Essays on Climate Policy and Agriculture

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Abstract

This thesis is a compilation of four papers that study energy demand, climate policy, production, and carbon sequestration within transport, agriculture and forestry. The four papers study separate topics, but have in common that they address issues that are relevant to Sustainable Development Goals. The first paper estimates the short-run and long-run price and income elasticities of gasoline and diesel demand in the EU-28 countries. The estimation method uses the ARDL bounds approach and tests the existence of a long-run relationship using data from 1978 to 2013. The study provides methodologically consistent elasticity estimates that are comparable across the EU-28 countries and allow the analysis and forecasting of the effect of a common fuel policy. Applying the estimated elasticities to an analysis of the EU's 2030 emission and fuel consumption reduction targets shows that the current tax level does not guarantee that the target will be achieved. The second paper estimates the cost to car owners of achieving the EU's 2050 transport sector emission reduction targets through passenger car switching from fossil fuel-driven to hybrid and electric-driven cars. Costs are calculated as decreases in consumer surplus using a dynamic optimization model. The results show that the total emission reduction cost amounts to 0.37% of the EU's GDP, and that Germany, Italy, Spain, France, and the UK account for approximately two thirds of the total cost. Hybrid cars are cost-effective means of abatement, while electric cars are a viable means of abatement only when coupled with grid decarbonization. The third paper examines the effect of time spent collecting water for household consumption on rural agricultural production. A household-level fixed effects estimation approach is employed using three-round panel data from Ethiopia. The results show that time allocated for water collection negatively affects agricultural production by displacing productive labor. The fourth paper reviews studies in economics on the efficient design of policies for forest carbon sequestration and compares their findings with the design systems in practice. The paper shows that specific design problems are associated with the heterogeneity of landowners, uncertainty, additionality, and permanence in carbon projects. Discounting the value of the forest carbon sink, optimal contract design, and offset baseline management are recommended in the literature for the management of most design problems.

Keywords: Gasoline and diesel demand, price and income elasticity, ARDL bounds, GHG emission reductions, EU 2050 targets, passenger cars, cost-effectiveness, water collection, agricultural production, policy design, forest carbon sequestration

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Dedication

To my mother Tadesech Damtew and my father Zeleke Aklilu.

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Aklilu, A.Z. (2019). Gasoline and diesel demand in the EU: Implications for the 2030 emission goal. (Submitted to *Renewable & Sustainable Energy Reviews*)

II Aklilu, A.Z. (2019). Cost to car owners of the EU's 2050 targets for CO2 emission reduction from the transport sector. (Manuscript)

III Aklilu, A.Z. Does water collection for household consumption affect agricultural production? Evidence from Ethiopia. (Manuscript)

IV Gren, I-M.*, & Aklilu, A. Z. (2016). Policy design for forest carbon sequestration: A review of the literature. *Forest Policy and Economics*, *70*, 128-136.

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1 Introduction

Sustainable development requires the collaborative effort of all economic sectors, among which transport, agriculture and forestry play an important role. On a global scale, the transport sector consumes and emits more than 20 percent of total energy production and carbon dioxide (*World Development Indicators*, 2019). Agriculture and forestry employ more than 30 percent of the global workforce and contribute more than 3 percent of global GDP (*World Development Indicators*, 2019). Forests help maintain the environment through carbon sequestration. The economic and environmental impacts of transport, agriculture and forestry are linked to the Sustainable Development Goals (SDGs) of the United Nations (Griggs et al., 2013).

