_{a'} QF_{fa't}}\right).WF_{ft}.\; WFDIST_{fat}\right];$$

f is capital; $a \in A$; $a' \in A$; $t \in T$ (64)

Sectoral share of new capital investment

$$\eta_{fat}^{a} = \left(\frac{QF_{fat}}{\sum_{a'} QF_{fa't}}\right).\left(\beta^{a}\left(\frac{WF_{f,t}\,.\; WFDIST_{fat}}{AWF_{ft}^{a}} - 1\right) + 1\right)$$

f is capital; $a \in A$; $a' \in A$; $t \in T$ (65)

Final quantity of new capital allocated to each sector

$$\Delta K_{fat}^{a} = \eta_{fat}^{a}\,.\frac{\sum_{c} PQ_{ct}\,.\; QINV_{ct}}{PK_{ft}};$$

f is capital; $a \in A$; $c \in C$; $t \in T$ (66)

Unit price of capital

$$PK_{ft} = \sum_c PQ_{ct} \cdot \frac{QINV_{ct}}{\sum_{c'} QINV_{c't}}; \ f \text{ is capital}; a \in A; \ c \in C; \ c' \in C; \ t \in T \quad (67)$$

Sectoral quantities of capital

$$QF_{f\,at+1} = QF_{f\,at} \cdot \left(1 + \frac{\Delta K^{a}_{fat}}{QF_{f\,at}} - \upsilon_f \right); \quad f \text{ is capital}; a \in A; \quad t \in T \quad (68)$$

The new aggregate quantity of capital

$$QFS_{f\,t+1} = QFS_{f\,t} \cdot \left(1 + \frac{\sum_a \Delta K_{fat}}{QFS_{f\,t}} - \upsilon_f \right); \ f \text{ is capital}; a \in A; \quad t \in T \quad (69)$$