This thesis comprises four papers that study energy demand, climate policy and production within transport, agriculture and forestry. The four papers address separate topics, but are related in that they address issues that matter for sustainable development. The first paper estimates short-run and long-run price and income elasticities for gasoline and diesel demand that are relevant for analyzing climate policy, which is shown by applying the estimated elasticities to examine the achievability of the EU's 2030 emission reduction targets under the existing tax scheme. The second paper estimates the cost to car owners of achieving the EU's 2050 transport emission reduction target through passenger car switching from fossil fuel-driven to hybrid and electric-driven vehicles. The third paper examines the effect of allocating time to water collection for household consumption on agricultural production and shows that in rural households this displaces productive labor from agricultural production, thus producing a negative effect. The fourth paper reviews the literature on the efficient design of policies for forest carbon sequestration. A comparison of findings in the literature with design systems in practice shows that policies targeting carbon sequestration have to address the specific design problems of heterogeneity, uncertainty, additionality, and permanence. The first and second papers addressing energy consumption, emission reduction and policy costs in the transport sector relate to the Sustainable Development Goals (SDGs) of sustainable consumption, energy efficiency and sustainable transport. The third paper, showing that time allocated for water collection has a negative effect on agricultural production of rural households, relates to the SDGs aiming at eradicating hunger and poverty. The fourth paper relates to environmental quality and wellbeing in the SDGs by highlighting issues of policy design for forest carbon sequestration.

The papers make contributions to their respective strands of literature. The literature on gasoline and diesel demand is broad and there are several reviews (such as Dahl (2012), Graham and Glaister (2004), and Espey (1998)). However, these studies present elasticity estimates across different countries of the EU-28 that vary depending on the estimation methods, underlying theoretical models and data. Examining the effectiveness and welfare impact of policies that affect gasoline and diesel consumption, such as fuel tax across the EU-28, requires methodologically similar elasticities. The first paper contributes to the literature by estimating short-run and long-run price and income elasticities for gasoline and diesel demand using the same econometric approach, type of data, types of variables and units of measurement. The elimination of methodological differences facilitates a consistent comparison of the effect of gasoline and diesel consumption-related policies across the EU-28. The applicability of the estimated elasticities to policy analysis is demonstrated by applying them to examine the achievability of the EU's 2030 emission target with the existing fuel tax.

With respect to the cost to car owners of achieving the EU's 2050 transport sector emission reduction cost, several studies calculate the minimum cost of achieving greenhouse gas emission reduction at global, regional and national scales. Their reviews can be found in Stanton et al. (2009) and Tol (2010) for example. The contribution of the second paper to the literature is that it estimates the cost to car owners of achieving the EU's 2050 transport sector emission reduction targets through passenger car switching from fossil fuel-driven to hybrid and electric-driven cars. It provides cost estimates for each of the EU-28 countries.

Agricultural household studies, such as Sekhri (2014) and Koolwal and Van de Walle (2013), examine the effect of access to water on rural households from the perspectives of health, gender relations, poverty and conflict. However, the effect of time allocated for water collection on agricultural production is not a well-studied aspect. The third paper in this thesis contributes to the agricultural household strand of literature by presenting evidence of the negative effect of time allocation for water collection on agricultural production. The paper's results show that the channel is through the displacement of productive labor from agricultural production.

Cost savings from the introduction of carbon sinks in climate policy programs, specific forest carbon projects, and the policy and cost of carbon sequestration are relatively well studied and reviews of this literature are provided by studies such as Sedjo et al. (1995), Angelsen (2008), Hufty and Haakenstad (2011) and Phan et al. (2014). However, economics literature on policy design for forest carbon sink enhancement is relatively sparse. The fourth paper in the thesis contributes to the literature on policy design by reviewing studies on the efficient design of policies directed at forest carbon sequestration.

The following section presents a summary of the four papers that feature in this thesis.

2 Summary of Appended Papers

2.1 Gasoline and diesel demand in the EU: Implications for the 2030 emission goal

Fuel tax is one of the most widely used policies to combat emissions (Brons et al., 2008; Kayser, 2000; Sterner, 2007). The effect of fuel tax depends on the responsiveness of the affected economic sectors. This responsiveness is captured by elasticities that signal the response of demand to changes in price and income (Goodwin et al., 2004).

The extant wide literature on gasoline and diesel demand has been reviewed by several studies such as Ajanovic et al. (2012), Dahl (2012), Espey (1998), Graham and Glaister (2002) and Labandeira et al. (2017). Most of the reviewed studies estimate gasoline or diesel demand elasticities either for an individual country, at most 20 OECD countries, or aggregate elasticities for regions covering several countries. Since elasticity estimates vary depending on the estimation methods, underlying theoretical models and data, individual country estimates are not comparable (Ajanovic et al., 2012; Graham & Glaister, 2002). Aggregate elasticities ignore differences between countries, such as habit formation, productivity, social structure and environmental awareness (Basso & Oum, 2007; Goodwin et al., 2004; Hunt & Evans, 2011).

An examination of the literature review shows that studies of gasoline and diesel demand agree that long-run price and income elasticities are higher, in absolute values, by a factor of 2 to 3 than their short-run counterparts. Gasoline and diesel demands are less responsive to price than income. Gasoline and diesel demands are mainly determined by respective prices, income, number of vehicles and population. However, several other demographic, economic, weather, vehicle and transport-related factors affect their demand.

This study has two aims: first to provide short-run and long-run price and income elasticity estimates of gasoline and diesel demand for the EU-28 countries that are comparable, and second, to use the estimated elasticities to examine the achievability of the EU 2030 transport emissions target under the existing fuel tax policy scheme.

The elasticities for the EU-28 countries are estimated using the same econometric approach, type of data, types of variables and units of measurement, and thus eliminate methodological differences across the estimates. The estimation data on gasoline and diesel consumption per capita, real prices, real GDP per capita, and number of vehicles per capita span from 1978 to 2013. The elasticities are estimated using the Autoregressive Distributed Lag (ARDL) bounds testing approach of Pesaran et al. (2001). The estimation method performs well in small samples, provides unbiased long-run estimates in the presence of endogenous regressors, and enables the existence of a long-run cointegration relationship in gasoline and diesel demands to be tested (Amusa et al., 2009; Harris & Sollis, 2003; Narayan, 2005; Odhiambo, 2009). Furthermore, the estimated model reliabilities are checked using the Breusch-Godfrey Lagrange multiplier test, the cumulative sum of recursive residuals (CUSUM) and CUSUM of squares (CUSUMSQ) plots.

The estimation results report elasticities for the EU-28 countries that are in line with the literature. For both gasoline and diesel demand, short-run and long-run elasticities have a negative sign for price and a positive sign for income. The estimated elasticities' statistical significance varies across countries. The average of the estimated price elasticities of gasoline demand are -0.24 in the short run and -0.82 in the long run, and the average of the income elasticities are 0.41 in the short run and 1.46 in the long run. In contrast, the average of price elasticities of diesel demand are -0.15 in the short run and -0.69 in the long run, and the average of income elasticities are 0.39 in the short run and 1.19 in the long run. In absolute values, both gasoline and diesel are more income elastic than price elastic, indicating that aiming to decrease emissions by increasing the price requires the price to increase at a higher rate than income. Furthermore, diesel is less responsive to changes in price and income than gasoline, indicating that policies that affect both fuels would have a greater impact on gasoline consumption than on diesel consumption.

The bounds test shows that a long-run equilibrium relationship exists in 21 countries in the case of gasoline and 18 countries in the case of diesel. The demands' estimated adjustment factors show that gasoline and diesel demand adjust from a shock towards a long-run equilibrium by an average of 36 percent per period and 44 percent per period respectively. The adjustment factor estimates assert the theoretical stance that fuel demand gradually adjusts towards the long-run equilibrium.

The estimated elasticities are used to analyze whether the EU's 2030 transport sector emission reduction targets can be achieved with the existing tax scheme. The EU's 2030 target is to reduce emission in the transport sector by about 20% by 2030 compared to emissions in 2008. The current tax scheme imposes a minimum tax rate of € 0.359/liter on gasoline and € 0.330/liter on diesel. Projections of the EU's 2030 emission from gasoline and diesel consumption at current trends put the emission levels above the target. Estimation of the required tax increment to achieve the target using the estimated elasticities shows that an increment of 3 percent tax on gasoline and 14 percent tax on diesel is required, corresponding to the current minimum tax rate being increased by € 0.0108/liter for gasoline and € 0.0462/liter for diesel. Raising the common minimum tax rate has varying benefits for individual EU-28 member countries in terms of tax revenue and a change in consumer surplus. The required tax increment implies that there is no guarantee that the EU's 2030 emission reduction targets will be reached at the current tax levels, and thus a more stringent fuel tax policy is essential.

2.2 Cost to car owners of the EU's 2050 targets for CO2 emission reduction from the transport sector

Conventional fossil fuel cars that have considerable polluting potential dominate passenger transport. In the EU-28 countries, light-duty vehicles are used for 80 percent of all passenger transport, leading to 522 million metric tons of greenhouse gas emissions per year (EUROSTAT, 2018). The EU aims to reduce emissions from the transport sector by 60% by 2050 compared to 1990 levels (EC, 2011). One of the main means of emission reduction in the transport sector is to substitute fossil fuel cars with hybrid and electric cars that have relatively low emission rates.

Studies estimating the costs of achieving the GHG emission reduction targets at global, regional and national scales apply general equilibrium models (Capros et al., 2016), partial equilibrium models (EC, 2018), and marginal abatement cost approaches (Gren et al., 2018; Munnich-Vass & Elofsson, 2016). Stanton et al. (2009) and Tol (2010) have provided reviews of these studies. Several other studies calculate the damage of emissions to the climate and the costs of GHG reductions from different measures at regional and global scales (Bosetti & Longden, 2013; Kok et al., 2011). However, to the best of the author's knowledge, no study has calculated the minimum costs of achieving the EU's 2050 emission reduction targets for the transport sector.

This study aims to estimate the cost to car owners of achieving the EU 2050 transport sector emission reduction targets through passenger car switching from fossil fuel-driven to hybrid and electric-driven cars. The cost of emission reduction and the optimal mix of passenger car types are estimated under cost effectiveness criteria by constructing a discrete time non-linear dynamic programming model. The costs are calculated as a change in consumer surplus as a result of switching from fossil fuel to hybrid and electric cars. The model accounts for price and fuel efficiency change as a result of exogenous technological change. The model is solved using 2016 as the business-as-usual level, and a sensitivity analysis is conducted with respect to values of elasticity, depreciation rate, efficiency increment rate, price reduction rate and discount rate. In the business-as-usual level, of the 250 million passenger cars in the EU, 97 percent are fossil fuel-driven, about 2 percent are hybrid and about 1 percent are electric-driven (EUROSTAT, 2018). At the business-as-usual levels, emissions are double that of the 2050 target, which implies that a drastic cut in emissions is required.

The numerical dynamic optimization model is solved in GAMS CONOPT solver. The results show that the minimum cost of achieving the emission and travel demand constraints, calculated as the difference in costs with and without emission constraints, amounts to 1872 billion euros. The average annual cost of approximately 55 billon euros corresponds to 0.37% of total EU GDP in 2016. The calculated cost is between 0.1% and 0.9% of EU GDP in current terms, which is the cost of achieving the 2050 climate targets estimated by Capros et al. (2016), assuming economic growth. The value of the Lagrange multiplier amounts to 30468 euros/metric ton in 2050, which gives an average annual increase in costs of 898 euros/metric ton. This is comparable to the results of Van Vliet et al. (2011) and Kok et al. (2011) that show the average abatement cost using hybrid and electric cars and the cost of transport sector GHG abatement under cost-effectiveness to be between 400 to 1900 euros per metric ton of CO_2.

The optimal share of passenger cars shows that hybrid cars are the most effective means of abatement, and their percentage share increases to 65 percent at the end of the policy period, while the percentage share of fossil fuel cars reduces to 32 percent and the percentage share of electric cars remains at 3 percent. The main reason for a low percentage share of electric cars is the result of high emission in the electricity generation process, implying that when electric vehicles are coupled with grid decarbonization, their emission reduction potential can be further enhanced (Thiel et al., 2010).

The cost distribution among the EU-28 countries shows that Italy, Spain, the UK, France, and Germany account for 66% of the cost since they are the largest passenger car markets in the EU. Total BAU emissions from the same countries correspond to 64% of total emissions. Except for Spain, the annual cost as a share of GDP in each country is relatively low for these countries.

The estimated cost sensitivity is examined with respect to model assumptions and changes in parameter values. In the model, it is assumed that travel demand is constant at the business-as-usual level. However, in reality all modes of travel demand increase in proportion to per capita income growth (Bosetti & Longden, 2013; Capros et al., 2016; Nocera et al., 2015). Assuming a growing travel demand proportional to per capita income growth, the minimum total discounted costs for achieving the emission constraint and the increased travel demand amount to 8138 billion euros. The cost-effective allocation of vehicles is similar to the reference case, and the five countries (Italy, Spain, the UK, France, and Germany) with the largest vehicles stocks and CO_2 emissions face the highest costs.

The sensitivity of the costs to parameter values of the rate of fuel efficiency improvement, the price decrease of hybrid and electric cars, the discount rate, and price elasticity are examined by assuming changes of 25% from the respective reference value. At most, the total minimum cost increases by approximately 50% when the rate of increase in fuel efficiency is reduced by 25%. In all cases, the allocation of vehicle types is similar, where hybrid cars replace fossil fuel cars and account for the main share of total vehicles in the final periods. With respect to the impacts on costs for different countries, the cost increase is higher in percentage terms for small countries such as Latvia and Estonia than it is for the largest countries.

2.3 Does water collection for household consumption affect agricultural production? Evidence from Ethiopia

Despite water being essential for life, more than 11 percent of the world's population, 42 percent of the sub-Saharan African population and 39 percent of the Ethiopian population lacked access to improved water sources in 2015 (WHO & UNICEF, 2017). With water sources being far away and the lack of modern transportation, rural households are forced to spend significant time and expend physical labor to meet daily necessities (FAO, 2017). Lack of access to the labor market constrains rural households to rely on internal labor to satisfy the labor demand of water collection, agricultural activities and household chores (Dillon & Barrett, 2017).

Previous studies have examined the impact of access to water on rural households through factors such as health, gender relations, poverty, conflict, and time allocation for off-farm employment, leisure and social activities (Devoto et al., 2012; Dinkelman, 2011; Koolwal & Van de Walle, 2013; Sekhri, 2014). However, studies examining the effect of access to water for household consumption on agricultural production are sparse. One such study is Meeks (2017). Using quasi-experimental evidence from Kyrgyzstan, Meeks shows that the time saved from increased access to improved drinking water source increases agricultural production by freeing up labor for agriculture from home production.

This study examines the effect of time allocated for water collection for household consumption on agricultural production in rural Ethiopia. The empirical strategy is a household fixed effects estimation, where the identification assumption is that time allocated to water collection is exogenous, conditional on observable water sources, household size, wealth, survey-round fixed effects and household fixed effects. This assumption is supported by two pieces of empirical evidence. First, an assessment of the relationship between the variable of interest and pseudo-outcome variable, which is a proxy for potential outcome, shows that a strong relationship is not detected. The second empirical evidence shows that, after controlling for the conditioning variables, the past value of non-conditioning variables does not explain the current value of the time spent collecting water. These two pieces of empirical evidence support the identification assumption of conditional independence (Imbens & Rubin, 2015).

The data is the three-wave panel Ethiopia Socioeconomic Survey (ESS) collected in 2011/2012, 2013/2014 and 2015/2016. Exploiting the panel structure of the data, the household-level fixed effects remove time-invariant unobservable confounding factors. The data have a low attrition rate between the three rounds, implying that almost all the households remain in the location where they were surveyed in the first round. This allows the possible households' choice of residential location in relation to a water source to be controlled for. Furthermore, the household fixed effects control for factors such as topography, surface and groundwater reservoir.

The data show that rural households in Ethiopia have an average size of five individuals and that they are subsistence farmers who practice rain-fed mixed agriculture composed of crop production and livestock rearing on an average landholding of 1.2 hectares. About 75 percent of crop production consists of wheat, barley, sorghum, maize and teff. More than 70 percent of agricultural production is retained for household consumption. Besides agriculture, water collection is one of the time-consuming activities in the household. On average, households spend one hour per day collecting water. The water collection time varies seasonally and across different administrative regions.

The results show that reducing the daily time spent collecting water by 1 percent increases agricultural output by about 0.2 percent at the margin, corresponding to a value of 1149 birr. An examination of the linking factor between time spent collecting water for household consumption and agricultural production shows that water collection deprives agricultural production of productive labor. A 1 percent decrease in time allocated for water collection leads to a 0.09 percent increase in agricultural labor supply. This shows that the time saved from water collection is also allocated to other household activities. The results are robust to other specifications and different levels of standard error clustering. Robustness checks of the results through alternative speciation of stylized difference-in-differences and reduced form show that the results hold. The policy implication of the results is that an improvement to non-agricultural related rural household impediments can improve agricultural production and help achieve the full potential of rural households' agricultural production.

2.4 Policy design for forest carbon sequestration: A review of the literature

Anthropogenic greenhouse gases are known to be harmful, and several international agreements have been made to stabilize atmospheric carbon content such as the Kyoto Protocol, the Paris Agreement, and the EU climate policy (IPCC, 2014). The international agreements focus on reducing emissions, however atmospheric carbon can also be reduced through carbon sink enhancement. Carbon sequestration can occur in aboveground biomass and belowground soil. Aboveground and belowground forest carbon sequestration in the period 2000-2007 amounted on average to 4.1 Pg C/year, corresponding to 30% of the emissions from fossil fuels in 2010 (IPCC, 2014; Pan et al., 2011). Forest carbon sequestration can be counteracted by deforestation that releases stored carbon. The potential of carbon sink enhancement through afforestation, forest management and delayed deforestation is recognized by the Kyoto Protocol, Paris Agreement and different national regulations (Kerr, 2013; Peters-Stanley, 2012). However, in 2013 total carbon sequestration accounted for just 0.5% of the total volume of carbon trade (World Bank, 2014).

A large body of literature shows that the marginal cost of carbon sink enhancement can be lower than carbon emission reduction (*e.g.* Phan et al. (2014), Sedjo et al. (1995)). Introducing carbon sinks into climate programs can have cost-savings of up to 40 percent (Gren et al., 2012; Michetti & Rosa, 2012). However, the realization of the cost advantage depends on policy design. This study examines the literature to answer how policies can be designed to foster changes in land users' behavior at minimum cost to society. To this end, 45 studies that specifically analyze policies directed at improving forest carbon sequestration are gathered using search engines and reviewed. Studies addressing specific policy design problems with carbon sink enhancement and carbon sink policies in practice are presented, compared and discussed.

Any type of policy targeting carbon sequestration has to deal with the specific design problems of heterogeneity, uncertainty, additionality, and permanence. Heterogeneity arises due to differences in carbon sequestration per unit of land as a result of geo-climatic differences. Uncertainty is the result of possible sequestration measuring and monitoring errors, and stochastic weather affecting biomass growth. The main findings in the literature with regards to heterogeneity and uncertainty are that a uniform price of carbon sink per unit can create high or low costs of inefficiency, depending on the variability in carbon sequestration per unit. Treatment of uncertainty as a risk discount increases the carbon sink enhancement cost. The main design features in practice to address heterogeneity and uncertainty are project-based offset and payment, with standards for monitoring and verification, and risk discounting of forest carbon offset.

Additionality refers to the ambiguity in determining whether the project would be implemented without the policy in question. The main findings in the literature show that agents' true type can be revealed through optimal contract design for additional sinks by paying rent to agents for their information advantage. In a two-sector system, with firms in compliance and carbon sinks as offsets, greater stringency in the carbon project's baseline emissions can foster additionality. In practice, additionality is addressed through tests on a project-basis upscaling of the business-as-usual baseline from individual projects to jurisdictions.

Permanence of carbon sequestration can be jeopardized by natural causes, lack of adherence to project rules, and the use of harvested wood for energy that releases the stored carbon. The main findings in the literature show that permanence can be assured through optimal contract design with a low base payment and high performance payment, liability on sellers, temporary credits, and discounting. In practice, permanence is assured through temporary and permanent credits, buffer credits, and performance-based or fixed payments.

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